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Trophic role of small cetaceans and seals in Irish waters

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Thesis submitted to the National University of Ireland (Cork) in fulfilment of the requirements for the degree of Doctor of Philosophy

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Academic Supervisors: Dr Emer Rogan and Dr David Reid

Dedicated to my Dad, my Mum,
my sisters, my brother in law
and my three little “monsters”

It is no longer a question of how much food do whales and dolphins need, but whether they are able to get the right kinds of food to survive.

Jerome Spitz

I declare that this thesis was composed by myself and represents work carried out by myself. It has not been accepted in any previous application for a degree. All sources of references and information have been specifically acknowledged.

Gema Hernández-Milián, BSc., MSc.

1st April 2014

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Although this research has been carried out over a period of 5 years, the conclusion of this thesis is due to the result of my years of "flirting" with science and research since 1995. From that time up to date, several people have contributed to the development of this work in different ways; without their input, help, encouragement, and motivation, this work would have been impossible to carry out.

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CONTENTS

GENERAL OVERVIEW

Understanding the role of marine mammals in specific ecosystems and their interactions with fisheries involves, inter alia, an understanding of their diet and dietary requirements. In this thesis, the foraging ecology of seven marine mammal species that regularly occur in Irish waters was investigated by reconstructing diet using hard parts from digestive tracts and scats. Of the species examined, two (striped and Atlantic white-sided dolphin) can be considered offshore species or species inhabiting neritic waters, while five others usually inhabit more coastal areas (white-beaked dolphin, harbour porpoise, harbour seal and grey seal); the last species studied was the bottlenose dolphin whose population structure is more complex, with coastal and offshore populations.

A total of 13,028 prey items from at least 81 different species (62 fish species, 14 cephalopds, four crustaceans, and a tunicate) were identified. 28% of the fish species were identified using bones other than otoliths, highlighting the importance of using all identifiable structures to reconstruct diet. Individually, each species of marine mammal presented a high diversity of prey taxa, but the locally abundant *Trisopterus* spp. were found to be the most important prey item for all species, indicating that *Trisopterus* spp. is probably a key species in understanding the role of these predators in Irish waters. In the coastal marine mammals, other Gadiformes species (haddock, pollack, saithe, whiting) also contributed substantially to the diet; in contrast, in pelagic or less coastal marine mammals, prey was largely comprised of planktivorous fish, such as Atlantic mackerel, horse mackerel, blue whiting, and mesopelagic prey.

Striped dolphins and Atlantic white-sided dolphins are offshore small cetaceans foraging in neritic waters. Differences between the diet of striped dolphins collected in drift nets targeting tuna and stranded on Irish coasts showed a complex foraging behaviour; the diet information shows that although this dolphin forages mainly in oceanic waters it may occasionally forage on the continental shelf, feeding on available prey. The Atlantic white-sided dolphin diet showed that this species prefers to feed over the continental edge, where planktivorous fish are abundant.

Some resource partitioning was found in bottlenose dolphins in Irish waters consistent with previous genetic and stable isotope analysis studies. Bottlenose dolphins in Irish waters appears to be generalist feeders consuming more than 30 prey species, however most of the diet comprised a few locally abundant species, especially gadoid fish including haddock/pollack/saithe group and *Trisopterus* spp., but the contribution of Atlantic hake, conger eels and the pelagic planktivorous horse mackerel were also important. Stomach content information suggests that three different feeding behaviours might occur in bottlenose dolphin populations in Irish waters; firstly a coastal behaviour, with animals feeding on prey that mainly inhabit areas close to the coast; secondly an offshore behaviour where dolphins feed on offshore species such as squid or mesopelagic fish; and a third more complex behaviour that involves movements over the continental shelf and close to the shelf edge.

The other three coastal marine mammal species (harbour porpoise, harbour seal and grey seal) were found to be feeding on similar prey and competition for food resources among these sympatric species might occur. Both species of seals were found to have a high overlap (more than 80%) in their diet composition, but while grey seals feed on large fish (>110mm), harbour seals feed mostly on smaller fish (<110mm), suggesting some spatial segregation in foraging. Harbour porpoises and grey seals are potentially competing for the same food resource but some differences in prey species were found and some habitat partitioning might occur.

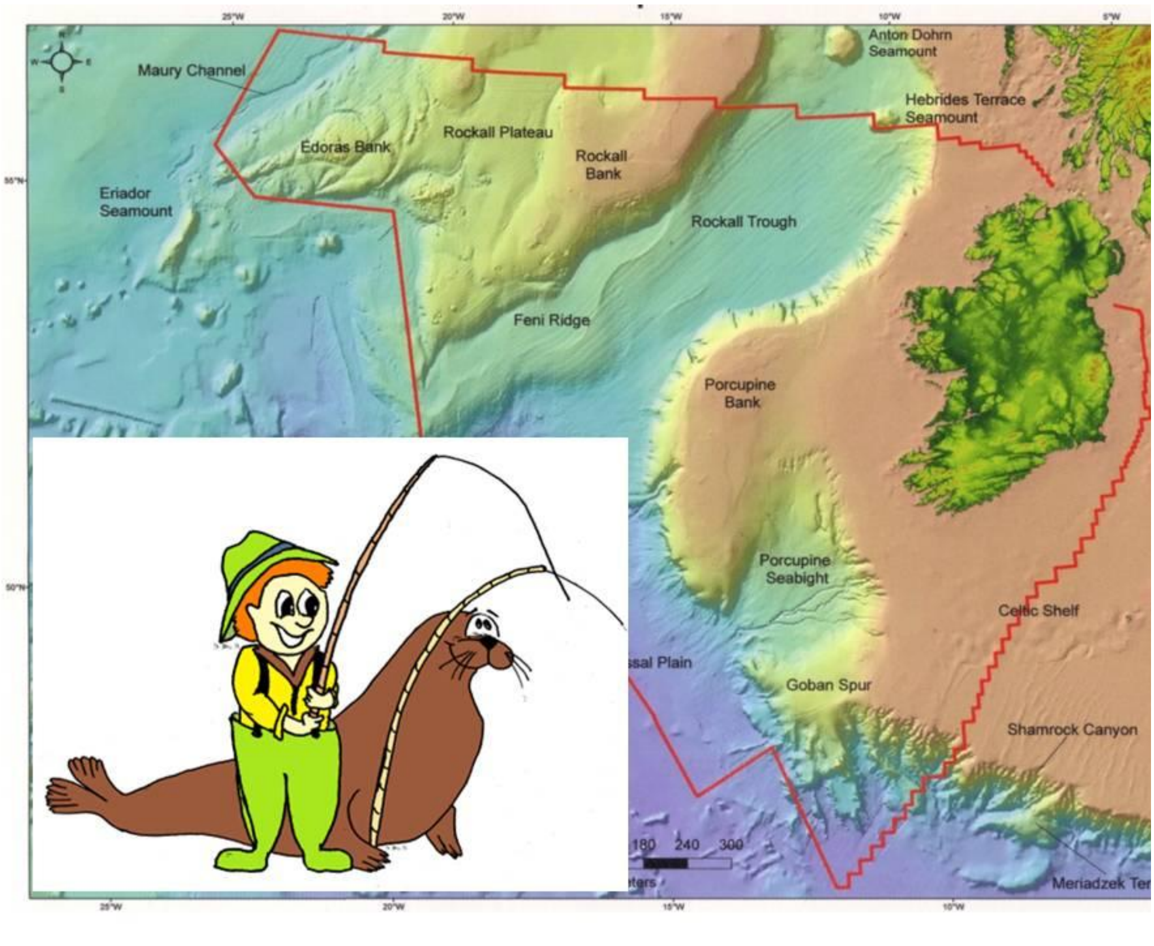
Direct interaction (by catch) between dolphins and fisheries was detected in all species. Most of the prey found in the stomach contents from both stranded and by catch dolphins were smaller sizes than those targeted by commercial fisheries. In fact, the total annual food consumption of the species studied was found to be very small (225,160 tonnes) in comparison to fishery landings for the same area (~2 million tonnes). However, marine mammal species might be indirectly interacting with fisheries, removing forage fish.

Incorporating the dietary information obtained from the four coastal species, an ECOPATH food web model was established for the Irish Sea, based on data from 2004. Five trophic levels were found, with bottlenose dolphins and grey and harbour seals occurring at the highest trophic level. A comparison with a previous model based on 1973 data suggests that while the overall Irish Sea ecosystem appears to be “maturing”, some indices indicate that the 2004 fishery was less efficient and was targeting fish at higher trophic levels than in 1973, which is reflected in the mean trophic level of the catch. Depletion or substantial decrease of some of the Irish Sea fish stocks has resulted in a significant decline in landings in this area. The integration of diet information in mass-balance models to construct ecosystem food-webs will help to understand the trophic role of these apex predators within the ecosystem.

Keywords: Striped dolphin, Atlantic white-sided dolphin, white-beaked dolphin, bottlenose dolphin, harbour porpoise, harbour seal, grey seal, *Trisopterus* spp., fisheries, Irish waters, ECOPATH

Chapter 1

GENERAL INTRODUCTION



CHAPTER 1

GENERAL INTRODUCTION

1.1 OVERVIEW

The main objective of this thesis is to improve ourknowledge of the feeding ecology of several marine mammals in Ireland. Dietary patterns of some of these species (Atlantic white-sided dolphin –*Lagenorhynuchus acutus*, Gray 1828-, white-beaked dolphin –*L.albirostris*, Gray 1846-, bottlenose dolphin –*Tursiops truncatus*, Montagu 1821- and harbour porpoise –*Phocoena phocoena*, Linnaeus 1758) have never been studied in Ireland before. Stripped dolphin (*Stenella coerueoalba*, Meyen 1833) diet has only being study until 1999 (O'Callaghan, 2000), however the lack of fish bones reference collection at that time made it difficult to identify 10% of the diet. The importance of these dietary patterns is related to the role of top predators within the ecosystem, therefore this thesis makes an important contribution to current and future studies on ecosystem functioning.

Since the 1980s different models have been built to investigate the linkages between the different compartments within marine ecosystems (Plagányi, 2007 and refs therein); however, most of these models require a large amount of data and expertise. In this thesis, a relatively "simple" simulation model was applied to the Irish Sea using the information on the diet of the top predators in the area. Previously, Lees and Mackinson (2007) built up an Ecopath model but with very limited information on top predators, especially marine mammals. For example, these authors considered that harbour porpoise (*Phocoena phocoena*, Linnaeus 1758) and common dolphin (*Delphinus delphis*, Linnaeus 1758) were the most commonly occurring small cetaceans, whereas it is now known the common dolphins occur infrequently in this area. A recent study on cetacean abundance and distribution indicated that the main species in the Irish Sea are harbour porpoise, bottlenose dolphin and minke whales (*Balaenoptera acutotostrata*, Lacépède, 1804) (Hammond et al., 2013). In addition to this, most of the top predator diet information used previously was obtained from studies carried out in the North Sea; a completely different ecosystem. Also, in contrast to Lees and Mackinson (2007) toothed cetaceans and seals functional groups were divided by species, as the diet of both cetaceans and seal species has been found different, thus providing more realistic and robust information for the area.

This thesis is written in the format of publishable papers and some of the information has been presented at National and International Conferences. It is organized in eight chapters, describing the diet of different marine mammal predators and finishing with an updated Ecopath model for the Irish Sea, exploring the trophic positioning of the marine mammal species in this area. The second chapter contains a general introduction of the area and outlines approaches used to study diet in marine mammal species, with a detailed description of the methodology used in Chapters 3 to 6. The third chapter presents information on the diet of striped dolphins (*Stenella coeruleoalba*, Meyen 1833) in the North east Atlantic. Chapter 4 provides the first insight into the diet of Atlantic white-sided dolphin and white-beaked dolphin in Irish waters; some of these results were presented at the European Cetacean Conference in 2010 and the paper is currently in preparation. Chapter 5 covers the diet of bottlenose dolphins; part of the results from this chapter was presented at the All Ireland Mammal Symposium in 2009 and the full work is currently in review. Chapter 6 compiles the information of the four coastal marine mammal species occurring in Irish waters and investigates their potential diet overlap; these results were presented at the Marine Biological Association Conference in 2012 and it is currently in preparation for publication purposes. Chapter 7 presents the updated Irish Sea multispecies mass-balance model using Ecopath with Ecosim software to investigate the role of top predators in the Irish Sea, their interactions among them and fisheries, as well as the structure of the ecosystem; the information obtained will help to improve our knowledge of the interactions among the top predators within the ecosystem and their interaction with fisheries. Chapter 8 contains a concluding discussion and some thoughts on future research work and direction.

1.2 AREA OF STUDY

Ireland is situated in the north east Atlantic. It is surrounded by the sea along its 7,500 km of coasts, but its sea area is more than ten times (220×10^6 acres) that of theland area ($\sim 21 \times 10^6$ acres). The sea area is comprised of different components; the Rockall area is a large shallow area with an average depth of 893m depth (the Rockall Basin), extended to a deeper (1,318m) shallow area to the west (the Rockall Plateau) and a deep channel on the east of the basin running from southwest to north east with an average depth of 2,763m (Rockall Trough) (Dorschel et al., 2010). The Porcupine area comprises a shallow area with an average depth of 270m (the Porcupine Bank), and a deep basin with a bay shape with an average depth of 2,369m (the porcupine Seabight) (Dorschel et al., 2010). Another two banks have been described in Irish waters, the Edoras bank on the north westernmost area with an average depth of 1,117m and the Goban Spur in the south easternmost area with an average depth of 796m (Dorschel et al., 2010). Finally, another two important areas in terms of economic value, the Celtic and Irish Sea, are included in Irish waters; the Celtic Sea is an extended shallow shelf (less than 150m) situated to the south of Ireland (Hardisty, 1990) while the Irish Sea is a semi-enclosed area between Ireland and the United Kingdom with a maximum depth of 315m (Vincent et al., 2004).

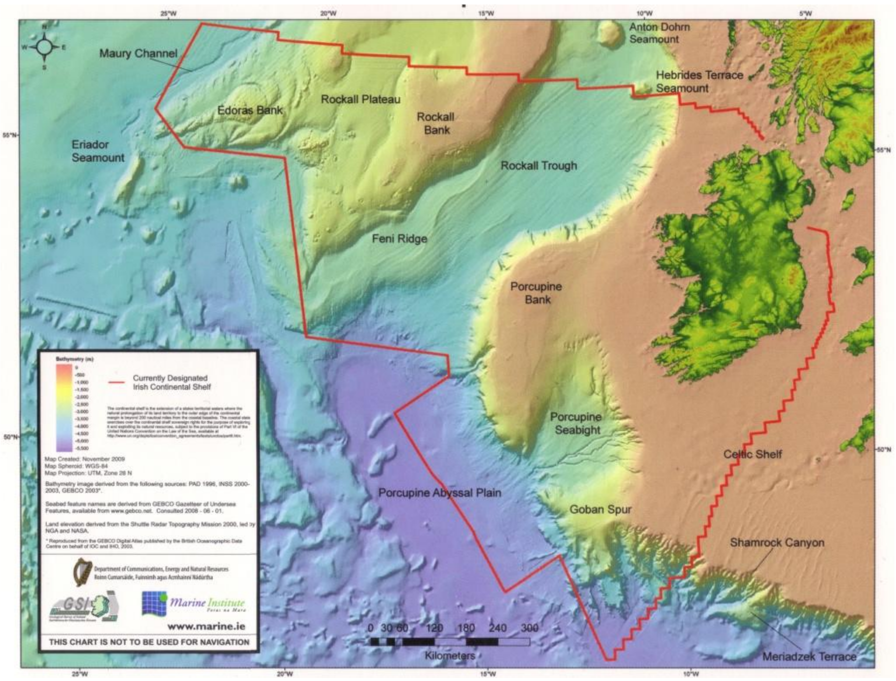


Figure 1.1 Map of Ireland showing some of the different habitats. The red line represents the currently designated Irish continental shelf (www.marine.ie)

Ireland is influenced by the North Atlantic Drift (Gulf Stream) current, which brings warm and saline water close to the coast moving in a northward direction producing the “Ocean conveyor” when converges with the south bound colder current; this conveyor belt system produces an important area of high productivity in Irish coasts (OSPAR,2010). The formation of eddies (Monahan et al., 1984; Tulloch and Tait, 1959) and ocean fronts (McMahon et al., 1995; Simpson, 1976) also increases the species richness and overall productivity of the area (e.g., Kumar et al., 2004; Oschlies and Garçon, 2010; Levy et al., 2012). In terms of fisheries resources, Ireland is situated in some of the most productive fishery areas (ICES VIIa-c, VIIg, VIIj-k, and VIa-b) in European waters (MI, 2013). It has been estimated that 23% (~1 million tonnes) on the international landings are carried out by the Irish fleet (MI, 2013), making it an important economic fishery resource for the country. The presence of this resource also benefits top predators such as marine mammals (cetaceans and seals) and seabirds.

To understand the trophic dynamics within ecosystems, knowledge of the diet of top predators is essential as they play an important role within the food web structure of ecosystems (Bowen, 1997). In general terms, information of their feeding ecology have been investigated since the 1900s (e.g., Brown, 1915; Fitch and Brownell, 1968; Gunter, 1942; Scheffer, 1953; Rae 1965, 1968); however, little is known about the diet and foraging of marine mammal species in the waters around Ireland (e.g., Brophy et al., 2009; Gosch et al., 2014.; Kavanagh et al., 2010; O’Callaghan, 2000). Also, the competition for resources among the different species in adjacent areas have been examined in more detail in the last few decades (Dinis et al., 2008; Garcia-Godos et al., 2004; Hassani et al., 1997; Hauksson and Bogason, 1997; Querouil et al., 2013; Spitz et al., 2006a, 2006b; Thompson et al., 1996; Villegas-Amtmann et al., 2013). More detail on prey distribution and availability are also being incorporated into models examining the distribution and abundance of top predators.

1.3. MARINE MAMMAL SPECIES

Marine mammal species have been recorded worldwide and inhabit a very diverse range of habitats from deep sea (Families Ziphidae and Physeteridae) to riverine systems (Families Platanistidae, Iniidae, Pontoporiidae and Lipotoidae), and from coastal areas (e.g., Phocids) to oceanic waters (e.g., *Stenella* spp., Gray 1866) (Jefferson et al, 2008; Ridgway and Harrison, 1999). However, certain species migrate long distances, from feeding to breeding grounds (e.g., Humpback whales -*Megaptera novaeangliae*, Borowski 1781-; Stevick et al., 2003), while others have populations that tend to be more “resident", such as bottlenose dolphins (e.g., Ingram, 2000; Lopez, 2003; Wilson, 1995) and killer whales (*Orcinus orca*, Linnaeus, 1758) (e.g., Ford, 2002; National Marine Fisheries Service, 2008).

A total of twenty-eight cetacean species (comprising whales, dolphins and porpoises, Table 1.1) and seven species of pinnipeds have been recorded as spending at least part of their lives in the waters of north west Europe (Reid et al., 2003). In Irish waters, twenty-three out of the twenty-eight cetacean species have been recorded stranded and/or sighted (Berrow and Rogan, 1997; Evans 1980), with 14 of these species are considered to regularly occur in Irish waters, five occur occasionally and four can be considered vagrant or unusual (DEHLG, 2009; Wall et al., 2013). Two species of seals are considered resident, with important breeding sites along the coast of Ireland (the grey seal –*Halichoerus grypus*, Fabricius 1791- and the harbour seal –*Phoca vitulina*, Linnaeus 1758) (Cronin et al., 2004; Ó Cadhla and Strong, 2007). Hooded seals (*Cystophora cristata*, Erxleben 1777) have also been recorded infrequently in Scotland and Northern Ireland, and unusual records of bearded seals (*Pagophius groenlandicus*, Erxleben 1777) have been reported in the North Sea and North West of the Iberian Peninsula (Jefferson et al., 2008).

Cetacean abundance has recently been estimated using two multinational surveys in offshore (CODA–Fig. 1.2b; CODA, 2009) and inshore (SCANS II –Fig. 1.2a; Hammond et al., 2013) European waters. To date, information on seals in this area are scant, but estimates derived from aerial surveys along Irish coasts are available for harbour seals (Cronin et al., 2004), while grey seal population abundance was estimated using a mark and recapture technique on the main breeding beaches (Kiely et al., 2000)

Table 1.1 Marine mammal species recorded stranded or sighted in Irish waters (from Evans, 1980; Berrow and Rogan 1997; Jefferson et al., 2008).

Marine mammal species	Common name	Status
Balaenoptera acutorostrata	Minke whale	Regular
Balaenoptera borealis	Sei whale	Occasional
Balaenoptera musculus	Blue whale	Occasional
Balaenoptera physalus	Fin whale	Regular
Megaptera novaeangliae	Humpback whale	Regular
Physeter macrocephalus	Sperm whale	Regular
Kogia breviceps	Pygmy Sperm whale	Vagrant
Delphinapterus leucas	White whale	Vagrant
Phocoena phocoena	Harbour porpoise	Regular
Lagenorhynchus albirostris	White beaked dolphin	Regular
Lagenorhynchus acutus	Atlantic white-sided dolphin	Regular
Grampus griseus	Risso's dolphin	Regular
Trusiops truncatus	Bottlenose dolphin	Regular
Stenella coeruleoalba	Striped dolphin	Regular
Delphinus delphis	Common dolphin	Regular
Pseudorca crassidens	False killer whale	Vagrant
Orcinus orca	Killer whale	Regular
Globicephala melas	Long-finned pilot whale	Regular
Mesoplodon bidens	Sowerby's beaked whale	Occasional
Mesoplodon europaeus	Gervais beaked whale	Vagrant
Mesoplodon mirus	True's beaked whale	Occasional
Ziphius cavirostris	Cuvier's beaked whale	Occasional
Hyperoodon ampullatus	Bottlenose whale	Regular
Cystophora cristata	Hooded seal	Vagrant
Phoca vitulina	Harbour seal	Regular
Pagophilus groenlandicus	Harp seal	Vagrant
Halichoerus grypus	Grey seal	Regular

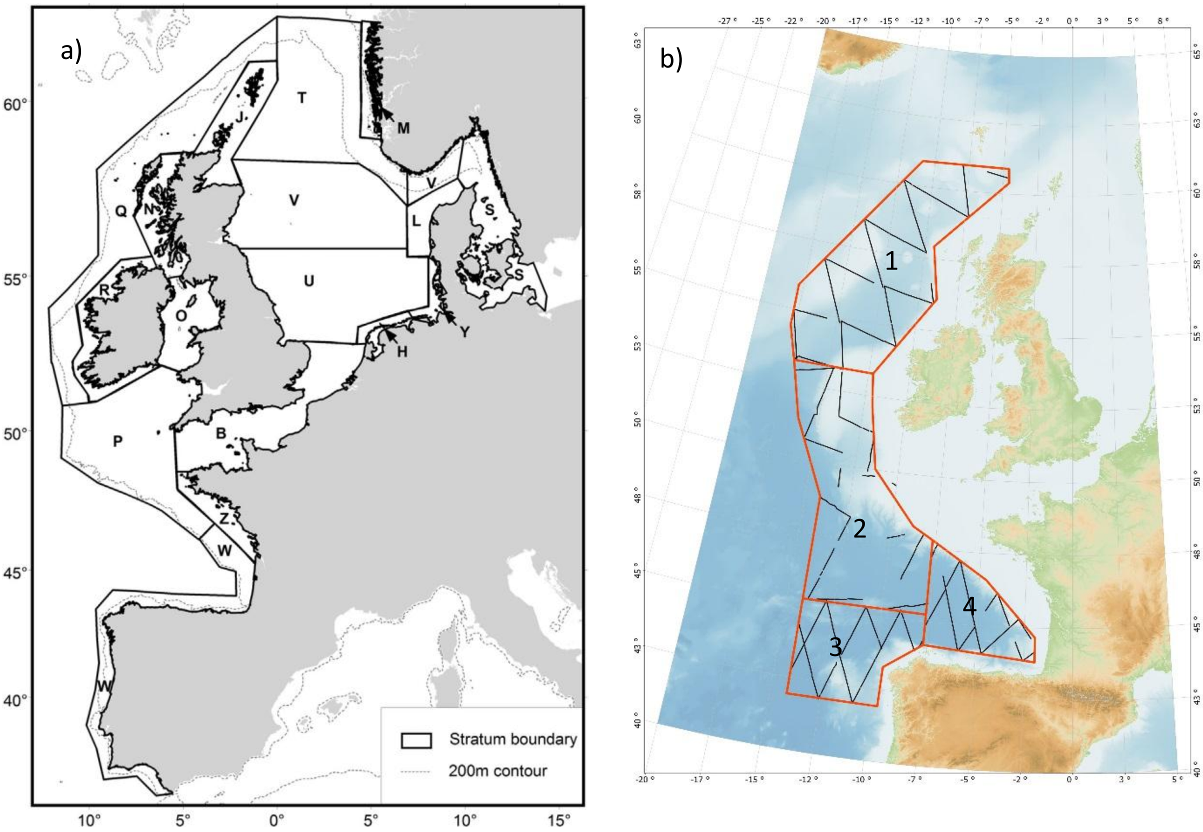


Figure 1.2 Survey maps showing the survey blocks for the population estimation of cetaceans in (a) inshore waters (from Hammond et al. (2013)) and (b) offshore cetaceans (modified from CODA (2009)).

Investigating the feeding behaviour of marine mammals, as well as other ecological and biological studies such life history, is a challenging task. Cetacean species spend most of their time under the water making it difficult to obtain biopsy samples. Another source of information is through the recovery of carcasses from beaches and fishing operations. However, strandings occur infrequently and only a small proportion of animals that die end up on beaches (Peltier et al., 2012, 2013; Williams et al., 2011). Incidental capture casualties are usually obtained when specific programs are running with scientific observers on board (e.g., Fernandez-Contreras et al., 2010; Rogan and Mackey, 2007; Stenson et al., 2011); in both cases data collection can be considered as an opportunistic source of data. In addition, there may be biases in the dataset with respect to age structure, cause of death or health of the animals (e.g., Díaz López, 2006; Murphy et al., 2005). However, strandings are considered to be representative of the species present in the area (Peltier et al., 2013).

Although bottlenose dolphins are relatively accessible because of the partially coastal distribution and site fidelity, the trophic ecology of this species is still difficult to study and likely to be complex, giving recent population structure information (e.g., Fernandez et al. 2011a; Louis et al., 2014; Mirimin et al., 2011). Stable isotope analysis from biopsy samples has provided some information on the trophic level of bottlenose dolphins in some areas (e.g., Fernandez et al., 2011b). Reconstruction of diet from stomach content analysis of stranded dolphins also requires a long time period as strandings of this species rarely occur and animals are usually in an advanced stage of decomposition. The most commonly stranded cetaceans are usually harbour porpoise, and common and striped dolphins (e.g., O'Connell and Berrow, 2010), and samples of different organs and tissues of these species are systematically collected. In this thesis, common dolphin samples were not included as the study of their diet is ongoing and has been examined and presented elsewhere (e.g., Brophy et al., 2009). Harbour porpoise data are not presented in detail here but were included within the diet of coastal marine mammals (Chapter 5) and included in the Irish Sea model (Chapter 6). Information about the diet of Atlantic white-sided dolphin in European waters is scarce and most of the samples were collected from by caught dolphins (Couperus 1997a; Desportes, 1985; Morizur et al., 1999); therefore the diet information was included in this thesis (Chapter 3).

1.3.1. Striped dolphin (*Stenella coeruleoalba*, Meyen 1833)

Striped dolphins are considered to be a cosmopolitan species inhabiting temperate and tropical waters of the Atlantic, Pacific and Indian Oceans, between 50°N and 40°S (Fig 1.2) (Archer and Perrin, 1999; Hammond et al., 2008a; Jefferson et al., 2008; Reid et al., 2003). In the North Atlantic Ocean, its distribution reaches as far north as Scotland in the east and Nova Scotia (Canada) in the west; however, it has been occasionally found as far north as Norway, the Faeroe Islands, Iceland, and Southern Greenland (Isaksen and Syvertsen, 2000; Jefferson et al., 2008). In the South Atlantic Ocean, it has been recorded south of South Africa in the east and San Matías Gulf (Argentina) in the west (Hammond et al., 2008a; Jefferson et al., 2008). This species inhabits mainly offshore/pelagic waters, beyond the continental shelf or along the continental slope (Aguilar, 2000; Archer and Perrin, 1999; CODA, 2009; Rogan and Mackey, 2007), and it has been found to be associated with productive and upwelling areas (Au and Perryman, 1985; Davis et al., 1998; Hammond et al., 2008a; Perrin et al., 1994; Reid et al., 2003); but in some areas they were also found shallower waters (Clua and Grosvalet, 2001; Van Waerebeek et al., 1999). In Irish waters, the striped dolphin is usually distributed in offshore waters (CODA, 2009; Hammond et al., 2013; Rogan and Mackey 2007; Wall et al., 2013); however, this species is the third most commonly stranded cetacean species on the Irish coasts (Wall et al., 2013).

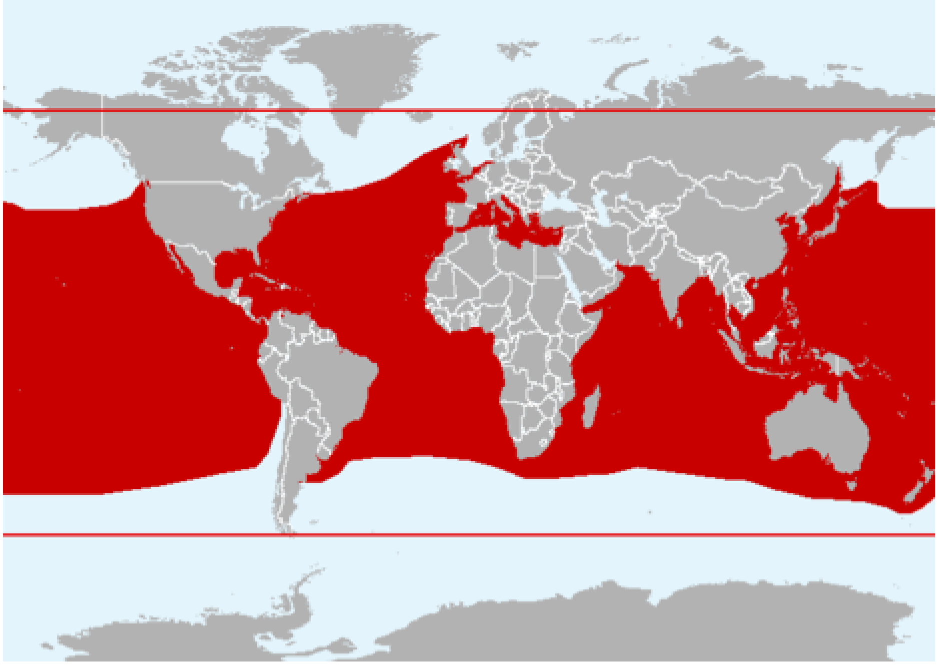


Fig 1.2 World distribution of striped dolphin. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

An abundance estimate of this species in Irish waters was derived from the multinational dedicated surveys in offshore (CODA, 2009) and inshore (Hammond et al., 2013) waters. Only 147 dolphins (21-1203 dolphins, CV=1.28) were estimated within the Celtic Sea (Block Z, Hammond et al., 2013). However, in offshore waters a total of 61,364 dolphins (12,323-305,568 dolphins, CV=0.93) was estimated for the whole area (from North Hebrides to North of Portugal; CODA, 2009). This survey also included a combined category (common and striped dolphin) where striped and common dolphin were not differentiated; the abundance of this group for the whole area surveyed was estimated to be 224,166 dolphins (90,979-552,331, CV=0.48). Potentially, the abundance of striped dolphin for the mixed group could be calculated by using the percentage of striped dolphin (34.2%) from the abundance estimate for both species combined.

Although similar in shape and size to common dolphins and other *Stenella* spp, they are more robust animals (Jefferson et al., 2008). As its'specific name suggests, the coloration is bluish-gray at its dorsal area, and whitish on the belly (Fig.1.3); from the eye, two stripes run backwards, one to the flipper and the second one to the anus, which gives the common name to the species (Archer and Perrin, 1999; Jefferson et al., 2008). Males are slightly larger than females reaching up to 2.56m (Archer and Perrin, 1999; Jefferson et al., 2008). While often occurring in large schools, sex segregation has been noted by some authors (e.g., Rogan and Mackey, 2007).

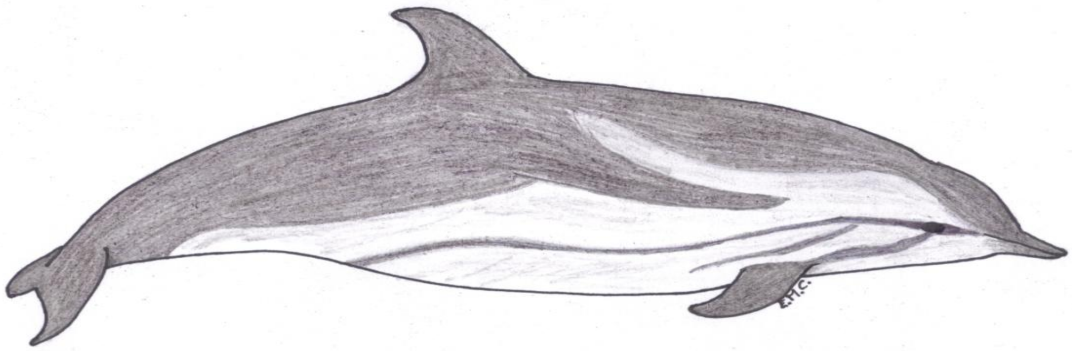


Figure 1.3. Striped dolphin showing the typical coloration pattern

Throughout most of the areas where diet has been described, it is reported to feed on deep sea and demersal prey (Blanco et al., 1995; Hassini et al., 1997; Ringelstein et al., 2006; Santos et al., 2008; Spitz et al., 2006a; Würtz and Marrale, 1993). However, this species has also been found to feed on prey inhabiting the continental shelf (Rogan et al., 1997b; Santos et al., 1994; Spitz et al., 2006a) on species such as whiting (*Merlangius merlangus*, Linnaeus 1758), and gobies. Although it has been suggested that this species behaves as a generalist predator, some prey preferences have been pointed out, including deep sea prey based on the fact that fish luminescent organs have occurred in a high proportion of stomach as well as cephalopod species (Archer and Perrin, 1999).

The Striped dolphin is listed in CITES (Appendix II) and classified as 'least concern' in the IUCN Red List. It is included in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS). This species has been listed in the Annex II of the Habitats Directive (92/43/EEC) and in the Annex A in the European Council Regulation 338/97.

1.3.2. Atlantic white-sided dolphin (*Lagenorhynchus acutus*, Gray 1828)

This delphinid species has a wide distribution in the cold temperate North Atlantic Ocean (Jefferson et al., 2008; Reeves et al, 1999a), occurring commonly from the Celtic Sea to south Iceland up to Svalbard Islands (Reeves et al., 1999a) (Fig.1.4); however, occasional sightings have been reported as far south as the Gibraltar Strait (Hammond et al., 2008b). The western populations inhabit waters over the continental platform (Waring et al., 2011), while the eastern population usually inhabits more offshore deep waters (Hammond et al., 2013; Wall et al., 2013).

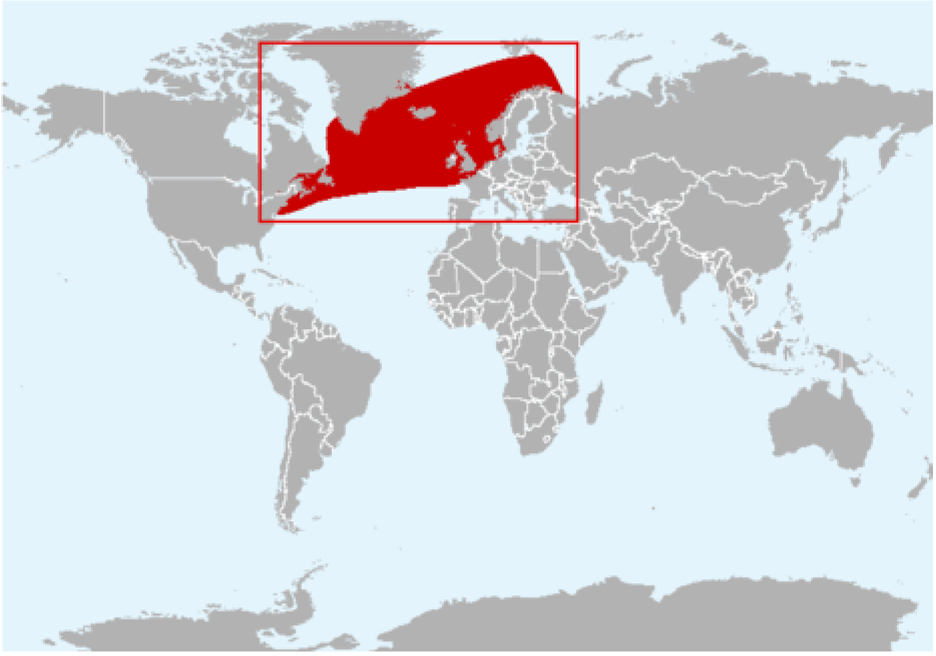


Figure 1.4 World distribution of white-sided dolphin. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

There are a number of estimates of abundance for Atlantic white-sided dolphins in the North east Atlantic derived on a number of different spatial scales. The multinational dedicated sighting survey SCANS II (Hammond et al., 2013) derived a combined estimate of abundance in Block Q (Figure 1.2) including the white-beaked dolphins of 7,736, with a density of 0.29 dolphins/km^2. MacLeod (2004) found that the relative abundance at the West Outer Hebrides was 21,371 (CV=0.54, 0.39 dolphins/km^2); and Ó Cadhla et al. (2004) estimated that the population in the Rockall Trough was 5,490 (CV=0.43; 0.046 dolphins/km^2). However, Evans et al. (2003) also indicated that this species does occurs elsewhere, probably in low numbers and/or seasonally including the Bay of Biscay and the Celtic Sea (Couperus, 1997b). Evans (1990) indicated that unlike white-beaked dolphin, this species does not commonly approach vessels; and Leopold and Couperus (1995) also indicated that this species might be more abundance than reported; therefore, the abundance reported by Ó Cadhla et al. (2001) and Hammond et al. (2013) might be underestimated.

The Atlantic white-sided dolphin is a robust delphinid species with a body girth of ~60% of total length, short beak and tall dorsal fin slightly falcate (Jefferson et al., 2008). Males are usually larger than females (Kinze, 2002); adult males reach 2.67-2.8 and weight 234-235kg, and females can measure 2.43-2.5m and weigh 182kg (Jefferson et al., 2008; Sergeant et al., 1980). As with other delphinid species it is dark dorsally and white on the ventral surface; but the conspicuous coloration on both flanks shows a white patch starting at the dorsal fin towards the flukes, and a yellowish patch continuing with the white patch to the keel, just before the flukes (Fig. 1.5) (Jefferson et al., 2008; Reeves et al, 1999a).

Figure 1.5. White-sided dolphin showing the typical coloration pattern

Previous diet studies have indicated that the diet comprises predominantly pelagic prey species such as Atlantic herring (*Clupea harengus*, Linnaeus 1758), Atlantic mackerel (*Scomber scombrus*, Linnaeus 1758), horse mackerel (*Trachurus trachurus*, Linnaeus 1758), and short-finned squid (*Illex illecebrosus*, Lesuer 1821) (Berrow and Stark, 1990; Couperus, 1997a; Jonsgård and Nordli, 1952; Morizur et al., 1999; Morizur and Antoine, 2003; Sergeant et al., 1980). This species has also been reported as being by-caught in fisheries targeting those species (Couperus, 1997a; Morizur et al., 1999; Northridge, 1984, 1991; Reeves et al., 1999a; Waring et al., 1999, 2006, 2007, 2011, 2013)

The Atlantic white-sided dolphin is classified as 'least concern' in the IUCN Red List, and it has been included in CITES (Appendix II) and in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS).This species is also listed in the European Council Regulation 338/97 (Annex A) and in the Habitats Directive (Annex IV).

1.3.3 White-beaked dolphin (*Lagenorhynchus albirostris*, Gray 1846)

The white-beaked dolphin is distributed in cold temperate and sub-arctic waters of the north Atlantic (Jefferson et al., 2008; Reeves et al., 1999b); but preferentially inhabits shelf coastal areas (Fig 1.6) (Jefferson et al., 2008). Their southern distribution is limited to the Celtic Sea (Reeves et al., 1999b), although rare sightings have also been recorded as far south as Strait of Gibraltar (Hashmi and Adloff, 1992). In the north east Atlantic it is considered an allopatric species with Atlantic white-beaked dolphin, preferring more shelf waters (Northridge et al., 1997) than the latter one, with the exception of the North Sea (Hammond et al., 2002).

The multinational dedicated sighting survey SCANS II (Hammond et al., 2013) derived an abundance estimate of 2,071 dolphins (CV=0.62, 0.014 animals/km^2) for Block Q and 273 dolphins (CV=0.86, 0.007 dolphins/km^2) in the Block R. Berrow et al. (2010) also reported sightings and strandings south and east of Ireland, although infrequently; and Hammond et al., (1995) estimated animal abundance of 833 animals (0.0041 dolphins/km^2) of *Lagenorhynchus* spp. in the Celtic Sea.

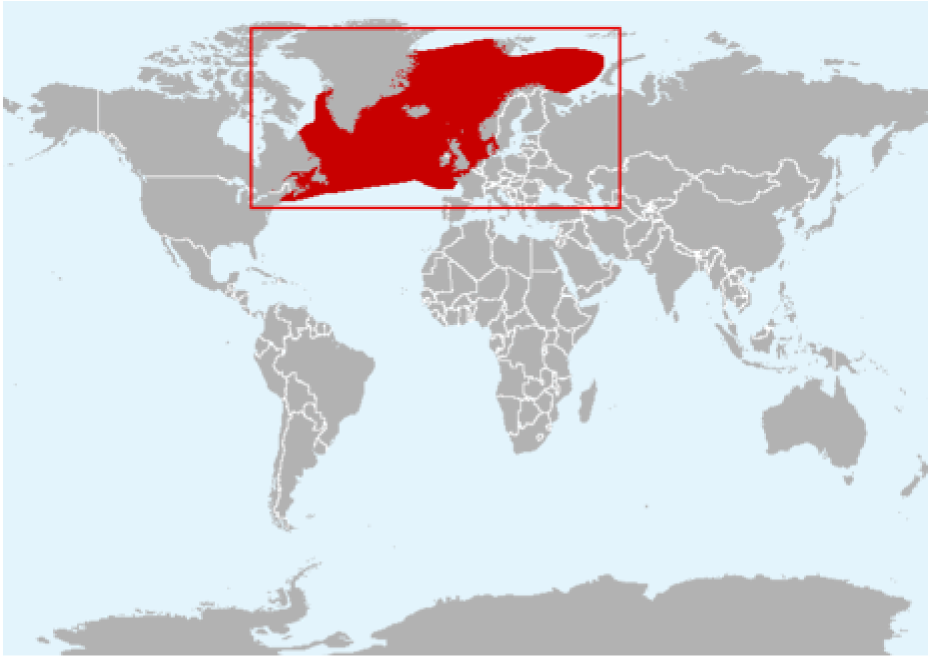


Figure 1.6 World distribution of white-beaked dolphin. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

They present similar size and features to the Atlantic white-sided dolphin; however they are slightly larger (2.4-3.1m for adult males and 180-350kg) (Jefferson et al., 2008). The coloration pattern is variable, but in general terms they present a white short beak continuing close to the flukes in the bottom area and dark in the back and sides; there is a lighter coloration from the beak to the melon, surrounding the eye, on the upper flank covering most of the tail (Fig. 1.7) (Jefferson et al., 2008; Reeves et al., 1999b).

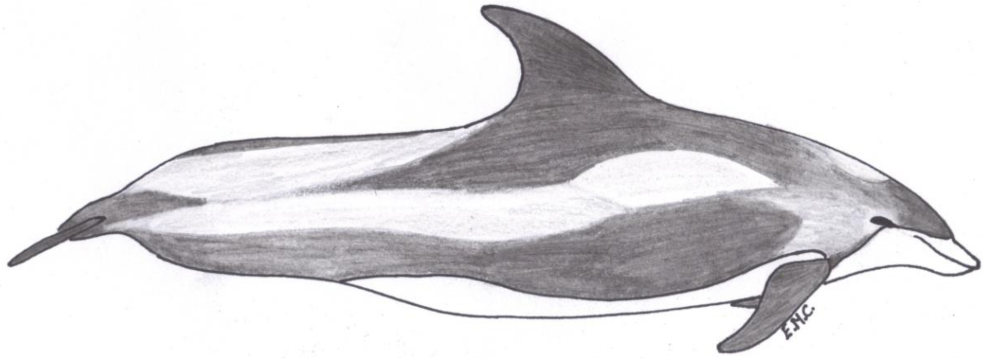


Figure 1.7. White-beaked dolphin showing the typical coloration pattern and white-beak.

Information about dietary preferences are reported mostly from the North Sea (Canning et al., 2008; Jansen et al.,2010; Santos et al., 1994), although a few diet studies have been carried out from animals stranded on the Canadian coasts (Reeves et al. 1999b and refs. therein). They appear to feed principally on Gadiformes species, especially whiting but other species are also consumed, including other pelagic species such as Atlantic herring and Atlantic mackerel as well as demersal species such as sandeels (Ammodytidae) and flatfish (Canning et al., 2008; Jansen et al., 2010; Reeves et al., 1999b).

The Atlantic white-beaked dolphin has the same international protection as Atlantic white-sided dolphin, classified as 'least concern' in the IUCN Red List, and been included in CITES (Appendix II) and in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS).This species is also listed in the European Council Regulation 338/97 (Annex A) and in the Habitats Directive (Annex IV)

1.3.4. Bottlenose dolphin (*Tursiops truncatus*, Montagu 1821)

The bottlenose dolphin is one of the most widely distributed Odontoceti species, from tropical to temperate waters including enclosed and semi-enclosed seas (Fig 1.8) (Caldwell and Caldwell, 1972; Jefferson et al., 2008; Hammond et al., 2002; Wells and Scott, 1999). Jefferson et al., (2008) indicated that they are more frequently recorded nearshore than in open waters. In the north east Atlantic, bottlenose dolphin distribution has been studied in a number of areas and on a number of spatial scales (e.g., Cañadas and Hammond, 2006; Clark et al., 2010; Fernandez et al., 2011a, 2011b; Grellier and Wilson, 2003; Ingram, 2000; Pesante et al., 2008; Wilson et al., 1999).

The multinational dedicated sighting surveys SCANS II (Hammond et al., 2013) and CODA (CODA, 2009) provided a relative abundance estimation of this species in European Atlantic waters, and specific local studies has given local populations estimations (e.g., Ingram, 2000; Lopez et al., 2004; Pesante et al., 2008; Thompson et al., 2004).

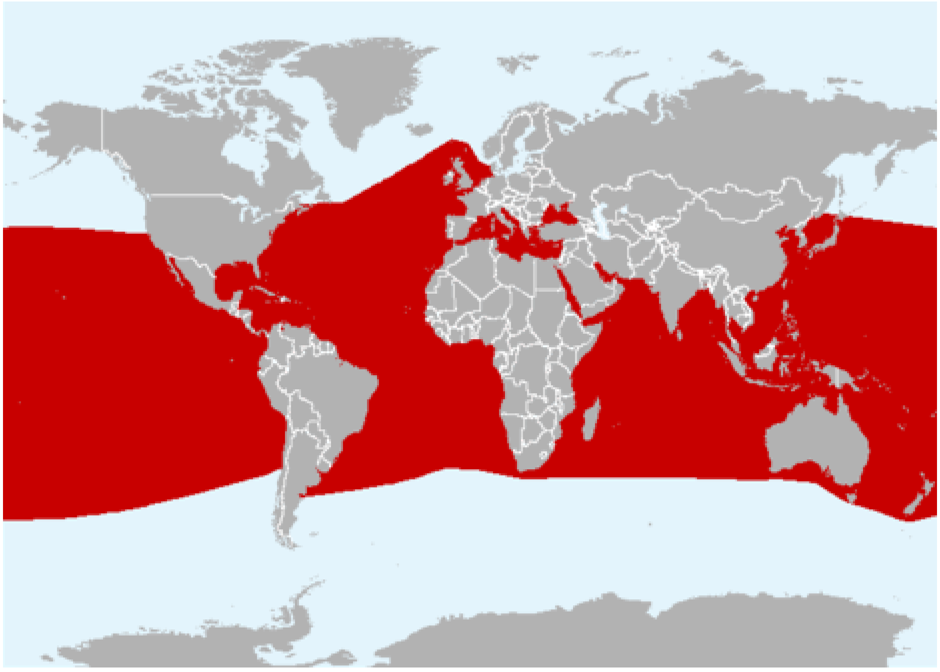


Figure 1.8 World distribution of bottlenose dolphin. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

The bottlenose dolphin is a medium-sized robust dolphin with a dark grey coloration on its dorsal part to light grey ventrally, with a white belly (Fig.1.9). It presents with a prominent beak and a falcate dorsal fin. Adults ranged between 2m and 3.8m depending on the geographical area (Perrin and Reilly, 1984; Wells and Scott, 1999), and it seems that body size is inversely related to water temperature (Hersh and Duffield, 1990; Ross and Cockcroft, 1990; Wells and Scott, 1999).

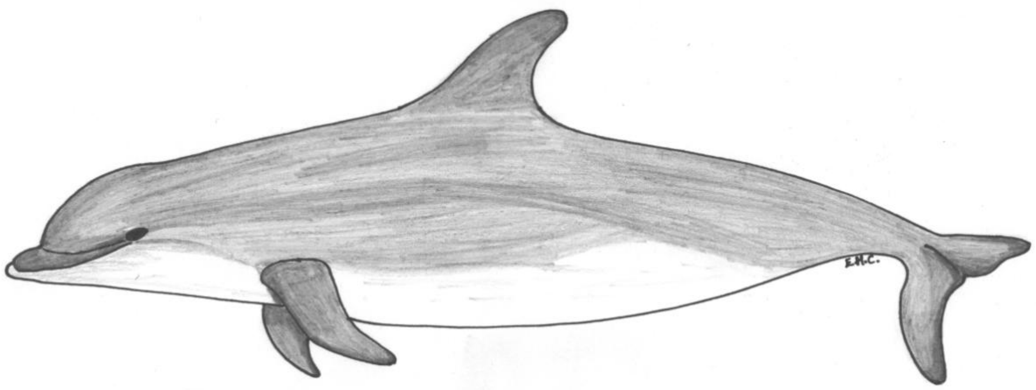


Figure 1.9. Bottlenose dolphin showing the typical coloration pattern

In the North West Atlantic, differences between inshore and offshore dolphins have been recorded based on morphology, genetic structure, trophic ecology and behaviour (Hoelzel et al., 1998, Jefferson et al., 2008; Natoli et al., 2005; Wells and Scott, 2002). However, to date, no differences have been found in the North East Atlantic (Fernandez 2010). Most of the populations studied in Ireland are concentrated along the west (Englund et al., 2007; Ingram et al., 2001; O'Brien et al., 2010) and south (Berrow et al. 1996, 2012; Ingram and Rogan 2003; Wall and Murray, 2009) coasts of Ireland. Wilson and Berrow (2006) and Wall et al. (2013) recorded bottlenose dolphins offshore, and in the Irish Sea bottlenose dolphins are known from Cardigan Bay (Evans et al., 2003; Pesante et al., 2008). Mirimin et al. (2011), found at least three genetically distinct bottlenose populations from stranded animals and biopsies from individuals taken along the west coast of Ireland. These populations include the resident group in the Shannon Estuary and Cork harbour, another one along the west coast of Ireland (represented by animals biopsied and stranded in Counties Galway and Mayo), and a third one of unknown origin from samples obtained from stranded dolphins. The later population had a high genetic variability (Mirimim et al., 2011) suggesting that they may be part of the offshore/pelagic population. Results from a recent study by Louis et al. (2014) are consistent with these results. These authors suggest the presence of a coastal population and an "offshore" population in the NE Atlantic.

Bottlenose dolphins are considered to be a generalist predator, but diet differences between western and eastern Atlantic populations have been reported; in European waters bottlenose dolphin seems to consume Gadiformes species (Blanco et al., 2001; De Pierrepont et al., 2005; Santos et al, 2001c; Santos et al., 2007; Spitz et al., 2006b), while in the western Atlantic distribution consumes pelagic fish and cephalopods (Barros and Wells, 1998; Barros et al., 2000; Walker et al., 1999).

The European Council Regulation 338/97 included bottlenose dolphin in the Annex A; also this species is also included in the Habitats Directive (92/43/EEC) in Annexes II and IV, and listed as 'least concern' on the IUCN Red List. It is also included in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS).

1.3.5. Harbour porpoise (*Phocoena phocoena*, Linnaeus, 1758)

The harbour porpoise occurs throughout the coastal waters of the northern hemisphere (Fig 1.10) (Jefferson et al., 2008; Read, 1999). To date, three subspecies has been identified throughout the area: *P.p.phocoena* occurring in the North Atlantic, *P.p.vomerina* in the North Pacific, and *P.p.relicta* in the Euro-Asian continental Seas (Black Sea and Sea of Azov) (Read, 1999 and refs therein). In Ireland, the harbour porpoise is one of the most commonly recorded coastal Odontoceti species (Evans et al., 2003; Hammond et al., 2013; Rogan and Berrow, 1996; Wall et al., 2013), with abundance estimations over 80,000 individuals in the North East Atlantic waters (Hammond et al., 2013).

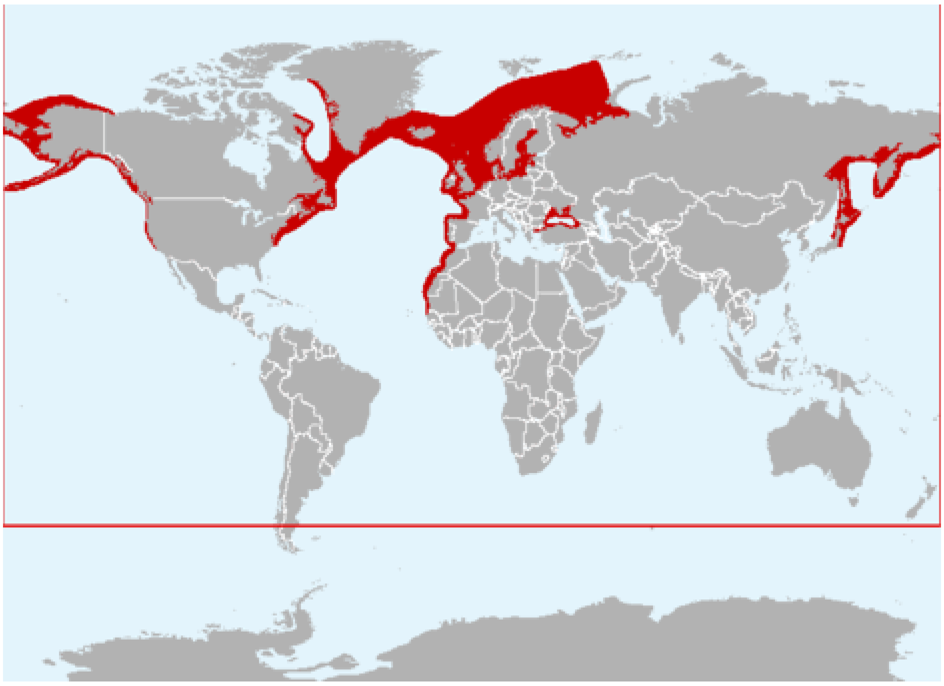


Figure 1.10 World distribution of harbour porpoise. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

Being the smallest cetacean species (145cm and 160cm for adult males and females, respectively; Lockyer, 1995a) in the North Atlantic, they are a very retiring species usually swimming in small groups (e.g., Clark et al., 2010; Read, 1999). Harbour porpoises lack a distinctive beak, have a small triangular dorsal fin, and have a dark dorsal area gradually turning lighter to the white belly and chin (Fig. 1.11) (e.g., Read, 1999). They are robust animals and are estimated to consume between 4% and 9.5% of their body weight per day (Kastelein et al., 1997; Lockyer et al., 2001), suggesting that they might need to feed frequently and probably on schooling and/or aggregated prey. In addition, in parts of their range they appear to give birth on an annual basis. Watts and Gaskin (1985) suggested that aggregations of porpoises were associated with Atlantic herring aggregations, and Johnson et al. (2005) reported that a greater relative abundance of harbour porpoises coincides with prey aggregations. Tynan et al. (2005) and Weird and O'Brien (2000) also found high densities of harbour porpoises were related with upwelling areas and higher prey densities. Different studies of dietary patterns have been carried out in specific areas of the European coasts (e.g., Jansen et al., 2013a; Santos and Pierce 2003 and refs. therein; Spitz et al., 2006b). Prey occurrence in this species was found to vary between areas, seasons and years (Santos and Pierce, 2003). For instance, whiting was the most important prey item followed by sandeels in porpoises analysed on Scottish coasts (Santos et al., 2004), while *Trisopterus* spp. (Rafinesque 1814), blue whiting (*Micromesistius poutassou*, Risso 1827) and Clupeids were found predominantly in porpoises recovered from the Bay of Biscay (Spitz et al., 2006b), and more than 90% of prey in harbour porpoises stranded in The Netherlands were demersal prey species, including cod (*Gadus morhua*, Linnaeus 1758) and poor cod (*Trisopterus minutus*, Linnaeus 1758) (Jansen et al., 2013b).

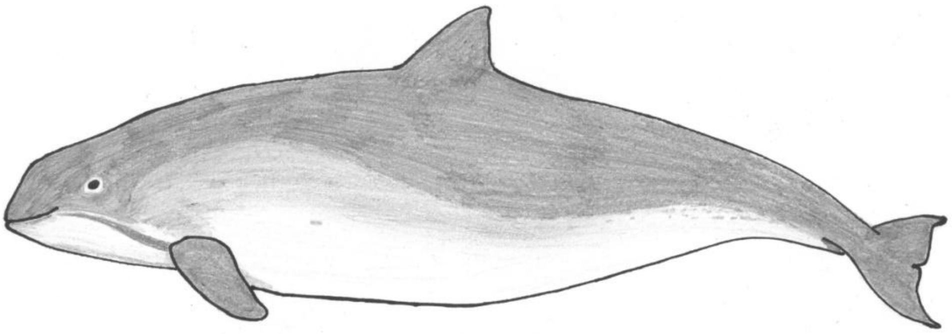


Figure 1.11. Harbour porpoise showing the typical coloration pattern

The harbour porpoise is included in the European Council Regulation 338/97 (Annex A), CITES (Appendix II), and in the Habitats Directive of the Council Directive 92/43/EEC (Annexes II and IV). IUCN red List classified the harbour porpoise as 'least concern' and is also included in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS).

1.3.6. Harbour seal (*Phoca vitulina*, Linnaeus 1758)

The common or harbour seal is one of the most widespread pinnipeds inhabiting the Northern Hemisphere from cold temperate to polar waters (Fig. 1.12) (Jefferson et al., 2008; Rice, 1998a; Thompson and Harkönen, 2008a). Five subspecies have been identified: *P.v.vitulina* (Linnaeus, 1758), inhabiting in European waters; *P.v.concolor* (DeKay, 1842) inhabiting in the Atlantic coasts of United States and Canada, as well as Greenland and Iceland; *P.v.mellonae* (Doutt, 1942) inhabiting lakes in Canada; *P.v.richardsi* (Gray, 1864) inhabiting the Pacific coasts of Mexico, United States and Canada up to Alaska, and *P.v.stejnegeri* (Allen, 1902) distributed from Alaska to the Japanese coasts (Thompson and Härkönen, 2008a). In the British Isles it is one of the most common pinniped species, along with grey seals. This species aggregates in haul-outs in rocky shores and sand or gravel beaches of bays, estuaries, and intertidal areas (Lockley, 1966; Thompson and Härkönen, 2008a). The abundance estimation of harbour seals for European Atlantic waters was reported to be about 500,000 (Folkens et al., 2002), but changes in their populations have been related to different causes such as fishery activities (Harwood and Croxall, 1988; Olesiuk et al., 1990), diseases (Harding et al., 2002; Reijnders, 1980), pollution (Mees and Reijnders, 1994; Reijnders,

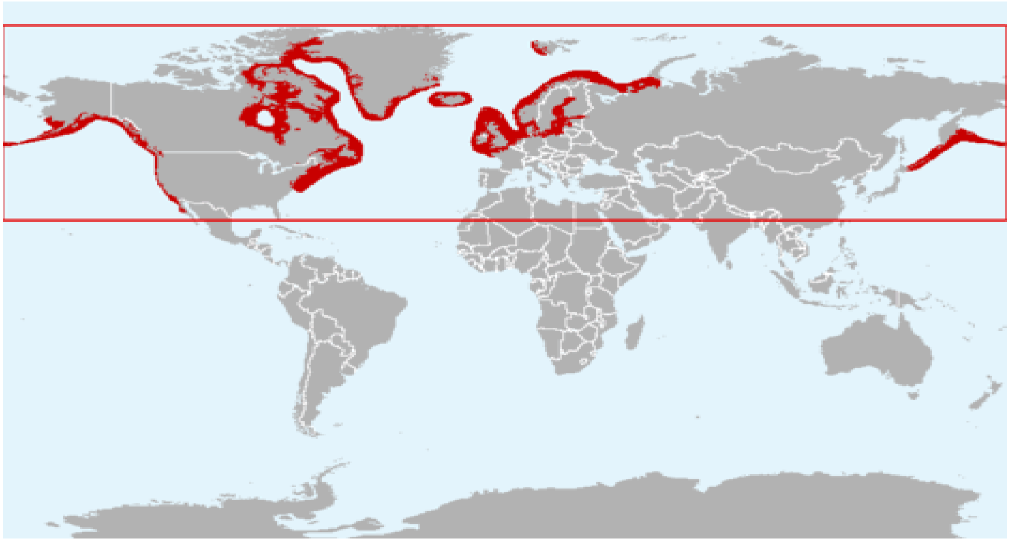


Figure 1.12 World distribution of harbour seal. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

1980), and prey availability (Matthews and Pendleton, 2006). In Ireland, there are only a few estimates (Cronin, 2007; Cronin et al., 2004; Lyons, 2004); the first study on population abundance was carried out in 2003 (Cronin et al., 2004), giving an estimation of 4,153 seals for the whole island.

Harbour seals have a general torpedo-like body shape, with a dark brownish coloration on their dorsal area and whiter on their belly with variable size spots over the whole animal (Fig.1.13) (Jefferson et al., 2008). It differs from the grey seal because nostrils are smaller in common seals and they have a “V”-shape, their head is small and roughly rounded, and the spots are smaller and more frequent (Bonner, 1977). Adults were reported to be as long as 1.9m (70-150kg) for males and 1.7m (60-110kg) for females (Jefferson et al., 2008).

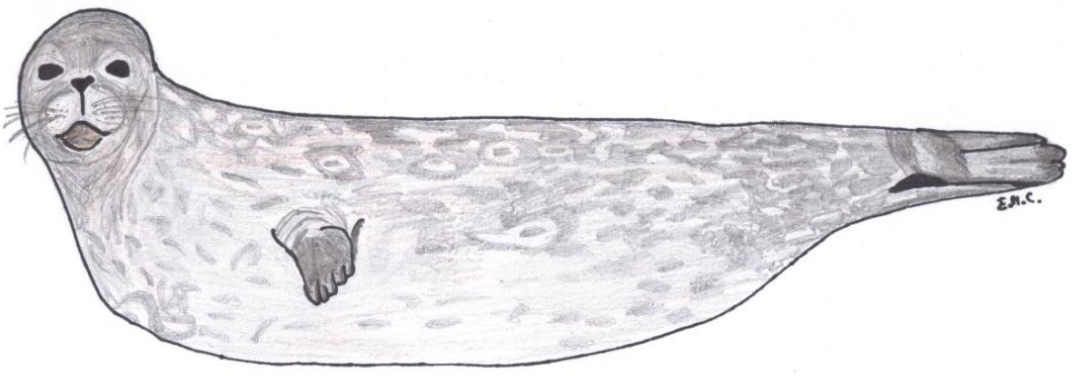


Figure 1.13. Harbour seal showing the typical coloration pattern

Different diet studies have been carried throughout its distributional range (e.g., Bjørge et al., 1995; Brown et al., 2001; Mees and Reijnders, 1994; Thompson et al., 1996), showing a preference for benthic prey (gobies and flatfish); however, Olsen and Bjørge (1995) indicated that they can shift onto pelagic prey if availability is high. In Ireland, only one study has been carried out using traditional methodology, identifying otoliths, and fatty acid analysis (QFASA, Quantitative Fatty-Acid Signature Analysis) using biopsies of blubber samples of common seals in south west Ireland haul outs (Kavanagh, 2008; Kavanagh et al., 2011); in this study, identification of hard remains from scats showed that the most frequently occurring prey was sandeels, followed by

Gadiformes and dragonets (*Callionymus* spp., Linnaeus 1758), although QFASA results showed a possible seasonality pattern.

Common seals are classified as 'least concern' on the IUCN Red list, and included in the Annexes II and V of the Habitats Directive. Hunting this species is prohibited in most of the countries, and only subsistence hunting in North America is allowed but restricted (Thompson and Härkönen, 2013).

1.3.7. Grey seal (*Haliochoerus grypus*, Fabricius 1791)

Grey seals are distributed throughout the north Atlantic from cold temperate to Arctic waters (Jefferson et al., 2008); however, Bonner (1981) indicated that they should be considered as three separate stocks: the western stock, the eastern stock (mainly around the British Isles), and the Baltic Sea stock (Fig 1.14). Their populations have been reported to have increased over the last few decades on both sides of the Atlantic (Härkönen et al., 2007; Thompson and Härkönen, 2008b; Waring et al., 2013). About

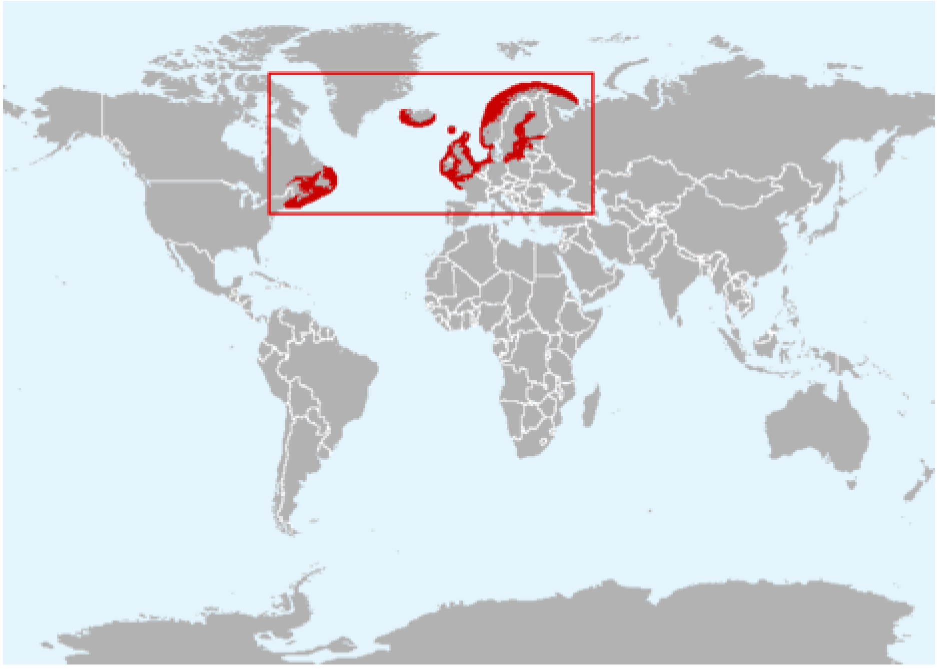


Figure 1.14 World distribution of grey seal. Maps by IUCN. Published by UNEP / CMS Secretariat, Bonn, Germany.http://www.cms.int/reports/small_cetaceans/index.htm)

45% (45,100 seals in UK and 300 seals in Ireland) of the whole population breeds in the British Isles (Thompson and Härkönen, 2008b); however, recent studies in Ireland estimated a population of 5,343 (Ó Cadhla and Strong, 2007) seals which will slightly increase this percentage. Grey seals aggregate at haul-outs preferably in remote and exposed coastal areas (Härkönen et al., 2007; Thompson and Härkönen, 2008b).

The grey seal is a robust pinniped with a larger and broader head than common seals (Jefferson et al., 2008). Sexual dimorphism is present, where males are substantially larger than females reaching up to 2.3-2.45m (170-310kg, while adult females are usually around 2m length (105-186kg) (Fig. 1.15) (Bonner, 1977; Jefferson et al., 2008). Nostrils in grey seals are larger than in common seals and the present a “W”-shape, and larger but less numerous spots on their coat (Bonner, 1977).

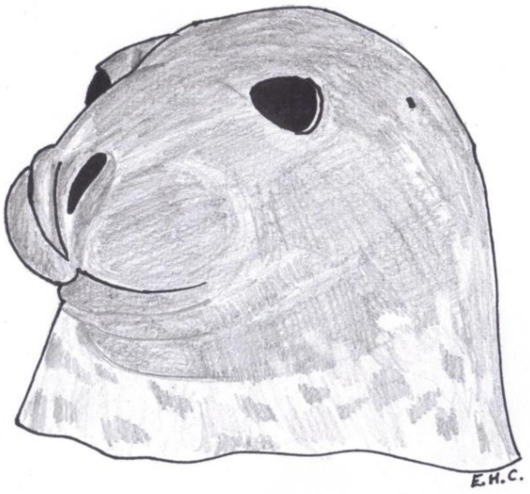


Figure 1.15. Grey seal showing the typical head shape and coloration pattern

Feeding ecology of this species has been studied in most of its distributional range (e.g., Bowen and Harrison, 1994; Hammond et al, 1994a, 1994b; Lundström et al., 2007; Pierce et al., 1991b; Ridoux et al., 2007). Although with some local variations, dietary preferences appear to be for demersal and benthic species such as sandeels, skates, demersal Gadiformes, dragonets and flatfish; however, they were also found to feed on schooling pelagic prey such Atlantic herring or Atlantic mackerel. The importance of salmonid species (Atlantic salmon –*Salmo salar*, Linnaeus 1758-, and sea trout –*Salmo trutta*, Linnaeus 1758) in the diet has been found to be low in grey seals (Butler et la., 2006; Lenky and Sjare, 2011; McConnell et al., 1984; Prime and Hammond, 1985) although the interaction with the salmonid industry is reported to be high (e.g., Butler et al., 2006; Lehtonen and Suuronen, 2010). In Ireland, a few studies have been carried out (Philpot, 2001; Gosch et al., 2014), reporting that this species might forage preferentially on demersal Gadoid species.

International classification within IUCN Red List of Threatened Species included the grey seal as ‘least concern’; however, this seal species is still hunted in some countries at low level (Thompson and Härkönen, 2008b). It is also included in Annexes II and V of the habitats Directive.

1.4 THE USE OF DIET STUDIES

Marine mammals expend most, if not all, of their time in the water so their morphology, physiology, and behaviour are adapted to this type of environment. Foraging behaviour and the type of prey ingested by these species will depend on the species itself, as well as the individual stage (e.g., age, size, sexual stage), the habitat, and the resources available (e.g., abundance and diversity of prey) (Beck et al., 2005, 2007a, 2007b; Bowen et al., 2002). On the other hand, their fitness, in part, is related to their foraging success and their energy intake. In order to satisfy nutritional requirements, the predator can adopt different strategies: it feeds on high energy prey when it is available, or it feeds on high numbers of prey of low calorific value but enough to meet their physiological requirements or it feeds using a combination of both strategies (Begon et al., 1996). Any strategy adapted by the predator will aim to obtain the highest fitness for survival and reproduction. Indeed, predator population growth has been suggested to be limited by food supply (Bowen et al., 2006; Boyd et al., 1994; Montevecchi, 1993).

Two main different feeding strategies can be considered: specialists and generalists. Specialist species are those who feed on a narrow spectrum of resources, while a generalist species present a wide type of prey within their diet (Begon et al., 1996).

The study of the diet of marine mammals has largely occurred in the last century (e.g., Brown, 1915; Fernández et al., 2011; Fitch and Brownell, 1968; Hammond et al., 1994a,1994b; Hooker et al., 2001; Mathisen et al., 1962; Perrin et al., 1973; Rae 1965) using mainly traditional methodology; however, over the last few decades other techniques such as stable isotopes, fatty acids, serology and genetic analysis have been also applied (e.g., Chapter 2, Das et al, 2003; Deagle et al., 2005; Fernández et la., 2011b; Mendez-Fernandez et al., 2013; Newsome et al., 2010; Pierce et al., 1990). The strengths and weakness of the different techniques and approaches has been largely discussed (Chapter 2; Budge et al., 2006; Pierce and Boyle, 1991; Pierce et al., 2004, 2007; Tollit et al., 2006). In this study, a traditional approach (Chapter 2) was used to reconstruct diet and to allow comparison between different species. In addition to that, it is possible to identify to species level prey items that are important in this geographical area. The use of this technique also allows for the estimation of the annual food consumption by prey items as well as populating and building up mass-balance models, such as Ecopath model.

Annual food consumption has been investigated in some parts of the world (e.g., Antonelis and Perez, 1984; Barlow et al., 2008; Col et al., 2012; Kaschner and Pauly, 2004; Kenney et al., 1997; Pierce et al., 2007; Sigurjónsson and Víkingsson, 1997; Trites et al., 1997). This information is important for feeding behaviour studies and in order to get a more realistic approach of the interactions between predators and fishery activities. Two approaches have been generally used for those estimations; the first one uses a general equation where data for specific populations are reconstructed using the daily average individual consumption/energetic requirement usually obtained in the literature (e.g., Col et al., 2012). The second approach takes into accounts the proportion by weight of individual prey species consumed (e.g., Pierce et al., 2007). In the former one, no information about the diet of the species in the area is necessary, being based solely on energetic requirements. In the latter, information about the estimated prey biomass is used. Using this approach, the use of traditional methodology identifying the hard remains in digestive tracts and scats allows us to obtain the prey length as well as the estimated biomass of the prey ingested, using back-calculation regressions applied over the measurements of those hard remains, providing an additional approach to addressing marine mammal fisheries interactions.

Given the large and differing habitats available in Irish waters, the diet of marine mammals occurring here is likely to vary substantially in comparison with other areas (CIESM, 2004). There are a few publications (Brophy et al., 2009; Gosch et al., 2014; Kavanagh et al., 2010; O’Brien et al. 2009) and MSc thesis (Brown, 1999; O’Callaghan, 2000; Davey, 2012; Luck, 2013) carried out in relation to the diet of small cetaceans in this area; however, they have not been studied in the context of their trophic roles and their interactions with fisheries.

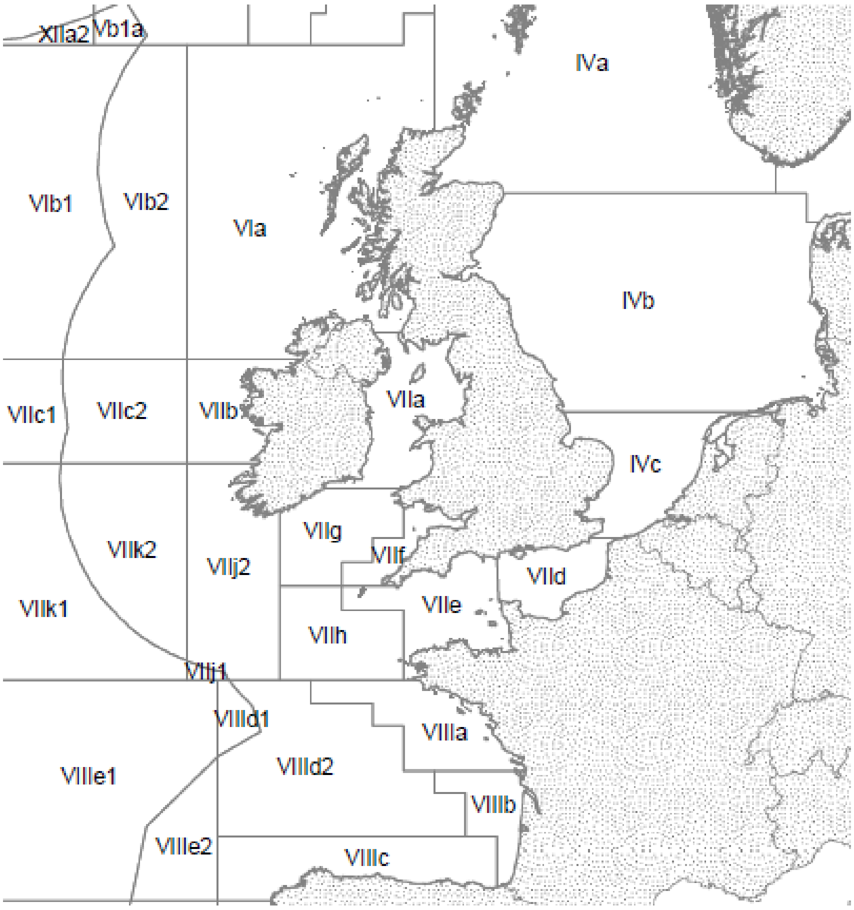


Figure 1.16. ICES Divisions in the North East Atlantic

Fisheries have been reported to be an important economic resource in Ireland, with a profit of €1,161 billion (MI, 2013). Fishing activities are assessed by ICES which divides the Northeast Atlantic into different Divisions and Sub-divisions for stocks and fisheries management purposes (Fig. 1.16). Marine mammals inhabiting Irish waters likely overlap with fisheries, and their interaction should be considered in relation to dietary requirements and potential competition with fisheries. In this study, these interactions have been investigated through the use of dietary information.

1.5 MULTI-SPECIES MODELS

The ecological functional role of top predators and the linkages within the marine ecosystems is essential to understanding the functioning ofmarine food-webs; therefore estimations of the prey ingested are important key points to understand the interactions within the ecosystem and natural mortality of their prey (Bowen, 1997; Trzcinski et al., 2006). Indeed, Montevecchi et al. (2006) indicated that “*The foraging behaviour and ecology of top predators are expressions of trophic and ecosystem dynamics*”. On the other hand, models investigating predator-prey behaviour may be useful in a management context, if correct parameterization and validation of the models are included (Croxall, 2006). Shifts in predator diet has been found to be related to environmental changes (e.g., Edwards and Richardson, 2004; Forcada et al., 2006; Hunsiker et al., 2013), but the population dynamics of their prey also plays an important role in these variations (Iverson et al., 2006).

The trophodynamic role of marine mammals within ecosystems have been recently studied through estimations of their food consumption and the total net production required to support their prey Barlow et al. (2008); however, other multispecies models can also contribute to improving our knowledge of the importance of top predators within the ecosystems. Multispecies studies are usually more difficult to investigate, but they provide more understanding of food-web dynamics than those single-species approach (e.g., Montevecchi et al., 2006; Plagányi, 2007). Marine mammals comprise one of the main groups of predators in the ocean, and their role within the trophic food webs and pelagic ecosystems may bean important link to top-down and bottom-up effects (e.g., Estes, 1996; Merrick, 1997). However, the use of these top predators as indicators might be difficult to explain as there are still uncertainties related to the effects of the top-down and bottom-up forces influencing their status (Thompson, 2006). One of the approaches used to investigate the role of top predators during the last decade is the construction of ecological trophic models using Ecopath with Ecosim (EwE) (e.g., Guénette et al., 2006; Pauly et al., 2000). This model provides important insights into the relationship of apex predators within the ecosystems; a depletion or reduction of one of them might have adverse results over the whole ecosystem (see review in Estes et al., 2009; Kaschner et al., 2006; National Research Council, 2003).

The waters around Ireland are considered important fishing areas (OSPAR, 2010), with a number of commercial species targeted by Irish and other European fleets. However, in some cases, commercial fish stocks have been depleted, and are outside of safe biological limits, curtailing fishing on these species. This may have implications for the prey choice and foraging behaviour of top predators, such as marine mammals. On the other hand, increasing, or apparently increasing marine mammal populations are often “blamed” for declining fish stocks, which in some scenarios have called for culls for these species, in particular seals. Marine mammal fisheries interactions often lead to the death of the mammal, with by-catch of a number of species reported from a number of fisheries operating in Irish waters and understanding and mitigating these interactions is important, particularly if the motivation for the marine mammals being near the net is food.

1.6 OUTLINE AND AIMS OF THE THESIS

The aims of this thesis are to:

i) to describe the diet of a number of marine mammal species,

ii) estimate the annual food consumption and prey requirements of these species,

iii) estimate the size and biomass of prey removed by these species,

iv) examine the overlap between the dietary requirements of these species and commercial prey species,

v) improve the Irish Sea model given by Lees and Mackinson (2007) with recent dietary information data, and

vi) quantify and model the ecological role of marine mammals in the Irish Sea.

This thesis is organized in eight chapters.

In the first chapter a general introduction of the area and the species studied is presented, including a brief resume of the methodology applied and the importance of the area.

The second chapter covers the approaches used to quantify diet, with a discussion on the different techniques and their advantages and disadvantages. A detailed description of how diet is examined and quantified in this thesis is also given.

In the third chapter, the diet of striped dolphins is described, along with the annual food consumption of this species.

In the forth chapter, the first insight into the diet of white-sided and white-beaked dolphins in Irish waters is provided. Further investigations into the diet of white-sided dolphin was carried out by comparing diet derived from mass stranding events with that from other (single) strandings, and annual food consumption for this species in the area was also estimated.

The fifth chapter covers the first study of the diet of bottlenose dolphins stranded in Irish coasts. The annual food consumption of this Annex II species in Irish waters was also estimated.

In the sixth chapter, diet of the four coastal marine mammals in Irish waters is presented and dietary overlap is investigated. The data presented in this chapter was also used as the base data for the following chapter (Chapter 7: Ecopath model).

In the seventh chapter, a model using the software Ecopath with Ecosim of the Irish Sea was build up (based on data from 2004) in order to investigate the linkages between fisheries and top predators and predict the effect of fisheries and apex predators in the area of study in the future. The model was built using the template (based on data from 1973) constructed by Lees and Mackinson (2007) but improved using more recent and more accurate information, in particular with respect to the apex predators.

The concluding chapter includes a general discussion of the whole thesis, with recommendations for further study.

Chapter 2

METHODOLOGY FOR MARINE MAMMAL DIET STUDIES

CHAPTER 2

METHODOLOGY FOR MARINE MAMMAL DIET STUDIES

2.3 Methodology

2.1. ABSTRACT

Foraging ecology of marine mammals has been studied since the beginning of the last century, usually through the identification of hard structures from prey recovered within the digestive tracts, scats, and spews. The biases related to this methodology have encouraged the development of new analytical techniques such as stable isotope analysis (SIA) and fatty acid analysis (FA) comparing predator tissues with potential prey tissues. A general overview of all of these techniques, as well as their biases, are summarised in this chapter. The chapter focuses on the traditional methodological approach, because this is the methodology used in this study. The description of the diet indices and food consumption estimation equations are also described.

2.2. INTRODUCTION

Studying the foraging ecology of marine mammals is difficult as they are animals that spend most of their lives or a large part of their time below the sea surface, and their hunting activities usually occur out of our sight. Indirect studies have been used to understand their trophic ecology and their habitats. Many of the dietary studies of marine mammals have been carried out over the last 100 years (e.g., Fernández et al., 2011b; Fitch and Brownell, 1968; Hammond et al., 1994a, 1994b; Hooker et al., 2001; Mathisen et al., 1962; Newsome et al., 2010; Perrin et al., 1973; Rae 1965). Different methodological approaches have been developed to investigate the feeding ecology of marine mammals; however, all techniques have their strengths and weaknesses (Budge et al., 2006; Pierce and Boyle, 1991; Pierce et al., 2004, 2007; Tollit et al., 2006). The importance of these studies is that they provide us with information about marine mammal feeding behaviour, habitat use and their interaction with fisheries. In the context of fishery interactions, it is important to obtain reliable information on the consumption of commercial prey by the predators occurring in the area of study. In addition, these studies have been also used for the estimation of annual food consumption and food requirements (e.g., Barlow et al., 2008; Col et al., 2012; Trites and Pauly, 1998). Annual food consumption is usually estimated using general equations where data about population size and the daily averaged individual consumption can be obtained in the literature (e.g., Barlow et al., 2008; Col et al., 2012; Trites and Pauly, 1998). However, when diet information is available, the weight proportion of prey species can be considered in the annual food consumption approximations (e.g., Pierce et al., 2007; Santos et al., 2011). It was believed that results from both approaches are important for comparison and the approaches used by Col et al. (2012) in the first case, and then Pierce et al. (2007) were applied in this study.

The methodologies associated with diet reconstruction can be classified into three main groups:

1- Traditional methodology: identification of prey remains (mainly otoliths and beaks) through gut contents, scats, and regurgitations.

2- Analytical methodology: using analytical laboratory techniques such as fatty acids, stable isotopes, chemical tracers, genetics, and serology.

3- Direct observation: limitations of this technique are large as the opportunity to observe these predators hunting are low (Pierce and Boyle, 1991). But the development of telemetry and animal-borne videos might help with observations, especially for foraging techniques.

The methodology used in this thesis is the traditional approach, as to date, it provides the most reliable and robust way of re-constructing diet.

2.2.1 Traditional methodology

The traditional methodological approach has been used since the 1900s (e.g., Brown, 1915; Fitch and Brownell, 1968; Gunter, 1942; Rae 1965, 1968; Scheffer, 1953), and is reviewed by Pierce and Boyle (1991), Pierce et al. (2004) and Tollit et al. (2010). It consists of the identification of remains found in the digestive systems of dead marine mammals (stranded, by-caught or hunted) as well as seal scats (collected at haul-outs), regurgitations/spewing/faecal remains (collected at sea), and stomach lavage. The analysis of the diet using digestive tracts of cetaceans and seals should be performed on the entire digestive tract, from the beginning of the oesophagus to the anus, as some remains can be retained more than others in different parts of the digestive tract. Most of the diet studies are carried out investigating only the remains found within the last part of the oesophagus and in the stomachs (e.g., Garcia-Godos et al., 2004; Jansen et al., 2010; Santos et al., 2001a, 2001b; Silva, 1999; 2002; Spitz et la., 2006b). Intestines are usually a tedious part of the digestive tract to investigate (they are usually more than 15 metres long) and if there are not sufficient facilities to store and/or analyse them, they are often discarded and information may be lost. Usually intestines contain small amounts of prey and often the hard structures are very eroded, but sometimes bones, otoliths and other remains are retained in particular areas of the intestines while only a few items are found in the stomach (Hernandez-Milian and Rogan, 2009).

Seal scats are generally collected during low tide at seal haul-out areas. Ireland is characterized to have 3-4 metres tides twice a day, and during high tide scats are usually washed out by the water; this characteristic allows for only a small window of opportunity to collect scats that were defecated during the last 12h. The size of scats varies in size and volume (from 50ml to 250ml) and consistency. Grey seal scats are easier to collect than harbour seals (*Phoca vitulina*, Linnaeus 1758) as grey seals (*Halichoerus grypus*, Nilsson 1820) are usually located higher on the beach than common seals (Martha Gosch, *pers. comm*). In addition, haul-out sites are often in areas that are inaccessible (Thompson and Härkönen, 2008a, 2008b). One of the areas which is relatively easy to access is the Blasket Islands (Co. Kerry), where one of the most important grey seal populations is concentrated (Ó Cadhla and Strong, 2007). However, it is also an important tourist area, especially in summer when the number of people visiting the area increases and the seals leave the main large beach and haul-out on small rocky islands that are more difficult to access.

Cetacean defecations, and in particular small cetacean defecations, are usually difficult to detect and collect, and regurgitations are rarely found (Gales and Pemberton, 1994; Longenecker, 2010), therefore gut contents is the usual procedure to investigate the diet of these animals. The stomach lavage technique is an intrusive technique that requires capture and immobilization of the animal using drugs and increases the stress of the animals and therefore is not commonly used (e.g., Antonelis et al., 1987; De Long and Steward, 1991).

Dietary studies reconstructed using the traditional approach likely represents the last few meals of the animal (e.g., Pitcher, 1980; Tollit et al., 2003), although Phillips and Harvey (2009) indicated that scats might have remains of food eaten more than six days previously, and similarly might occur in dolphin species. In addition, sometimes only part of the prey is eaten (especially those prey depredated from long-line and net fisheries, for example); however, identification to species level is usually possible if enough training has been acquired by the researcher, as well as the availability of guides and atlases of otoliths, bones, beaks and crustaceans of the study area, along with local reference collections of potential prey. Different studies have pointed out the biases associated with using this technique (Beck et al., 2007b; Dehn et al., 2007), and in general terms these have been reviewed by Pierce and Boyle (1991) and Pierce et al. (2004) and recently by Bowen and Iverson (2013) and are summarised below:

1- All prey items recovered from digestive tracts and scats correspond to the last few meals. In regurgitations/spewing probably the last meal.

2- Only using otoliths to reconstruct fish prey remains limits identification of some species. For example otoliths of whiting (*Merlangius merlangus*, Linnaeus 1758) and blue whiting (*Micromesistius poutassou*, Risso 1827) are not easy to identify when they are worn, however other hard structures can be used to differentiate both species. Prey species that present fragile and very small otoliths but with other stronger hard structures (e.g., dentaries, premaxilla, and vertebrae) will usually be underestimated if only otoliths are used (Pierce and Boyle, 1991; Pierce et al., 1993).

3- Prey size and biomass estimations can be obtained from hard parts, however, bones and otoliths will often be highly eroded, and therefore digestion correction factors should be applied. A number of studies have calculated partial and full digestion correction factors for a limited number of otoliths of fish species and cephalopod beaks (Bowen, 2000; da Silva and Neilson, 1985; Dellinger amd Trillmich, 1988; Grellier and Hammond, 2006; Harvey, 1989; Harvey and Antonelis, 1994; Jobling, 1987; Murie and Lavigne, 1985; Tollit et al., 1997), but no correction factors for bones are available in the literature; therefore, some of the prey size and biomass might be over- or under-estimated. In addition, these correction factors were designed to be applied to prey remains in seal scats, which are usually more eroded than the prey remains found in stomachs.

4- This type of approach requires a long time period for sample collection, especially in the case of cetaceans, as strandings occur infrequently and the carcasses are often decomposed and/or scavenger damaged, limiting sampling. Seal scats can be collected relatively easily, but they should be collected separately, to avoid clumping of separate scats as one, as well as with a reasonable time interval between sampling events to ensure that samples are not duplicated.

On the other hand, the identification of prey remains found in scats is difficult, because after passing through the entire digestive system, the prey remains are usually broken and often eroded. The most delicate otoliths and bones may disappear during the digestive activity, and stronger-medium otoliths might appear broken or eroded. However, the digestion/erosion of individual prey remains will vary depending on many factors such as predator species (Bowen, 2000), meal size (Marcus et al., 1998), prey size (Tollit et al., 1997) and metabolic activity.

2.2.2 Analytical methodology

The analytical approaches to studying diet are relatively new and are still being developed and refined to improve and compliment the more traditional approaches (Beck et al., 2005; Pierce et al., 1993; Tollit et al., 2006; Tollit et al., 2010). This type of approach allows for the integration of dietary information over different timescales (from several weeks to months), depending on the tissues sampled and samples can be obtained from free living animals (through biopsies) as well as from dead animals and scats. Different techniques have been used, such as quantitative fatty acid signature analysis (QFASA), stable isotopes analysis (SIA), serology analysis and DNA identification of prey remains. Although the inference about the predators' diet may be integrated over a longer timescale (e.g. SIA and QFASA), these techniques are more expensive than the traditional approaches and while SIA gives an idea of the trophic level or habitat type that animals have been feeding on, QFASA requires fatty acid libraries from the time that the dolphin stranded (e.g., Iverson 1993; Nordstrom et al., 2008; Tollit et al., 2006). In most of the cases, identification to specific taxonomic level is not possible (SIA) or extremely expensive (FA, serology, DNA). For predators that are specialist feeders (feeding on four or five prey species) these techniques may be useful for prey identification (e.g., Abend and Smith, 1997; Stauss et al., 2012), or when we want to identify and quantify a specific prey species that is economically important (e.g., Atlantic salmon, *Salmo salar* Linnaeus 1758).

Quantitative fatty acid signature analysis has been used to determinate dietary patterns and dietary shifts in a number of feeding ecology studies (e.g., Beck et al., 2005; Grahl-Nielsen and Mjaavatten, 1995; Iverson et al., 1997a, 1997b, 2004; Møller et al., 2003). Fatty acids are lipids with a chain length of 14 or more carbon molecules, which incorporate into the predators' adipose tissue with minimal modification (Iverson et al., 1997b); their diversity and distribution pattern between the different prey facilitates their use in the identification and quantification of prey in marine mammals (e.g., Iverson et al., 1197b). However, Iverson et al. (2004) indicated that in predators with a large amount of potential prey items this technique might have some biases. These authors concluded that for this technique to be successful that as a prerequisite, a database of fatty acids of the potential prey for the predator in question was necessary, and then those fatty acids might allow prey species to be distinguished.

The use of SIA has largely been used to investigate the trophic ecology of different animal species (e.g., Das et al., 2003a, 2003b; Fernandez et al., 2011b; Kelly, 2000; Mendez-Fernandez et al., 2013). Analyses of ratios of naturally occurring stable isotopes have emerged as powerful tools in many areas of ecology including, feeding ecology and animal movement (e.g. Hobson, 1999, 2005; Rubenstein and Hobson, 2004; West et al., 2006). It has been shown that stable isotopes vary geographically (e.g., Schmidt et al., 2005), and by examining ratios of isotopes absorbed through diet, researchers have been able to track animal movements and differentiate aggregations based on differences in local food webs and geographic foraging locations. A number of different isotopes have been used to study marine mammal ecology, including the isotope ratios of carbon, nitrogen, and sulphur. The tissues used also vary, depending on the research question being asked, but include skin samples (which are easily obtained though non lethal sampling, via biopsy), whiskers, teeth, baleen and muscle. The technique is based on the enrichment of chemical compounds, mainly carbon-isotope ratio ($^{13}C/^{12}C$) and nitrogen-isotope ratio ($^{15}N/^{14}N$), in the tissues of predators; these ratios have been found to be related to assimilation of the prey material by predators and related to their trophic level position (e.g., DeNiro and Epstein, 1978; Kelly, 2000; Peterson and Fry, 1987). The application of SIA can therefore provide useful information about trophic structure, habitat use, latitude and carbon sources (e.g., Burton and Koch, 1999; Dehn et al., 2007; France, 1995; Kelly, 2000; Petersen and Fry, 1987; Smith et al., 1996). Nitrogen-isotope ratio enrichment may be usefully related to trophic level as well as to latitude and ocean temperature (Kelly, 2000 and references therein).

Carbon isotope ratios ($^{13}C/^{12}C$) display little or no change in abundance between trophic levels following the primary producer to primary consumer link. As such, isotopes of this chemical element are useful to discriminate areas of primary productivity where areas of isotopically distinct sources are present (e.g., phytoplankton vs. kelp forests). In the marine environment, benthic and coastal food webs are enriched in ^{13}C relative to pelagic food webs. In contrast, the stable isotope nitrogen ratios ($^{15}N/^{14}N$) show a systematic enrichment with trophic level, a relatively constant effect considered to be 2 – 5‰ between producers and consumers (Peterson and Howarth, 1987, Vander Zanden and Rasmussen, 2001), which can be used to model the position of consumers in the marine food webs (e.g., Bearhop et al., 2004, Mendez-Fernandez et al., 2013). Recent analysis has also suggested that there is variability in inshore vs. offshore $\delta^{15}N$ signatures (Chouvelon et al., 2012) as a result of differential update of N from difference sources by phytoplankton.

Sulphur ($\delta^{34}S$) is less commonly used, but is considered useful as an estuarine indicator (Rubenstein and Hobson, 2004, Barros et al., 2010) separating and enhancing the differences in terrestrial/freshwater vs. marine sources from estuary, inshore and offshore habitats for bottlenose dolphins, for example (Barros et al., 2010, Olin et al., 2012) and estuarine residency times for fishes (e.g., Connolly et al., 2004, Fry and Chumchal, 2011).

The application of serological methods, using the muscle proteins of particular prey species, has been used as a complementary technique for the identification of fish in marine mammal diet (Pierce et al., 1990a; 1990b); however this methodology has only been used to identify particular prey species as it is an expensive technique and biases in the methodology, such as rapid loss of antigenity when passing through the digestive tract and cross-reaction antisera from different species which may give a wrong identification.

The use of ribosomal, mitochondrial and nuclear DNA for the identification of species has been used in dietary studies since 1992 (e.g., Höss et al., 1992; Jarman et al., 2002; Pierce et al., 1993). It has been found to be a very successful technique for the identification of prey species whose digestibility is high and the identification/quantification of it difficult (Jarman et al., 2002; Matejusová et al., 2008). To date, the wide-spread use of this technique has been restricted, mainly because of the expensive cost of the analysis.

2.2.3 Direct observation

Direct observation of hunting activities is very difficult to observe as these predators usually carry out their feeding activities below the sea surface. However, the use of opportunistic records of animals hunting and photographic material has been used to identify particular prey (Díaz López, *pers. comm.*; Manel Mazo, *pers. comm.*; Ingram, 2000; Muñoz-Cañas et al., 2012).

On the other hand, foraging behaviour has been investigated in the last couple of decades using animal-borne video systems including crittercams (e.g., Davis et al., 1999, 2003; Parrish et al., 2000; Parrish and Littnan, 2008). The development of telemetry for foraging ecology studies, in particular in seals and deep diving species (e.g., Friedlander et al., 2006; Goldbogen et al., 2012; Johnson et al., 2009; Thompson et al., 1991) has increased over the few decades. However, due to the cost of these techniques the application has to date, been confined to a small number of species, with a low sample size.

2.3. METHODOLOGY

2.3.1 Sample collection and study areas

Dolphin carcasses stranded on the Irish coasts have routinely been recovered for post-mortem examination from the early 1990s by University College Cork staff and research students. Post-mortem examinations followed the standard protocol of the European Cetacean Society (Kuiken and García Hartmann, 1993). Dolphins incidentally captured in a number of fisheries, including a drift net fishery targeting Albacore tuna *(Thunnus alalunga,* Bonnaterre 1788) in 1996 and 1998, were recovered by on-board observers and returned to post for port-mortem examination. An additional two bottlenose dolphin stomach samples were collected by the Irish Whale and Dolphin Group (IWDG) members and the stomach contents were used in this study. During post mortem examination, dolphins were measured, sexed and whenever possible, additional samples for age determination, reproductive status and histopathological and genetic studies were collected. Digestive tracts were usually frozen (-4º or -20ºC) prior to analysis. For this study, full digestive tracts (oesophagus, stomach and intestines) of bottlenose dolphins, harbour porpoises, Atlantic white-sided dolphins, white-beaked dolphins and striped dolphins were obtained during the post-mortem dissections.

The morphology of the stomachs of marine mammals differs depending on their dietary preferences, their habitat use and foraging behaviour. Seals have a single chambered stomach, while cetaceans present a complex stomach with a series of chambers from 4 to 12 (Mead, 2007). In this study, only delphinid digestive tracts were used; the stomach of a delphinid generally has four chambers (Mead, 2007, 2009; Ridgway and Harrison, 1999) Fig 2.1:

a) Forestomach: this is a pyriform or pyramidal chamber with a thick wall generally white, when fresh, presenting longitudinal folds. Mead (2009) indicated that the function of this chamber is mainly storage although some digestion activity occurs due to the "reflux of digestive fluids from the main stomach"

b) Main stomach or fundic stomach: this is a spherical chamber with thick dark red/brown wall; the digestion mainly occurs in this compartment.

c) Third stomach, connecting chambers: this usually consists of two chambers connecting the main and the pyloric stomachs, with a smooth thin wall.

d) Pyloric stomach or duodenal ampulla: this is a tubular chamber with a similar epithelium of the small intestine, where the secretions of the pancreatic and the bile ducts enter the digestive tract.

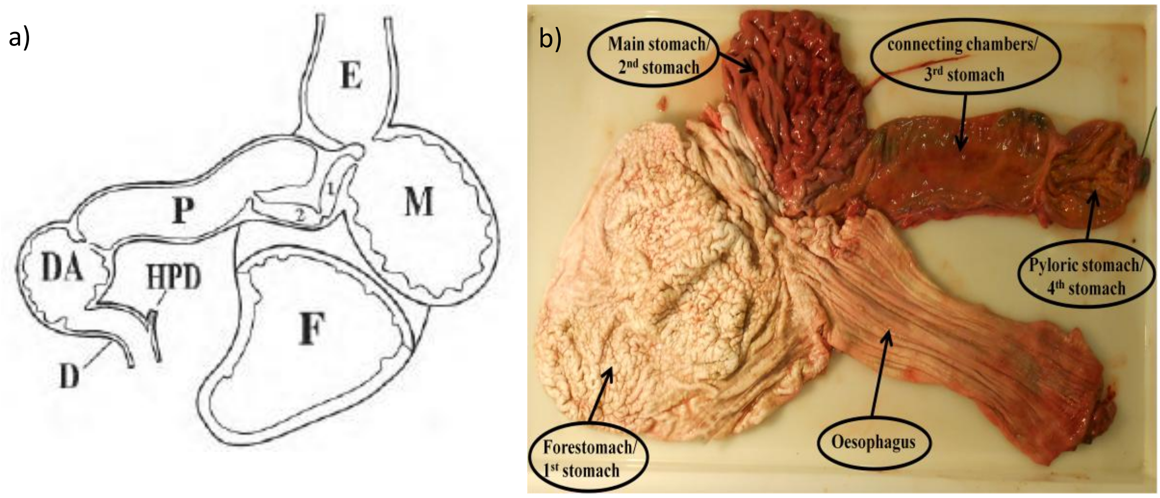


Figure 2.1-. a) Schematic draw of a *Stenella longirostris* stomach (Mead, 2007). E: oesophagus; F: forestomach or mechanical stomach or first stomach: with a fold wall; M-. main stomach, chemical stomach or second stomach: with a reticulated wall; P: pyloric stomach: with a flat wall; DA: duodenum ampulla: with a fold wall; D: duodenum which continues with the intestine; HPD is the hepatopancreatic duct. b) photograph of the different stomach compartments of a bottlenose dolphin stomach (BND 2/13)

Each compartment of the digestive tract was washed individually, and any abnormality (such as ulcers, cysts) was noted, measured, photographed, and stored in formaline for further studies. Intestines were measured and divided in 20 pieces of equal size in order to investigate the distribution of parasites, as well as to recover prey items and potential obstructions and lesions.

Seal scats were collected during low tide at three seal haul-out areas (and stored frozen at -20ºC). Harbour seal scats were collected in areas that are inhabitated by humans and on small islands that were difficult to access (Glengarriff, Co. Cork) and a quiet area only used by mussel farmers, and by kayaking trips during the summer months (Ballyvaughan, Co. Clare). While it is possible that a seal made two different depositions within the same area on the beach and that one of them contained otoliths and the other bones from the same prey, each scat was treated as coming from a different animal, as most scat samples were spatially separated (Kavanagh, 2008; Kavanagh et al., 2010). Grey seal scats were further sampled for genetic analysis, in particular to investigate the incidence of Salmonid species as prey.

Both scats and gut contents were washed through a set of three nested sieves with different mesh sizes (from 118µm to 1,000µm) under tap water, allowing mechanical removal of the flesh and unnecessary parts (e.g., pebbles). The bigger mesh size sieve was settled on the top while the smaller one was in the bottom, this allowed big structures to be removed easily, while smaller ones dropped down to the other sieves. Flesh was removed using smooth brushes to keep the hard part remains as clean as possible. Food remains were separated from parasites and transferred into 70% ethanol for between 2 and 24 hours; this process was carried out to remove odour and prevent the formation of mould. Hard structures, such as otoliths, bones and shells were subsequently removed from the ethanol, dried in trays, and once dried were then transferred to labelled plastic bags for future identification. Cephalopod beaks and pens, crustaceans, and soft remains were transferred to labelled vials with ethanol 70%.

2.3.2 Prey identification

Identification of all fish prey remains (otoliths, premaxillae, dentaries, maxillae, preopercula, cleithra, vertebrae, and post-temporal bones) was carried out to the lowest taxonomic level using fish bones and otolith reference collections held at University College Cork, the digital image library of the fish material held at the University of Aberdeen (Scotland, U.K.), and published guides (Härkonen, 1986; Watt et al., 1997; Campana, 2004; Tuset et al., 2008). Cephalopod remains (lower and upper mandibles or beaks) were identified using published guides (Clarke, 1986; Xavier and Cherel, 2009) and reference material held at the University of Aberdeen. Usually, cephalopods can only be identified to genus level; and Hastie et al. (2009) was used to confirm some of the cephalopod species occurring in the study area.

Cephalopod beaks, fish bones and otoliths were measured using a microscope fitted with an eyepiece graticule (when the biggest measurement of the prey item was smaller than 1cm), and a digital callipers (0.01mm). Whole fish that were not digested or damaged were measured (standard length); however, in most cases, length and weight of the fish prey and cephalopods were extrapolated from standard otolith/bone and beak measurements respectively, using published regressions (see Appendix I). For some species, regressions were not available in the literature, and new ones were derived using the fish reference collection held in University College Cork and the University of Aberdeen. However, when regressions were not available, the size estimation of prey was obtained based on proportions published in guides and in the reference collections. Regressions are usually built for a particular size range of fish, and estimations for very small and large specimens can be under and overestimated respectively; in those cases proportions (ratios) from the smaller/largest specimen of the reference collection was used.

The minimum number of teleost fish prey per sample was estimated in the first instance using otoliths. When possible, otoliths were separated into lefts and rights, and they were matched using shape and size of otolith. However, when otoliths were too eroded to be separated into left and right and they had similar size, the total number was divided by two (one fish has two otoliths). Bones were also used especially when otoliths were not present or the size of the bone did not correspond with the size of the otoliths. For cephalopods, beaks were used to identify species (Clarke, 1986), and as cephalopods have an upper and a lower beak; the maximum number of lower or upper beaks was used for the estimation of the minimum number of cephalopod prey within the samples.

2.3.3. Digestion coefficient factors for otoliths

During the digestion process, prey remains suffer different degrees of erosion depending on the type of structure and robustness (see Grellier and Hammond, 2006; Tollit et al., 1997, 2004), and therefore prey sizes can be underestimated. Very few studies on digestion correction factors have been carried out in European waters (Tollit et al., 1997; Grellier and Hammond, 2006), with some authors using different terminology to describe the degree of erosion and the mathematical equations (factors). In this study, the terminology used by Grellier and Hammond (2006) was adopted. Both Tollit et al. (1997) and Grellier and Hammond (2006) provided a scale for some otolith erosion rates. For otoliths identified as whiting, blue whiting, or whiting/blue whiting the digestion coefficients for whiting was applied, as the otoliths for both species are similar in shape and robustness. Haddock (*Melanogrammus aeglefinus*, Linnaeus 1758), pollack (*Pollachius pollachius*, Linnaeus 1758) and saithe (*Pollachius virens*, Linaeus 1758) otoliths are also similar in shape, robustness and length-weight relationships (Harkönen, 1986), however there are only correction factors available for haddock (Grellier and Hammond, 2006) and cod (*Gadus morhua*, Linnaeus 1758) (Tollit et al., 1997) in the literature; therefore in this study the digestion coefficients for haddock was applied to *Pollachius* spp. (Nisson, 1832) and the haddock-*Pollachius* spp. group. Poor cod (*Trisopterus minutus*, L.1758) and bib (*T. luscus*, L.1758) present similar otoliths and the Grellier and Hammond (2006) digestion coefficient factor for poor cod was used for the species group poor cod/bib. For those species where digestion coefficients were not available, coefficients from otoliths of similar shape, thickness and size were applied. For example, the digestion coefficient of Atlantic mackerel (*Scomber scombrus*, Linnaeus 1758) (Grellier and Hammond, 2006) was applied to horse mackerel (*Trachurus trachurus*, Linnaeus 1758). On the other hand, otoliths presented different grades of digestion at different sizes, therefore it was considered more realistic to use the value given for the size as a better estimation than the general one given for the degree of digestion. Correction factors applied to bones are very scarce in the literature (Tollit et al. 2007); therefore, no corrections factors were applied when fish length was estimated using bones. Eyeballs are not usually considered in dietary studies as they only can be identified as teleost fish, cephalopods or crustaceans; in this study, eyeballs from fish and squid were also counted and when they were in larger number of other remains in pairs of similar size were considered as unidentified fish or cephalopods.

2.3.4 Diet quantification

The importance of individual prey species/taxa in each digestive tract/scat was evaluated in terms of occurrence, number and summed estimated weight. Overall diet was described using three standard indices:

- Frequency of occurrence, %F:

$$\%F = (F_i / F_t) * 100 \qquad \text{eq. 2.1}$$

Where F_i is the number of digestive tract/scats containing the prey type "*i*", and F_t is the total number of stomachs/scats containing food

- Percentage by number, %N:

$$\%N = (N_i / N_t) *100 \qquad \text{eq. 2.2}$$

Where N_i is the total number of prey type "*i*", and N_t is the total number of prey items per predator.

- Percentage by reconstructed weight, W:

$$\%W = (W_i / W_t) *100 \qquad \text{eq. 2.3}$$

Where W_i is the total biomass of prey type "*i*", and W_t is the total biomass of all prey items within the marine mammal species.

Following (Hyslop, 1980) the Index of Relative importance (IRI) was used to measure the importance of each prey species. The use of the frequencies explained above might give a partial idea of the diet of the predators; a predator could prey on a large number of small fish, and percentage of biomass could be smaller than another predator that preys on small numbers of larger prey. The use of this index gives a better idea of the importance of the different prey items in thediet. Although the use of the combination of all frequencies has received some criticism, it is included here to allow comparison with studies on trophic ecology carried out in European Atlantic waters and elsewhere. The index follows the equation:

$$IRI = (\%N + \%W) * \%F \qquad \text{eq. 2.4}$$

Where %F is the percentage frequency of occurrence of each prey, %N is the percentage of importance by number of each prey, and %W is the percentage of importance by weight.

2.3.5. Annual food consumption

The annual food consumption for dolphin populations in Irish waters was applied in two different ways; firstly food consumption (C) was calculated using the equation from Col et al. (2012):

$$C = N * E * Res * T \qquad \text{eq. 2.5}$$

where (N) is the estimated number of marine mammals in the area; (E) is the daily averaged individual consumption, following the Col et al. (2012) approach:

$$E = \alpha \text{ x } M^b \qquad \text{eq. 2.6}$$

where (M) is the average body weight of the predator and α and b are species-specific consumption parameters given by Col et al. (2012).

(Res) the residential ratio, and (T) time (days) is 365. Abundance estimates were obtained from a number of sources; for all dolphin species estimates were obtained from the SCANS II survey for Block R (north, west and south of Ireland) and O (Irish Sea) (SCANS II, 2008) and CODA (CODA, 2009); the harbour seals population estimate for the Irish Sea was obtained from Cronin et al. (2004); the grey seal population for the Irish Sea was obtained from Kiely et al. (2000) and O'Cadhla and Strong (2007).

Weight is not routinely measured during post-mortem examination, and therefore dolphin weight (W in kg) was calculated from dolphin length for each of the animals examined, using equations from a number of publications as follows: Kastelein et al. (2002) for bottlenose dolphins (*Tursiops truncatus*, Montagu 1821) (eq. 2.7), Trites and Pauly (1998) for Atlantic white-sided dolphin (*Lagenorhynchus acutus*, Gray 1828) (eq. 2.8); Lockyer (1995) for harbour porpoise (*Phocoena phocoena*, Linnaeus 1758) (eq. 2.9 for males and 2.10 for females), and Di-Meglio et al. (1996) for Striped dolphin (*Stenella coeruleoalba*, Meyen 1833) (eq. 2.11):

$$W = 17.261\ e^{0.0156(L-100)} \qquad \text{eq. 2.7}$$

$$\text{Ln } W = -8.702 + 2.382 \text{ Ln } L \qquad \text{eq. 2.8}$$

$$\text{Log } L = 1.607 + 0.346 \times \text{Log } W \qquad \text{eq. 2.9}$$

$$\text{Log } L = 1.609 + 0.347 \times \text{Log } W \qquad \text{eq. 2.10}$$

$$\text{Ln } W = -8.702 + 2.382 \text{ Ln } L \qquad \text{eq. 2.11}$$

where *L* is the length of the dolphin (tip of rostrum to tail fluke in cm).

Residential ratios were obtained from the Col et al. (2012) study for the North-East USA coast. No residential ratio was available for striped dolphin; migration patterns in the North East Atlantic are unknown, but it is reported that in other areas some seasonality due to warm-water intrusions might occur (Perrin et al., 1994 and refs. therein); similar to common dolphin in North East Atlantic (Gowans and Whitehead, 1995); therefore, the same residential ratio (0.93) given by Col et al. (2012) for common dolphins was assumed for the striped dolphin in Irish waters. Col et al. (2012) reported a residential ratio of 0.68 for Atlantic white-sided dolphin in the Northeast US (Gulf of

Maine, Georges Bank and Southern New England), and this ratio was also applied for this species. Col et al. (2012) reported a residential ratio of 0.66 for bottlenose dolphins in the Northeast US Continental Shelf; in Ireland there is no residential value of the population but based on occupancy rates in the Shannon estuary (Ingram, 2000), it is likely to be similar and a residential ratio of 0.66 was used in this study also. Harbour porpoise residential ratio was assumed to be the same as that given by Col et al. (2012) (0.26).

Secondly, annual food consumption for the main prey items was estimated using the equation in Pierce et al. (2007) where the biomass proportion of different prey groups is considered:

$$I = N \times Pi \times F \times T \qquad \text{eq. 2.12}$$

Where (N) is the abundance estimate for the marine mammal species, (Pi) is the proportion of prey species i by weight in the diet, (F) is the average weight of food, and (T) time (days) is 365.

The food requirements for each species were calculated using equations given in Innes et al. (1987) for adult Odontoceti (eq 2.13) and Phocidae (eq. 2.14):

$$E = 0.313 * W\^{}0.66 \qquad \text{eq. 2.13}$$

$$E = 0.0547 * W\^{}0.84 \qquad \text{eq. 2.14}$$

where E is the individual's daily consumption (kg per day) and W is the weight (in kg) of an average dolphin or seal.

The percentage by weight is the most important value used for ecological models; however, these values are usually influenced by those stomachs that contain more prey items, as they contribute more. Pierce et al. (2007) and Santos et al. (2011) suggested that an alternative approach to evaluate the consequences of alternative choices by the different animals would be to apply an equal weighting to all prey found (all prey weights rescaled to sum to 1.0 for each non-empty stomachs) and weighting related to the body weight of the animal. This approach was also applied in this study.

Food consumption/requirements of these species were compared with landings of commercial prey species during the study period. Landings data were obtained from ICES (www.ices.dk) for ICES subarea VI and VII in the FAO area 27 (Fig. 1.16).

2.4 DISCUSSION

Although different methodologies have been used to study the foraging ecology of marine mammals, none of them is a panacea, but the different techniques have different strengths and weaknesses and should be viewed as complementary. The traditional methodology of the identification of hard structures found in the digestive tracts and scats has being the most common technique used, due to the relative ease in recovering samples and reasonable economic and material costs, despite the time consuming processes involved and the training required. This approach likely only provides information on recent feeding; for example, Tollit et al. (2003) reported that the digestion of prey occurs during the 2-56h period after ingestion depending on the type of prey, and characteristics of the predator (e.g., activity, state); however, small bones could be retained within the folds of the digestive tract and appear up to 92h after ingestion. To date, diet studies using marine mammal carcasses have usually been confined to investigating stomach contents only (e.g., Blanco et al., 2001; Santos et al., 2007; Spitz et al., 2006a, 2006b). Most of prey items are usually found within the stomach chambers and, in general, intestines have not been included in diet studies; however, the use of the full digestive tracts could increase the frequency of prey items found (Pierce et al., 1989).

The degradation of these structures when passing through the digestive tracts of the predators and restricting identification and quantification of fish prey remains to otoliths also introduces bias. In fact, Tollit et al. (2003) indicated that some species with fragile and small otoliths (e.g., clupeids, smelts and salmonids) are underestimated in the diet, while other species with large and robust otoliths (e.g. gadoids) can be overrepresented and overestimated (Grellier and Hammond, 2005). The utilisation of a variety of hard structures has been shown to minimize the bias in the detection of fish prey as well as improving the quantitative estimation of the diet (Cottrell et al., 1996). For example, Cottrell (1995) identified 55% of fish prey using hard parts other than otoliths in harbour seal scats, and Olesiuk et al. (1990) reported that only 42% of fish prey found in harbour seal scats were identified by otoliths. On the other hand, a small number of studies found that spew in seals showed a higher incidence of specific prey species remains than in the scats (Gudmundson et al., 2004; Kiyota et al., 1999); these findings might indicate another source of bias in the diet identification of prey items using only digestive tracts and scats.

The degradation of hard structures throughout the digestive tract has been a concern in using this type of technique to reconstruct diet, and some studies have developed a number of digestive coefficient factors to account for otolith degradation (Bowen, 2000; Grellier and Hammond, 2006; Tollit et al., 1997). The digestion of the different hard structures depends on different factors, such as prey size (Tollit et al. 1997), the amount of food ingested (Marcus et al. 1998), and the predator size (Cottrell et al. 1996). In combination with this, a number of studies have investigated food passage rates in pinniped species, to investigate differences in digestibility between predator species (e.g., Cottrell and Trites, 2002; Goodman-Lowe et al., 2001; Helm, 1984; Krockenberger and Bryden, 1994). For example, Bowen (2000) did not find significant differences when he compared the digestive efficiency between harbour and grey seals; however, fish otoliths and bones were found to be much more eroded in harbour seals than in grey seals when comparing the same prey species. To date, there have been no studies examining the erosion of prey in cetacean digestive tracts.

Although new sources for the identification of fish and cephalopod hard structures have been developed during the last few decades, they are still scarce (Cannon 1987; Casteel, 1976; Fitch and Brownell, 1968; Hansel et al., 1988; Harkonen, 1986). The establishment of regionally focussed reference collections and the publication of regression analysis is something that would be of considerable use to all researchers working on the diet of all marine predators and trophic ecology. Alongside that, taxonomic training for prey identification is probably one of the most important issues when applying this technique.

Although fatty acid analysis has been widely used for diet studies (e.g., Iverson et al., 1997b; Kavanagh et al., 2010; Koopman et al., 1996; Møller et al., 2003; Ridoux et al. 2007; Walton and Pomeroy, 2003), a number of studies (Bowen et al., 2002; Grahl-Nielsen et al., 2000, 2003; Kirsch et al., 2000) have indicated that FA profiles in adipose tissue, using the QFASA technique, might not be reliable for diet studies because they can change depending on the biological conditions of the predator (e.g., reproductive status, age). Kirsch et al. (1998) point out that the use of fatty acids as diet indicators is a good tool for organisms that feed at higher trophic levels, such as seals. Also, for a realistic result when using this technique prey samples should be taken at the same time that the predators are sampled, which involves an important economic investment, especially when studying samples from carcasses.

Stable isotopes analysis is a promising technique; however its use for identifying prey in generalist predators becomes difficult, requiring examples of all the putative prey items, ideally sampled at the same time. This technique has successfully been applied when the number of prey items are small (e.g., Abend and Smith, 1997; Stauss et al., 2012), in examining trophic position and niche width within ecosystems (e.g., Mendez-Fernandez et al., 2013, Kelly, 2000 and references therein) and in differentiating diet within and between species (e.g., Ryan et al., 2013). When predator samples are difficult to collect (e.g., beaked whales), this technique might be a good approach to investigate feeding behaviour (e.g., MacLeod, 2005). SIA has also been used to investigate latitudinal distribution and onshore/offshore feeding strategies in a number of species (e.g., Burton and Koch, 1999).

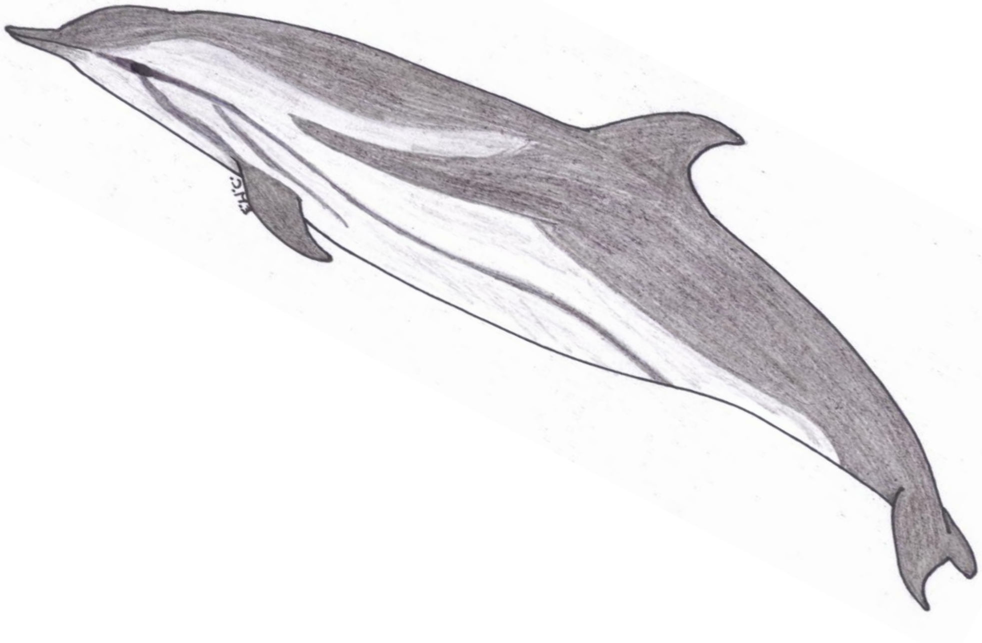
The use of serological methods could be considered as a potential complementary technique for the identification of specific prey species (Pierce et al., 1990a; 1990b); however, the lack of knowledge on stomach acid composition and the loss of antigenicity when they prey pass through the digestive tract might reflect some distortion (Pierce et al., 1990a).

The combination of both traditional and analytical methodologies has been indicated to be a more realistic approach for reconstructing diet (Burns et al., 1998; Hobson et al., 1997), as they provide more detailed information on the feeding ecology of particular species. However, only FA analysis is useful for mass-balance models such as Ecopath. The diet of bottlenose, Atlantic white-side, white-beaked and striped dolphins presented in this thesis has been re-constructed using the traditional approach in order to study their roles within the ecosystem, to examine potential overlaps with commercial fisheries and fisheries interactions and to help implement and inform an ecosystem approach in fisheries management.

In this study, otoliths, fish bones, and cephalopod beaks were identified using the available atlas/catalogues (Campana, 2004; Clarke, 1986; Harkonen, 1986; Tuset et al., 2008; Watt et al., 1991) and two bones reference collections: the Natural Museum of the University of Aberdeen, and University College Cork. Quantification of prey importance was carried out using different indices commonly use in diet studies, and finally annual food consumption was estimated for all species.

Chapter 3

FORAGING ECOLOGY OF STRIPED DOLPHIN IN IRISH WATERS



CHAPTER 3

FORAGING ECOLOGY OF STRIPED DOLPHIN IN IRISH WATERS

3.3 Material and Methods

3.4 Results

3.1 ABSTRACT

The foraging ecology of striped dolphins in Irish waters was studied using prey hard part recovered from the digestive tracts (oesophagus, stomachs and intestines) of dolphins stranded on the Irish coasts and by caught in a fishery targeting tuna. There were very large differences in diet of this species depending on the source. The diet of the stranded dolphins comprised continental shelf fish species, where *Trisopterus* spp. was the most important prey group (79%F, 49%N), followed by whiting/blue whiting (68%F, 16%N). However, by caught dolphins presented with mainly mesopelagic prey species; mesopelagic fish (e.g., *Benthosema glaciale*, *Notoscopelus kroyeri, Diaphus* spp.) comprised 65% of prey by number, cephalopods (e.g., *Histioteuthis* spp., *Gonatus* spp., *Teuthowenia megalops*) comprised 24% by number, and crustaceans (*Pasiphaea* spp. and *Notostomus* spp.) made up 6% by number. Differences in the diet were found between the two groups of dolphins (by caught and stranded), as well as between mature and immature dolphins. No significant sex-related differences were found in the diet. The annual food consumption of striped dolphins for the whole area was estimated to be 15,652 tonnes of prey, and the annual food consumption estimated for the only commercial fish species (whiting) was estimated to be 1,422 tonnes.

3.2 INTRODUCTION

The striped dolphin (*Stenella coeruleoalba*, Meyen 1833) is one of the most cosmopolitan toothed dolphins usually inhabiting tropical and warm-temperate waters between 50°N and 40°S in all oceans (Hammond et al., 2008a; Jefferson et al., 2008; Reid et al., 2003), usually close to the continental slope (Davis et al., 1998; Hammond et al., 2008a; Perrin et al., 1994; Reid et al., 2003). The abundance of the species has been estimated in Irish offshore waters (CODA, 2009), however, the inshore population has not been quantified due to the difficulty in distinguishing it from common dolphins (*Delphinus delphis*, Linnaeus 1758) and only a combined estimate exists (Hammond et al., 2013)..

This dolphin species has been found associated with other pelagic predators such as common dolphins, tuna, swordfish (*Xiphias galdius*, Linnaeus 1758) and pelagic sharks (e.g., Hassani et al., 1997; Ringelstein et al., 2006; Rogan and Mackey, 2007). In particular, tuna and swordfish are predator species targeted by fisheries and dolphins are frequently by caught during these fishing operations (Au and Pitman., 1986; Green et al., 1971; Northridge, 1984; Scott et al., 2012). Although the association is common, it is still not clear why these aggregations occur and varying hypotheses exist, depending on the tuna species and the geographical area (Au and Pitman, 1985; Clue and Grosvalet, 2001; Edwards, 1992; Scott and Cattanach, 1998). However, several studies associate these aggregations to common food patches (e.g., Das et al., 2000; Clua and Grosvalet, 2001; Hall, 1998 and refs there in; Sazima et al., 2006)

Dietary studies of striped dolphin in European waters have been carried out in Scotland (Santos et al., 2008), Bay of Biscay (Spitz et al., 2006a), North West of Spain (Mendez-Fernandez et al., 2013; Santos et al., 1996) and in the Mediterranean Sea (Blanco et al., 1995; Gomez-Campos et al., 2011; Würtz and Marrale, 1993). In addition, some information has been presented on the diet of dolphins by caught in the tuna fishery (Das et al., 2000; Hassani et al., 1997; Ringelstein et al., 2006). This is the first in-depth examination of the diet of striped dolphins from the waters around Ireland, an area close to the edge of the distributional limit of this species. In addition, a comparison between the diet found in stranded and by caught individuals will contribute to our knowledge of the foraging ecology of the striped dolphin in European waters. The annual food consumption for this species is also estimated and fisheries implications examined.

3.3 MATERIAL AND METHODS

3.3.1 Study area and sample composition

A total of 292 striped dolphins, both stranded and by caught, have been recorded on Irish coasts and waters, respectively (Appendix II). Ten specimens were reported within the UCC stranding database that has not been published yet. Striped dolphins were recorded as by-catch during an on-board observer programme examining the ecological affects of the drift net fishery targeting albacore tuna (*Thunnus alalunga,* Bonnaterre 1788) operating in the waters to the South West of Ireland in 1996 and 1998 (Appendix II). UCC staff and research students dissected and collected samples of striped dolphins following the standard protocol of the European Cetacean Society (Kuiken and García-Hartmann, 1993). Length and sex of dolphins have being recorded in most cases, and age and male maturation stage (Table 3.1) of some of the animals were obtained from former unpublished studies (Kervick, 2012; Quinn, 2001; Rogan et al., 1997). When maturity stages of individuals were not available, published information on body length was used to assign maturity (IUCN). Dolphin age was not used in this part of the analysis, as maturation stage was considered to be more appropriate given likely different energetic demands of the different life stages.

3.3.2 Prey identification and quantification of diet

Fish prey remains were identified to the lowest possible taxon (Chapter 2). The dietary study of the by caught striped dolphin was carried out using the reference collection of mesopelagic fish, in addition to published guides such as Campana (2004). Other prey remains (otoliths, bones and beaks) were identified using guides and reference collections (see Chapter 2, Section 2.3.2). Crustacean specimens were identified by Dr Sammy DeGrave (UCC). It was not possible to identify Tunicates to species level and these were only quantified. Prey size and biomass was estimated using back calculation regressions (Appendix I) as well as comparing with reference material (see Chapter 2, Section 2.3.2).

Table 3.1 Stranded and by caught striped dolphins in Irish coasts and waters. Stranding: S: found dead, A: live stranding, BC: by caught dolphin. Sex: M: Male, F: female. Maturation stage M: mature, I: Immature. Body length in cm and Age in years. c: estimated length was.

Sample	Date	Stranding	Sex	Body length	Maturation stage	Age	Latitude	Longitude	Location	Contents
SD 2/92	17/09/1992	S	M	201	I	6	52.13783	-10.27563	Kerry	FOOD
SD 1/93	26/01/1993	S	M	158	I	2	52.2622	-10.15161	Kerry	FOOD
SD 2/93	30/08/1993	S	M	187	I	4	52.60616	-9.70787	Clare	FOOD
SD 1/94	22/03/1994	S	F	151.5	I	2.5	51.93948	-7.84609	Cork	FOOD
SD 2/94	22/03/1994	S	F	143	I	2	51.93855	-7.84847	Cork	FOOD
SD 1/95	16/02/1995	A	F	191	-	-	55.10592	-8.31597	Donegal	EMPTY
SD 2/95	13/10/1995	A	M	221	M	21	53.11722	-9.67373	Galway	FOOD
SD 3/95	21/11/1995	A	F	214	-	-	53.60705	-9.98617	Galway	EMPTY
MW T1 H1 SD1	16/07/1996	BC	M	197	M	NA	49.13	-13.2	SW Eire	FOOD
MW T1 H1 SD2	16/07/1996	BC	NA	197	M	11	49.13	-13.2	SW Eire	FOOD
MW T1 H1 SD4	16/07/1996	BC	M	218	M	10	49.13	-13.2	SW Eire	FOOD
MW T1 H1 SD5	16/07/1996	BC	M	172	I	2	49.13	-13.2	SW Eire	FOOD
MW T1 H1 SD6	16/07/1996	BC	M	119.5	-	-	49.13	-13.2	SW Eire	MILK
MW T1 H1 SD7	16/07/1996	BC	F	117.6	I	0.5	49.13	-13.2	SW Eire	FOOD
MW T1 H1 SD8	16/07/1996	BC	M	106	I	0.5	49.13	-13.2	SW Eire	FOOD
DOL T1 H1 SD1	23/07/1996	BC	F	112	I	0.5	47.12	-12.42	SW Eire	FOOD
DOL T1 H1 SD2	23/07/1996	BC	M	166.5	-	-	47.12	-12.42	SW Eire	EMPTY
MW T3 H1 SD1	06/08/1996	BC	M	115	-	-	50.4	-15.4	SW Eire	EMPTY
MW T3 H2 SD1	07/08/1996	BC	M	228	-	-	50.4	-13.2	SW Eire	EMPTY
SD 1/96	07/08/1996	S	F	99	-	-	51.64838	-10.05624	Cork	EMPTY
HW T1 H1 SD1	14/08/1996	BC	F	169	I	2	51.14	-13.44	SW Eire	FOOD
MW T4 H2 SD16	14/08/1996	BC	M	124	I	0.5	51.05	-13.04	SW Eire	FOOD
MW T4 H2 SD17	14/08/1996	BC	M	132	I	0.5	51.05	-13.04	SW Eire	FOOD
MW T4 H2 SD18	14/08/1996	BC	F	111	M	14	51.05	-13.04	SW Eire	MILK
MW T4 H2 SD19	14/08/1996	BC	F	201	I	NA	51.05	-13.04	SW Eire	FOOD

Table 3.1 *Cont.*

Sample	Date	Stranding	Sex	Body length	Maturation stage	Age	Latitude	Longitude	Location	Contents
JB T1 H3 SD1	15/08/1996	BC	M	201	M	NA	50.8908333	-15.9	SW Eire	FOOD
JB T1 H3 SD2	15/08/1996	BC	M	163.5	I	3	50.8908333	-15.9	SW Eire	FOOD
JB T1 H4 SD F	16/08/1996	BC	F	116	-	-	50.7433333	-16.795	SW Eire	EMPTY
JB T1 H4 SD J	16/08/1996	BC	M	124	I	0.5	50.7433333	-16.795	SW Eire	FOOD
JB T1 H4 SD M	16/08/1996	BC	M	209.5	M	18	50.7433333	-16.795	SW Eire	FOOD
DOL T3 H2 SD3	28/08/1996	BC	M	c170	I	4	51.44	-12.22	SW Eire	FOOD
JB T2 H5 SD1	28/08/1996	BC	M	235	M	18	51.8383333	-13.1	SW Eire	FOOD
JB T2 H5 SD2	28/08/1996	BC	M	170	I	-	51.8383333	-13.1	SW Eire	FOOD
JB T3 H6 SD1	07/09/1996	BC	M	217	M	15	51.3165	-13.023	SW Eire	FOOD
JB T4 H2 SD1	12/09/1996	BC	M	220	M	12	51.4058333	-12.994	SW Eire	FOOD
JB T4 H2 SD2	12/09/1996	BC	F	145	I	2	51.4058333	-12.994	SW Eire	FOOD
JB T4 H3 SD1	13/09/1996	BC	M	149	I	1	51.4308333	-12.903	SW Eire	FOOD
JB T4 H4 SD1	14/09/1996	BC	M	179	I	2	51.166	-13.2851667	SW Eire	FOOD
JB T4 H6 SD1	16/09/1996	BC	M	123	I	0.5	51.2501667	-12.0321667	SW Eire	FOOD
JB T5 H3 SD1	21/09/1996	BC	M	117	-	-	51.4766667	-11.9748333	SW Eire	EMPTY
JB T5 H3 SD2	21/09/1996	BC	F	133	I	133	51.4266667	-11.9748333	SW Eire	FOOD
DOL T1 H8 SD2	30/09/1996	BC	M	1-2years	-	-	48.28	-17.25	SW Eire	MILK
SD 3/96	31/10/1996	S	F	192.5	I	6	52.13191	-10.36565	Kerry	FOOD
SD 4/96	20/11/1996	S	F	174	-	-	54.6321	-8.20413	Donegal	FOOD
SD 1/98	21/12/1997	S	M	195	I	-	52.93231	-9.34734	Clare	FOOD
SD 3/98	27/07/1998	S	M	185	I	-	51.86269	-9.68081	Kerry	FOOD
RM T1 H1 SD1	01/08/1998	BC	F	140	I	NA	49.074	-14.1638333	SW Eire	FOOD
RM T1 H1 SD2	01/08/1998	BC	F	162	M	NA	49.074	-14.1638333	SW Eire	FOOD
RM T2 H3 SD1	23/08/1998	BC	M	148.5	I	NA	50.7116167	-15.0768333	SW Eire	FOOD
RM T2 H3 SD2	23/08/1998	BC	F	201	-	-	50.7116167	-15.0768333	SW Eire	FOOD

Table 3.1 *Cont.*

Sample	Date	Stranding	Sex	Body length	Maturation stage	Age	Latitude	Longitude	Location	Contents
RM T2 H3 SD3	23/08/1998	BC	F	96	-	-	50.7116167	-15.0768333	SW Eire	MILK
RM T3 H7 SD1	12/10/1998	BC	M	205	-	M	51.0921667	-15.0045	SW Eire	FOOD
RM T4 H1 SD1	19/10/1998	BC	F	155	I	NA	51.4183333	-15.075	SW Eire	FOOD
SD 1/99	15/02/1999	S	M	174	I	-	54.34381	-8.57644	Sligo	FOOD
SD 2/99	15/04/1999	S	M	241	-	-	54.33162	-8.64671	Sligo	EMPTY
SD 3/99	15/04/1999	S	M	223	M	-	54.33162	-8.64671	Sligo	FOOD
SD 4/99	21/07/1999	A	F	162	-	-	52.25066	-10.08245	Kerry	FOOD
SD 1/00	15/09/2000	S	F	169	I	-	55.18006	-8.17765	Donegal	FOOD
SD 2/00	17/09/2000	S	M	172	I	-	52.0731	-9.97525	Kerry	FOOD
SD 3/00	04/11/2000	S	F	168.5	I	-	52.17992	-10.40581	Kerry	FOOD
SD 4/00	22/11/2000	A	F	158	I	-	54.33227	-9.78285	Mayo	FOOD
SD 5/00	22/11/2000	A	F	150	-	-	54.33227	-9.78285	Mayo	FOOD
SD 1/01	24/04/2001	A	M	142	-	-	51.78439	-8.29314	Cork	MILK
SD 1/02	15/09/2002	A	M	168	-	-	51.64087	-8.57125	Cork	FOOD
SD 3/02	30/10/2002	S	F	185	-	-	54.22942	-10.06921	Mayo	EMPTY
SD 2/02	05/11/2002	S	F	209	M	-	51.86017	-7.99505	Cork	FOOD
SD 4/02	06/11/2002	A	F	181	-	-	52.28238	-6.38795	Wexford	EMPTY
SD 1/03	14/06/2003	S	M	203	-	-	51.56501	-8.99507	Cork	EMPTY
SD 1/04	01/11/2004	S	M	210	M	-	51.7705	-8.3061	Cork	FOOD
SD 4/06	11/10/2006	A	M	140	-	-	51.91897	-7.87544	Cork	FOOD
SD 5/06	11/10/2006	A	M	134	-	-	51.92463	-7.87081	Cork	FOOD
SD 6/06	11/10/2006	A	F	134.5	-	-	51.92812	-7.86798	Cork	FOOD
SD 1/08	06/01/2008	S	F	150	I	-	51.59483	-8.86572	Cork	FOOD
SD 1/11	07/09/2011	S	M	188	I	-	52.17997	-10.4064	Kerry	FOOD
SD 2/11	10/09/2011	S	F	189	I	-	51.93589	-7.85488	Cork	FOOD
SD 3/11	10/11/2011	S	M	200	I	-	52.12204	-10.37625	Kerry	FOOD

Digestion coefficient factors (Grellier and Hammond, 2006) were used and applied to the remains obtained in digestive tracts of stranded dolphins, as most of them presented a high erosion degree. However, those stomachs obtained from by caught animals presented prey remains in very good condition and digestion coefficient factors were applied to only a few remains. There were some species or group of species where digestion coefficient factors were not available in the literature and other approaches were used (see Chapter 2, Section 2.3.3). However, digestion coefficient factors were not available for other species identified in the diet of striped dolphins and the average value of all the 3 grade-specific digestive coefficients given by those authors (0.44) was used.

Diet quantification was carried out using the standard indices %F, %N, %W, as well as the Index of Relative Importance (IRI) (see Chapter 2, section 2.3.4).

3.3.3. Annual food consumption and statistical analysis

Striped dolphin annual food consumption in Irish waters was estimated using the two different approaches described in Chaper 2 (Section 2.3.5).

For the striped dolphin population estimation in Irish waters, estimations from the two multinational dedicated sighting surveys, SCANS-II (Hammond et al., 2013; Fig. 1.2a) and CODA (CODA, 2009; Fig. 1.2b), were used. However, they were not able to provide a realistic estimation for striped dolphins due to the difficulty of differentiating this species from common dolphins at sea. The CODA survey provided an offshore population value of 519 (CV=1.05) and 33,254 (CV=1.57) for striped dolphin in areas 1 and 2 respectively (Fig. 1.2b), however a value of 4,065 (CV=0.67) and 115,398 (CV=0.8) for the combined group of striped dolphin and common dolphin was given for areas 1 and 2, respectively (Fig. 1.2b). In order to get a more realistic value of the offshore striped dolphin population both species were summed and the percentage of striped dolphin derived from this sum (12.8%) was assumed for the combination of both species; considering that the common summer range of this species is as far north as the British Isles, giving a total population of 78,455 dolphins offshore. No separate estimate was derived for the continental shelf SCANS survey, but there was an estimate for the combined common and striped dolphins. In order to estimate an approximate value, the same percentage estimated within the CODA data was assumed for SCANS areas Q, R and P (Fig. 1.2a) obtaining a value of 10,352 dolphins; therfore, a total population of 88,807 striped dolphins was considered in this study for Irish waters.

The daily averaged individual consumption for striped dolphins was estimated using the model suggested by Innes et al. (1987) for adult Odontoceti (Chapter 2, eq. 2.13)

Most of the prey identified in striped dolphin digestive tracts was not commercially important, except whiting. However, due to the erosion of most of the otoliths it was not always possible to differentiate whiting from blue whiting. Most of the whiting was identified within the stranded dolphins, which were also feeding on other demersal gadoids such as *Trisopterus* spp. (Rafinesque, 1814); assuming that all whiting/blue whiting prey might be whiting as it is also a demersal gadoid, landings of whiting during the period of study (ICES Catch Statistics 1985-2012, www.ices.dk) were examined in relation to the reconstructed biomass obtained in dolphin diet. Landings data of whiting from Divisions VIa, VIb, VIIb, VIIc, VIId, VIIf, VIIg, VIIh, VIIj2 and VIIk in the FAO area 27 (Fig. 1.16) were used.

Differences in the diet between the sexes, maturation stages, and between by caught and stranded dolphins were investigated using Mann Whitney U rank tests. Maturity was determined in two previous studies and was used here (Quinn, 2001, Kervick, 2012). Prey-type preferences were explored using the multivariate redundancy analysis (RDA) and results are presented following Zuur et al. (2007). All analyses were carried out using the R Statistical Software (www.r-project.org).

3.4. RESULTS

3.4.1. Study area and sample composition

From 1912 to 2010, a total of 256 striped dolphins were recorded stranded along the Irish coastline or incidentally by caught in Irish waters (Appendix II, Fig 3.1). However, from 1913 to 1983 inclusive there was no record of this species from the Irish coasts. Strandings of striped dolphins appear to have increased from 1984 to 2010 (Fig 3.2); however, a peak was detected due to a mass stranding at Bundola Bay (Bellmullet Peninsula, Co. Mayo) in October 2006, where twelve out of fourteen dolphins were successfully refloated (Appendix II). Most of the strandings were of single animals, with a further 10 comprising two individuals and on three occasions, three dolphins stranded together. When strandings were examined by season, most of the strandings were reported during the autumn and winter months (Fig 3.3). In addition, 30% (n=54) of the stranded dolphins were reported to strand alive, where 33% (n=18) of them were successfully released. All of the strandings occurred on the south and west coasts of Ireland, with no stranding recorded in the Irish Sea. Post mortem examination was performed on 16 (44%) of the 36 dolphins that stranded alive and subsequently died. Of the by caught animals, the majority were recorded during the observer programme

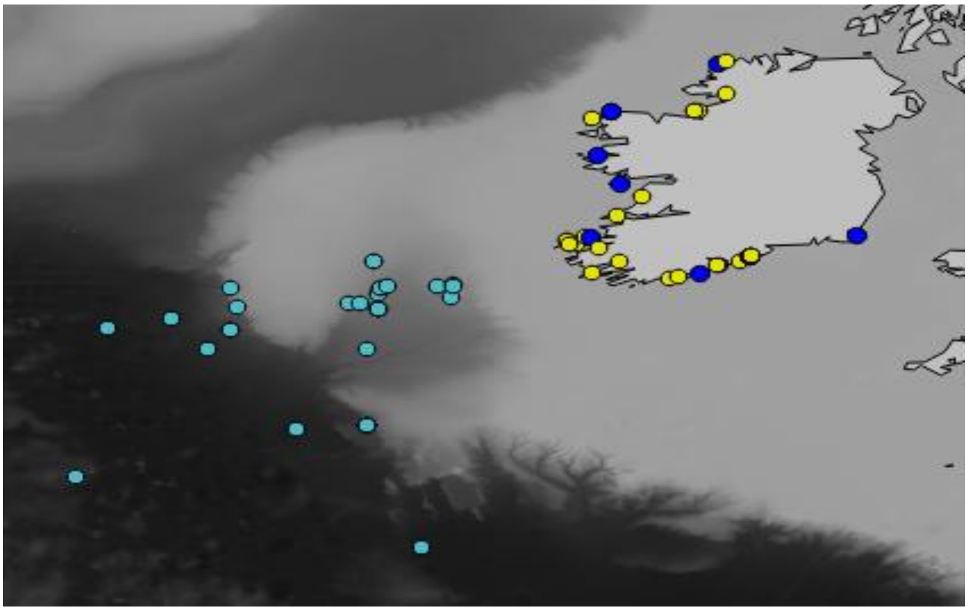


Figure 3.1 Map with the locations of live strandings (dark blue), dead strandings (yellow) and by caught (light blue) striped dolphins used in this study.

on drift net fisheries targeting albacore tuna in 1996 and 1998 respectively, 64 individuals were recorded in 1996 and 16 in 1998.

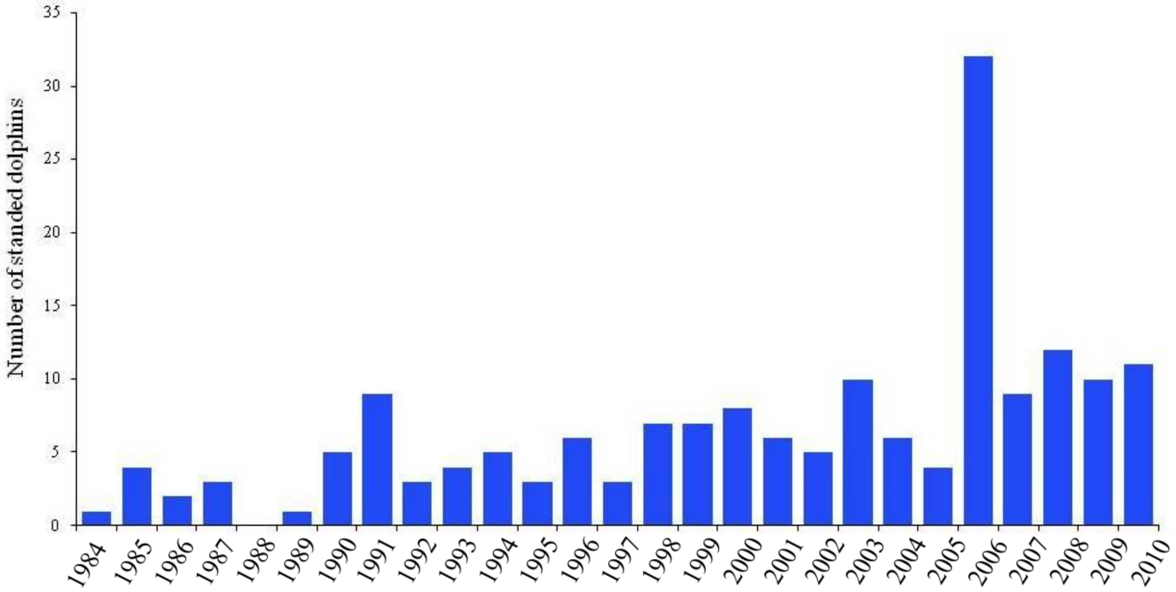


Figure 3.2 The number of striped dolphin strandings on the Irish coast from 1984 to 2010. Note that a mass stranding of 14 striped dolphin occurred in 2006.

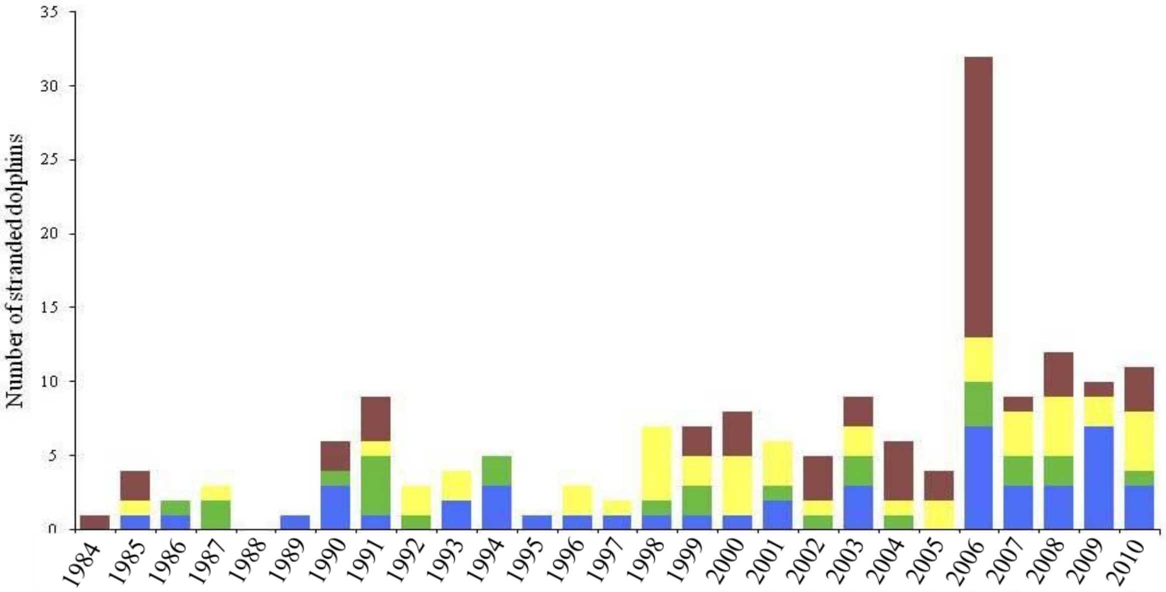


Figure 3.3 Seasonal (Winter in blue, Spring in green, Summer in yellow and Autumn in brown) distribution of striped dolphin strandings from 1984 to 2010.

Samples were collected from 35 stranded and 40 by caught animals. Of these, 75 digestive tracts were examined, 13 digestive tracts were found empty (six by caught dolphins and seven stranded dolphins) while five (four by caught and one stranded) contained milk (Table 3.1). Food remains were found in the digestive tracts of 11 females and 19 males of by caught dolphins, and 13 females and 15 male stranded dolphins (Table 3.1). Body size of the dolphins studied ranged from 96cm to 201cm for by caught females, from 123cm to 235cm for by caught males, from 135cm to 209cm for stranded females, and from 134 to 223cm for stranded males (Table 3.1). One of the dolphins examined, one individual (SD 1/02, Table 3.1) presented with two pieces of white plastic bag: one in the oesophagus (4x55cm) and another piece within the first stomach (13x10cm).

3.4.2. Prey identification and quantification of diet

A total of 7,966 prey items were identified within the digestive tracts of striped dolphins stranded and incidentally caught in Ireland, with 83.6% of all items being identified to at least genus level (Table 3.2 and Table 3.3). By caught dolphins presented with a higher proportion of prey (64.8% by number -5,164 prey items- and 71.1% by biomass -83,229g) than stranded dolphins (35.2% by number -2,802 prey items- and 28.9% by biomass -33,778g) especially when reconstructed biomass was compared (Table 3.2 and Table 3.3). Most of the fish remains in stranded dolphins were identified from otoliths; however 35.3% of the fish prey items found within the digestive tracts of the by caught dolphins were identified using different bones (dentary, premaxilla, cleithrum and vertebrae).

Stomach contents in by caught dolphins showed that both fish and cephalopods occurred in 93.6% of the stomachs, but fish made up 69.7% by number and 16.9% by biomass while cephalopods made 23.9% by number and 81.9% by weight. At least 22 fish species, eight cephalopods and three crustacean taxa were identified, belonging to a total of 20 families (Table 3.2). Mesopelagic fish comprised the most abundant prey group (64.8%N), followed by cephalopods (23.9%N). Within the mesopelagic fish, the most important prey species was the glacier lantern fish (*Benthosema glaciale*, Reinhardt 1837) with 28.2%N, followed by *Diaphus* spp. (Eirgenmann 1890) with 15.6%N, and the lancet fish (*Notoscopelus kroyeri*, Malm 1861) with 7.9%N. The most important cephalopod prey group was the Histioteuthidae comprising 15.6% by number and 73.0% by biomass (Table 3.2). Crustaceans also occurred frequently (45.2%F), but number and biomass percentage were low (5.8% and 1.2% respectively) (Table 3.2).

Other miscellaneous items comprised tunicates occurring in 6.5% of the stomachs and 0.5% percentage by number, and a fish egg masse in one stomach (Table 3.2). Comparing the IRI results, *Histioteuthis* spp. (Orbigny 1841) group appeared to be more important (7,558.59 IRI), followed by the glacier latern fish (2,695.4 IRI) and the *Diaphus* spp. group (1,187.4 IRI).

Fish length in the stomachs of the by caught dolphins varied between different species groups (Table 3.2). The largest prey found was the spotted barracudina (*Arctozemus risso*, Bonaparte 1840) followed by other mesopelagic fish; however, more than 75% of fish ranged from 55 to 115mm length (Fig. 3.4). Most of the fish (93.5%) were found to be larger than their maturation length (Fig 3.4). Cephalopod size ranged from 11 to 185mm mantle length with common squid (*Loligo* spp., Lamarck 1798) being the

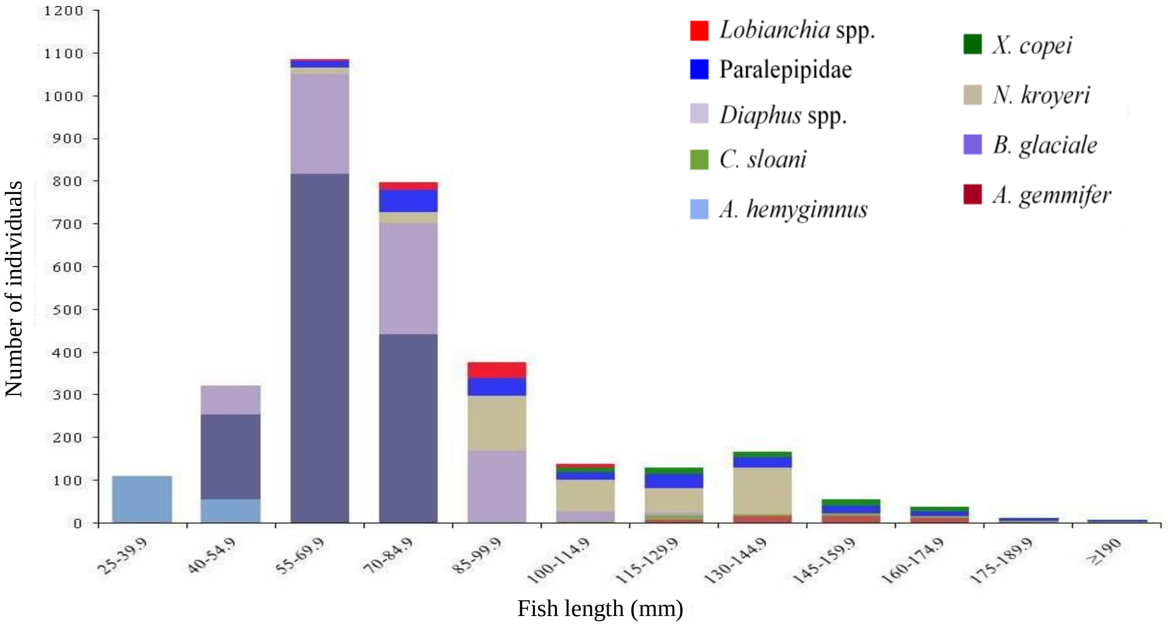


Fig 3.4 Length frequency distribution (mm) of mesopelagic fish prey recorded from the stomach contents of the by-caught striped dolphin (1996 and 1998)

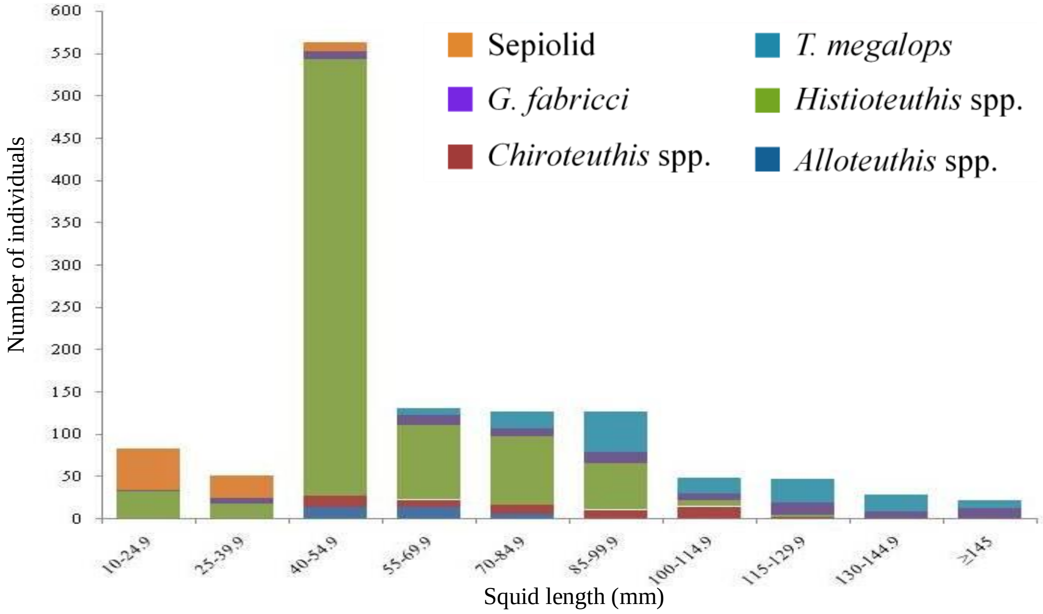


Fig 3.5 Length-frequency distribution (mm) of cephalopod prey recorded from the by-caught striped dolphin (1996 and 1998)

largest prey item followed by the Atlantic cranch squid (*Teuthowenia megalops*, Prosch 1849) (Fig. 3.5). *Histioteuthis* spp. was found to present the widest size range (Fig 3.5). All crustaceans were found to be below 5cm length, where *Pasiphaea* spp. (Savigny, 1816) shrimp was less common but usually larger than *Notostomus* spp. (Milne-Edwards, 1881) (Fig 3.6).

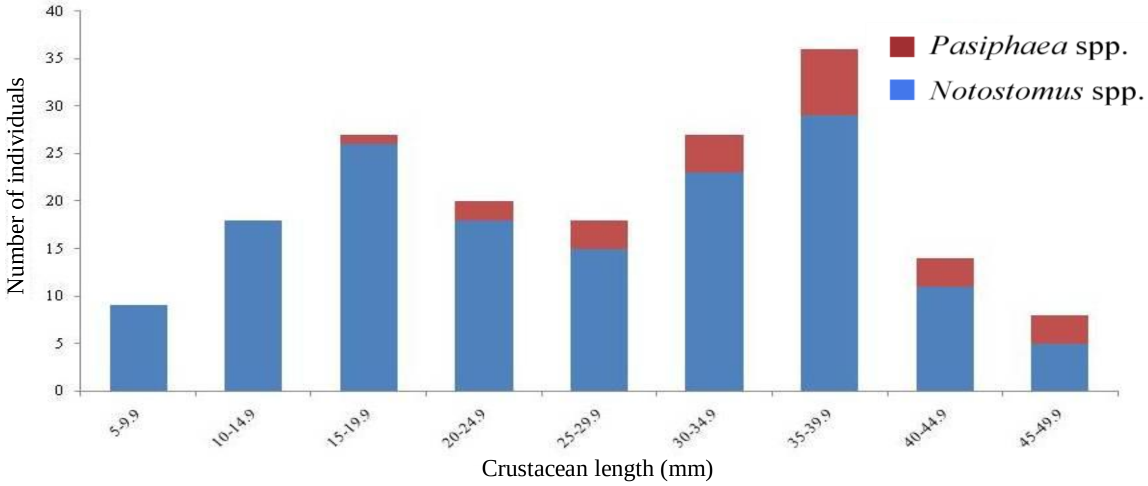


Fig 3.6 Length (mm) frequency distribution of crustacean prey occurring within by caught striped dolphin (1996 and 1998)

Digestive tracts of stranded dolphins showed that most of the diet comprised fish prey (94.4% by number and 57.5% by weight) (Table 3.3). Most of the fish prey was

Table 3.2- Prey species identified from by caught striped dolphins (n=30). Each prey is shown as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W); index of relative importance (IRI) is also presented. Length of prey is total length for fish in mm and dorsal mantle length for squid in mm; weight is estimated in grams. * Data was estimated after removing the stomachs only contained miscellaneous items.

Prey species	F	F%	N	N%	W	W%	IRI	Length range	Av. length	Weight range	Av.weight
Osteichthyes											
Osmeriformes											
Alepocephalidae											
Xenodermichthys copei	6	19.36	68	1.32	820.82	0.99	44.58	101-170	136	8.66-16.87	12.07
Argentinidae											
Argentina spp.	4	12.90	18	0.35	83.39	0.10	5.79	59-102	86	1.05-7.64	4.63
Stomiiformes											
Sternoptychidae											
Maurolicus muelleri	2	6.45	11	0.21	13.68	0.02	1.48	30-73	48	0.13-4.31	1.24
Argyropelecus spp.	12	38.71	168	3.25	101.35	0.12	130.65	25-46	37	0.39-0.99	0.60
Stomiidae											
Arctozemus risso	4	12.90	18	0.35	38.43	0.05	5.09	64-468	120	0.29-4.95	2.14
Astronesthes gemmifer	6	19.36	60	1.16	2,331.55	2.80	76.71	121-177	148	14.75-27.76	38.86
Chauliodus sloani	3	9.68	46	0.89	150.59	0.18	10.37	64-220	137	0.90-11.28	3.27
Paralepidae											
Paralepsis kroyeri	8	25.81	55	1.07	100.00	0.12	30.59	63-204	110	0.28-8.75	1.82
Paralepsis spp.	12	38.71	120	2.32	245.87	0.30	101.39	51-204	114	0.15-8.76	2.05
Unidentified Paralepidae	4	12.90	45	0.87	43.61	0.05	11.92	59-134	93	0.23-2.56	0.97
Myctophiformes											
Myctophidae											
Benthosema glaciale	27	87.10	1,456	28.20	2,290.50	2.75	2,695.41	40-81	64	0.3-3.79	1.57
Diaffus effulgens	20	64.52	392	7.59	1,538.95	1.85	609.04	50-94	72	0.85-8.48	3.93
Diaffus raffinesquii	13	41.94	289	5.60	1,150.49	1.38	292.66	50-94	72	0.85-8.48	3.98
Diaphus spp.	7	22.58	74	1.43	460.45	0.55	44.85	50-122	86	0.85-11.4	6.22
Lampanyctus spp.	2	6.45	4	0.08	12.21	0.02	0.59	66-106	88	1.14-4.22	3.05
Lobianchia gemellari	5	16.13	68	1.32	411.42	0.49	29.21	67-100	87	2.64-11.35	6.05
Notoscopelus kroyeri	5	16.13	409	7.92	3,241.81	3.90	190.57	51-144	109	1.85-15.14	7.93
Lophiiformes											
Lophiidae											
Lophius spp.	1	3.23	1	0.02	51.36	0.06	0.26	150	-	51.36	-
Gadiformes											
Gadidae											
Micromesistius poutassou	2	6.45	10	0.19	100.23	0.12	2.03	78-130	97	4.63-21.09	10.02
Gadiculus argenteus thori	5	16.13	46	0.89	268.72	0.32	19.58	64-165	84	1.54-45.92	5.84
Lotidae											
Ciliata mustela	1	3.23	1	0.02	3.48	0.01	0.08	65	-	3.48	-

Table 3.2 Conti.

Prey species	F	F%	N	N%	W	W%	IRI	Length range	Av. length	Weight range	Av.weight
Beloniformes											
Belonidae											
Belone belone	3	9.68	5	0.10	4.49	0.01	0.99	87-142	111	0.34-1.85	0.90
Perciformes											
Carangidae											
Trachurus trachurus	6	19.36	100	1.94	134.95	0.16	40.62	22-106	56	0.04-8.04	1.35
Gobiidae											
Pomatochistus spp.	3	9.68	26	0.50	172.16	0.21	6.87	34-109	81	0.35-13.75	6.62
Unidentified Gobiidae	3	9.68	110	2.13	265.03	0.32	23.70	25-99	58	0.14-10.17	2.41
Cephalopods											
Sepiolida											
Sepiolidae	13	41.94	86	1.67	452.26	0.54	92.63	19-50	27	0.23-13.22	5.26
Teuthida											
Loliginidae											
Alloteuthis subulata	8	25.81	36	0.70	143.34	0.17	22.44	43-75	59	2.26-6.11	3.98
Loligo spp.	2	6.45	4	0.08	286.32	0.34	2.72	99-185	130	32.67-153.22	71.58
Chiroteuthidae											
Chiroteuthis spp.	10	32.26	59	1.14	971.85	0.17	74.52	41-115	81	1.19-39.08	16.47
Cranchidae											
Teuthowenia megalops	9	29.03	151	2.92	2,432.74	2.92	169.75	66-161	106	3.67-42.85	16.11
Gonatidae											
Gonatus fabricii	9	29.03	95	1.84	3,157.75	3.79	163.56	21-158	95	2.01-89.87	33.24
Histioteuthidae											
Histioteuthis dofleani	7	22.58	49	0.95	2,917.94	3.51	100.59	11-153	42	6.01-517.20	59.55
Histioteuthis reversa	19	61.29	722	13.98	55,551.45	66.75	4,947.76	48-124	58	50.95-333.19	76.94
Histioteuthis spp.	5	16.13	34	0.66	2,286.07	2.75	54.92	11-122	45	6.01-320.91	67.24
Crustaceans											
Decapoda											
Oplophoridae											
Notostomus spp.	10	32.26	155	3.00	834.57	1.00	129.17	6-49	27	0.04-20.89	5.38
Pasiphaeidae											
Pasiphaea sp1	4	12.90	19	0.37	129.24	0.16	6.75	16-49	35	0.96-14.10	6.80
Pasiphaea sp2	2	6.45	4	0.08	30.01	0.04	0.73	26-43	37	3.03-10.43	7.50
Unidentified crustacean	8	25.81	123	2.38	NA	NA	NA	NA	NA	NA	NA
Miscellaneous											
Tunicates	2	6.45	25	0.48	NA	NA	NA	NA	NA	NA	NA
Egg masse	1	3.23	1	0.02	NA	NA	NA	NA	NA	NA	NA
Unidentified item	1	3.23	1	0.02	NA	NA	NA	NA	NA	NA	NA
Milk	4	-	-	-	-	-	-	-	-	-	-
TOTAL*	**31**		**5,164**		**83,229.06**						

Table 3.3- Prey species identified from stranded striped dolphins (n=30). Each prey is shown as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W); index of relative importance (IRI) is also presented. Length of prey is total length for fish in mm and dorsal mantle length for squid in mm; weight is estimated in grams. * Data was estimated after removing the stomachs only contained miscellaneous items.

Prey species	**F**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**	**Length range**	**Av. length**	**Weight range**	**Av weight**
Osteichthyes											
Osmeriformes											
Argentinidae											
Argentina spp.	2	7.14	235	8.39	3,818.15	11.30	140.66	139-203	172	5.80-32.85	16.25
Myctophiformes											
Myctophidae											
Notoscopelus kroyeri	1	3.57	2	0.07	6.78	0.02	0.33	126-147	137	2.61-4.16	3.39
Gadiformes											
Gadidae											
Micromesistius poutassou	6	21.43	10	0.36	237.49	0.70	22.71	149-204	175	11.92-39.56	23.75
Merlangius merlangus	11	39.29	104	3.71	6,203.93	18.37	867.36	65-353	160	.38-384.10	59.65
M.poutassou/M.merlangus	16	57.14	345	12.31	5,716.60	16.92	1,670.66	70-378	128	0.98-384.10	16.57
Melanogrammus aeglefinus/Pollachius spp.	7	25.00	51	1.82	648.69	1.92	93.51	161-292	249	0.02-50.92	12.72
Trisopterus esmarkii	3	10.71	42	1.50	273.73	0.81	24.74	68-120	104	1.42-8.93	6.52
Trisopterus minutus	4	14.28	12	0.43	25.93	0.08	7.21	30-77	45	1.14-5.43	2.16
T.minutus/T.luscus	7	25.00	73	2.61	1,021.89	3.03	140.76	9-191	34	0.146-70.39	14.00
Trisopterus spp.	21	75.00	1,250	44.61	7,048.77	20.87	4,910.90	5-373	72	0.03-881.85	2.64
Gadiculus argenteus thori	1	3.57	10	0.36	11.71	0.04	1.40	104-126	113	0.87-1.73	1.17
Lotidae											
Ciliata mustela	1	3.57	3	0.11	1,322.03	3.91	14.36	440-469	455	400.18-482.08	440.68
Phycis spp.	2	7.14	20	0.71	444.47	1.32	14.50	144-327	241	4.4-49.64	22.22
Unidentified Gadiformes	8	28.57	55	1.96	2,975.13	8.81	307.73	10-237	104	0.05-41.38	54.09
Perciformes											
Carangidae											
Trachurus trachurus	4	14.28	66	2.36	112.31	0.33	38.40	29-148	81	0.06-6.90	1.70
Gobiidae											
Gobius spp.	1	3.57	6	0.21	483.96	1.43	5.88	20-192	53	0.04-154.45	1.68
Unidentified Gobiidae	9	32.14	288	10.28	1,094.22	3.24	435.50	179-219	199	115.84-260.30	182.37
Unidentified Mugilidae	1	3.57	2	0.07	28.68	0.09	0.56	153	153	14.34	14.34
Labridae											
Labrus spp.	1	3.57	5	0.18	922.13	2.73	10.40	214-240	225	153.57-233.93	184.43

Table 3.3- Cont..

Prey species	F	F%	N	N%	W	W%	IRI	Length range	Av. length	Weight range	Av weight
Scorpaeniformes											
Triglidae											
Eutrigla gurnardus	2	7.14	53	1.89	1,059.27	3.14	35.91	167-194	181	14.48-26.49	19.99
Unidentified fish	6	21.43	13	0.46	NA	NA	NA	NA	NA	NA	NA
Cephalopoda											
Sepiolida											
Sepiolidae	8	28.57	49	1.75	126.17	0.37	60.64	20-25	21	1.62-5.18	2.58
Teuthida											
Loliginidae											
Alloteuthis subulata	5	17.86	12	0.43	52.88	0.16	10.44	46-96	62	2.51-9.80	4.41
Loligo spp.	2	7.14	2	0.07	169.81	0.50	4.10	137-159	148	68.96-100.85	84.90
Cranchidae											
Teuthowenia megalops	2	7.14	5	0.18	42.99	0.13	2.18	72-95	88	4.96-10.45	8.60
Gonatidae											
Gonatus fabricii	7	25.00	21	0.75	392.55	1.16	47.79	17-124	61	2.05-59.49	18.69
Histioteuthidae											
Histioteuthis spp.	4	14.82	12	0.43	142.40	0.42	12.14	4-26	18	3.00-18.05	11.87
Unidentified Ommastrephidae	3	10.71	7	0.25	44.38	0.13	4.09	-	-	5.97-6.55	6.34
Unidentified cephalopod	4	14.29	49	1.75	NA	NA	NA	NA	NA	NA	NA
Miscellaneous											
Other mollusc	2		2								
Crustacean	1		1								
Plastic	1		1								
Milk	1										
TOTAL*	**27**		**2,802**		**33,778.36**						

Gadiformes, as all three indices show (85.7% of occurrence, 73.5% by number and 77.6% by biomass). The most important Gadiformes species was the *Trisopterus* spp. group occurring in more than one third of the stomachs (78.6%) and in relatively high numbers (49.1%). The second main prey group was whiting/blue whiting occurring in 67.9% of the stranded dolphins and representing 16.4% of the prey items; however, the percentage by biomass was higher in the latter (35.0%W for whiting/blue whiting and 24.1%W for *Trisopterus* spp.). Within the cephalopods, the highest occurrence was sepiolids (28.6%F, n=49), followed by the boreoatlantic armhook squid (*Gonatus frabricii*, Lichtenstein 1818) (25.0%F, n=21), the European common squid (*Alloteuthis* spp., Linnaeus 1758) (17.9%F, n=12), and the *Histioteuthis* spp. group (14.8%F, n=12) (Table 3.3). Crustacean remains were only found in one individual in the last part of the intestine of SD 1/08 and they were not considered as a direct prey item but as a secondary item; other mollusc remains were also found in two dolphins but they were not considered as primary items as they were small pieces of shell. Comparing the IRI between species/species group, the most important prey appeared to be the *Trisopterus* spp. group (5,752.4 IRI), followed by the whiting/blue whiting group (3,487.9 IRI); benthic prey were found to have an IRI of 819.7, where gobids were the most important prey (483.1 IRI) (Table 3.3). Cephalopods presented 389.8 of the Index of Relative Importance.

Reconstructed fish length also varied between the different species groups, where the largest prey were rocklings, followed by whiting/blue whiting and *Trisopterus* spp. (Table 3.3, Fig. 3.7). However, only 2% (n=47) of fish were over the minimum landing size or length at first maturity after applying the digestion factors. On the other hand, most of the larger fish prey found in stranded dolphins where Gadiformes, especially rocklings (Table 3.3). A total of 72.3% of the fish were between 20 and 120 mm length, and the percentage increased to 87.9% when fish ranged up to 180mm were included (Fig. 3.7). Cephalopod prey were small in size, with 64.7% below 30mm length (n=66), sepiolids made up the 74% of this size; the largest cephalopods were mainly boreoatlantic armhook squid and European common squid (Fig. 3.8).

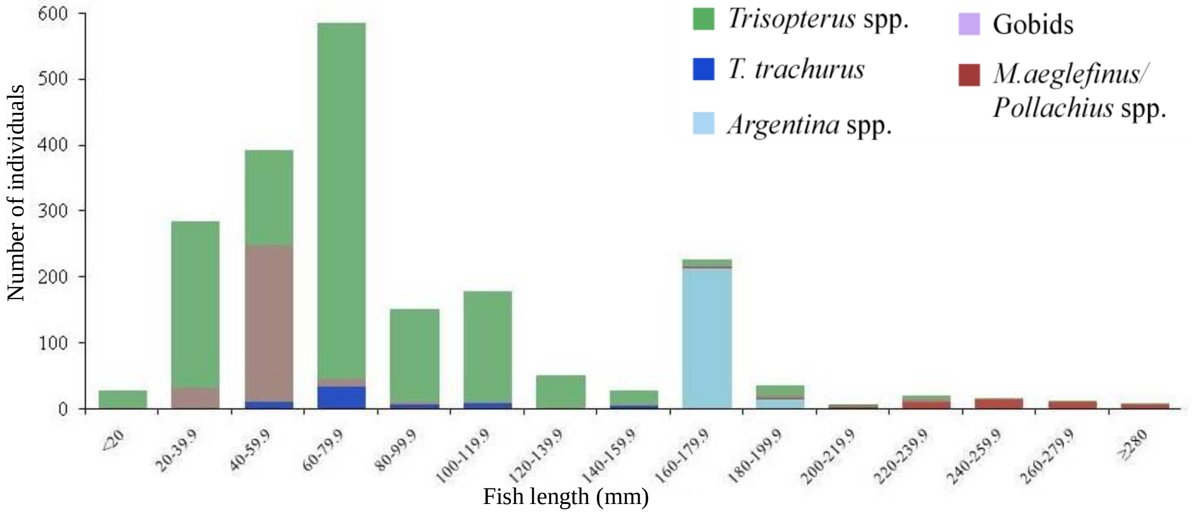


Fig 3.7 Length frequency distribution (mm) of fish prey occurring within the digestive tracts of striped dolphin stranded on the Irish coasts.

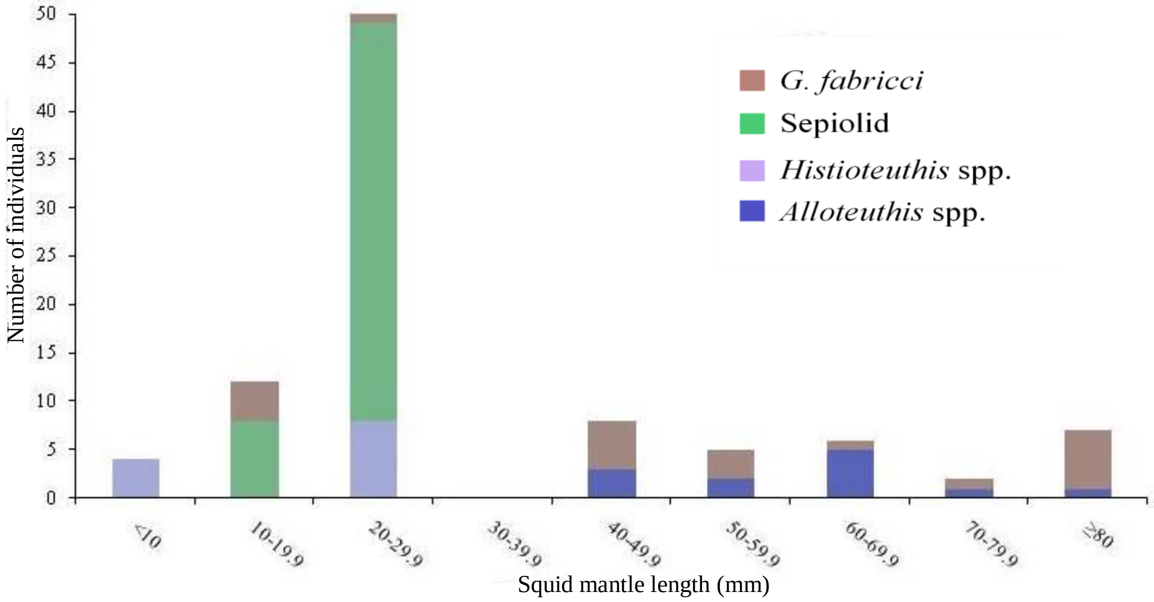


Fig 3.8 Length frequency distribution (mm) of cephalopod prey occurring within the digestive tracts of striped dolphin stranded on the Irish coasts.

3.4.3. Annual food consumption

The estimated dolphin weights ranged from 10.3 to 102.6 kg in females and from 13.6 to 146.1 kg in males. Average estimated weight was 49.4 kg (SD=25.1) for females and 62.5 kg (SD=26.8) for males; when all data were pooled, average weight was estimated to be 57.2 kg (SD=26.8). If the total striped dolphin population in Irish waters is considered to be 88,807 dolphins (78,455 and 10,352 estimated from CODA and

SCANS, respectively), the annual food consumption using the Col et al. (2012) equation is estimated as 126,963 tonnes; however, the total annual consumption estimated using the prey consumed separately gave a value of 15,562 tonnes (Table 3.4). Annual food consumption by prey species showed that striped dolphins in Irish waters might consume 8,026 tonnes of cephalopods, 1,545 tonnes of mesopelagic fish (including *B.glaciale*, *Diaphus* spp., and *N.kroyeri*), 1,422 tonnes of whiting/blue whiting, and 971 tonnes of *Trisopterus* spp. annually (Table 3.4). However, when the Pierce et al. (2007) approach was used, most of the fish groups increased in their relative contribution when equal weighting of stomachs was applied, while cephalopods decreased (Table 3.4). Gadoid prey consumption was found to increase when the dolphin weight approach was applied, while for the other prey groups this decreased (Table 3.4).

	No Weighting	E Weighting	D Weight
Mesopelagic fish	16,200.9	20,283.1	18,070.7
Whiting/blue whiting	14,281.0	21,238.8	13,365.3,
Trisopterus spp.	9,707.6	18,089.2	8,885.8
Pelagic fish	302.6	1,055.7	407.28
Benthic fish	4,839.1	3,250.8	5,066.8
Cephalopods	80,923.0	61,321.2	78,200.4
Total	**136,465.3**	**136,465.3**	**136,465.3**

Table 3.4. Annual food consumption of the main prey of striped dolphin (stranded and by caught dolphins data were pooled) not rescaled (No weighting), after applying equal weighting (E Weighting), and after applying the weighting related to the body weight of the animal (D Weight) (following Pierce et al., 2007). Results are tonnes.

Landings of whiting have decreased during the period of study in the whole area, despite a few small peaks (Figure 3.9). Most of the dolphins that contained whiting/blue whiting were stranded or by caught in the autumn and winter (Table 3.1), and the smaller biomass of this species was found in years that sample size was of 2 dolphins (1996, 2000) and 3 dolphins (2011). The fluctuations in the occurrence of whiting/blue whiting in the diet might follow the peaks in the fish landings of whiting.

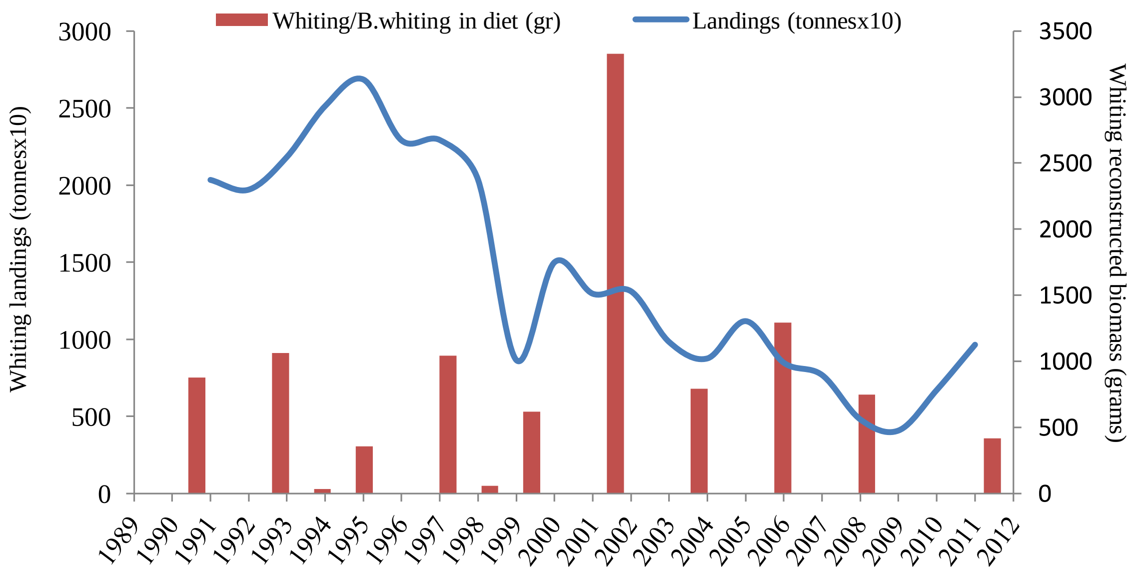


Fig. 3.9. Whiting landings (blue), in tonnes x10, fished within Irish waters during the study period; total whiting/blue whiting reconstructed biomass (red), in grams, found in striped dolphin digestive tracts in Ireland.

No significant differences in the diet were found between sexes (W=7071933, p=0.2589); however, differences in diet were found when comparing the mature and immature dolphins (W=5543413, p<0.005). Differences were also found in the diet of stranded dolphins when compared with that obtained from the by caught dolphins (W=4306139, p<0.05). RDA analysis indicates that by-caught animals showed a preference for mesopelagic fish, while stranded dolphins appear to consume more *Trisopterus* spp. (AIC= 538.96, p-value<0.05). Males and mature animals seemed to consume more cephalopods and whiting/blue whiting, in contrast females and immature dolphins consumed more Argentines and pelagic prey. However RDA showed that maturity stage was the only variable with a significant result (AIC=516.41, p-value<0.5) (Fig 3.10).

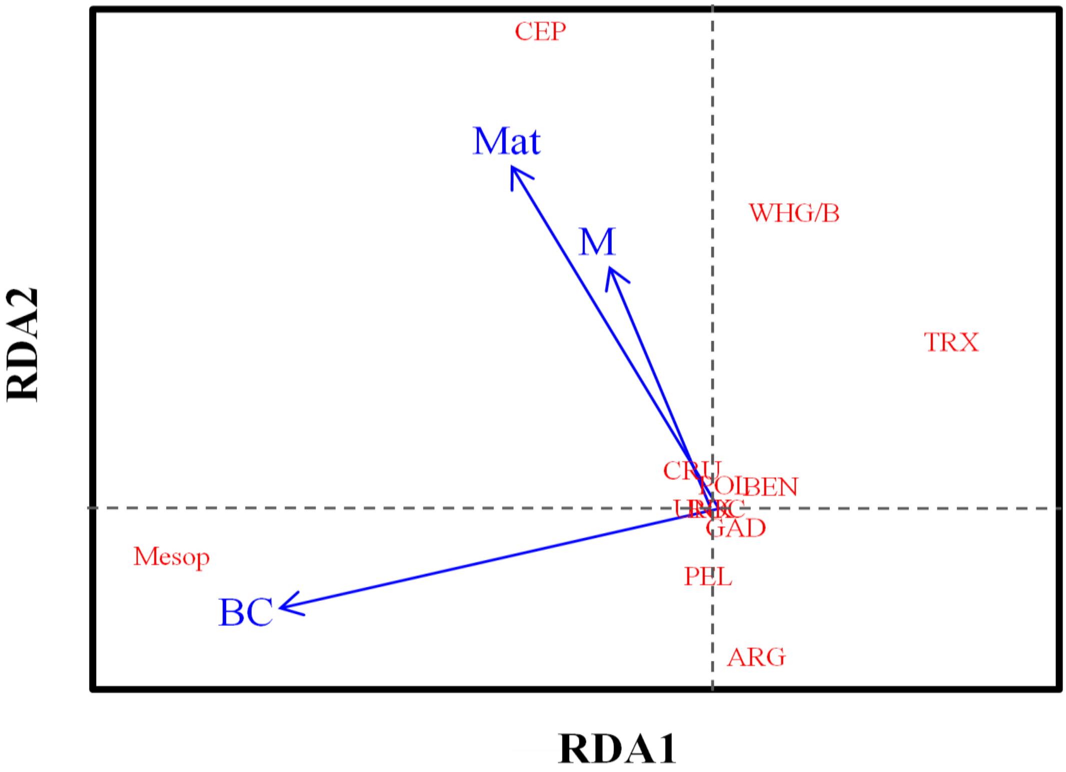


Fig 3.10. RDA biplots for striped dolphin diet; prey species were grouped according with the type of prey: Mesopelagic fish species (Mesop), whiting/blue whiting group (WHGB), haddock/pollack/saithe group (POL), *Trisopterus* spp. (TRX), rocklings (ROC), other gadoids (GAD), argentines (ARG), pelagic fish (PEL), benthic fish (BEN), unknown fish (UNK), cephalopods (CEP), and crustaceans (CRU). Response variables, represented by lines, were type of dolphins (By caught-BC- versus stranded -STR), maturity stage (mature -Mat- and immature -Imm), and sex (male -M- and female -F); only BC, Mat and M are shown in the graph.

3.5. DISCUSSION

The striped dolphin is mainly considered an oceanic species (Reid et al., 2003; Jefferson et al., 2008; CODA, 2009; Hammond et al., 2008a, 2013), and the low number of striped dolphins stranded along the Irish coasts in comparison to other more coastal species such as harbour porpoise and common dolphin (www.iwdg.ie) supports this. These circumstances compromise the availability of dolphins for studies on foraging ecology and population partitioning. Biopsy sampling might help to increase our knowledge of feeding ecology, however biopsy studies have been only carried out to date in Mediterranean waters for pollutant analysis (Panti et al., 2011; Spinsanti et al., 2006).

Dietary information on striped dolphin therefore usually relies on animals recovered from strandings on beaches and on by caught dolphins recovered from dedicated programmes to investigate the interactions of fisheries with dolphins. Throughout their range, striped dolphins appear to forage on mesopelagic prey and pelagic cephalopods within the 200-700m water depths (Archer, 2002; Hassani et al., 1997; Mendez-Fernandez et al., 2012, 2013; Miyazaki et al., 1973 (in Spitz et al., 2006a); Perrin et la., 2008; Ringelstein et al., 2006; Sekiguchi et al., 1992; Würtz and Marrale, 1993). In European waters, the diet of striped dolphins also shows more inshore prey species in the diet, such as *Trisopterus* spp, atherines, and gobies (this study; Würtz and Marrale, 1993; Spitz et al., 2006; Desportes, 1985; Santos et al., 2008). In this study, dolphins by caught in the tuna-fishery contained mesopelagic prey and cephalopods that usually occur in offshore waters, which is consistent with the fish assemblage in the area (Freijser, 2012; O'Leary, 2009) where they were incidentally captured (Porcupine area); however, stranded dolphins contained a large percentage of demersal fish prey usually occurring over the continental shelf.

On the other hand, recent investigations in southern European waters based on stable isotopes analysis indicated that striped dolphins showed an offshore dietary pattern (Chouvelon et al., 2012; Mendez-Fernandez et al., 2012, 2013), despite the fact that some of the dolphins presented with more inshore prey species in their stomach content analysis (Spitz et al., 2006a; Santos et al., 2008). It is possible that those striped dolphins that inhabit areas close or over the continental shelf are doing inshore movements and they feed on prey species more frequently occurring in continental shelf waters. A large presence of gobids were found in all studies carried out on dolphins stranded in European Atlantic waters using the traditional methodology of identifying prey remains from digestive tracts (this study; Spitz et al., 2006a; Santos et al., 2008). The incidence of gobids was reported to be 26%N in North West of Spain, 26%N in the Bay of Biscay and 10%N in this study. In this study, gobids were found to occur within the same stomachs that contained *Trisopterus* spp. (usually pouting and poor cod). It is known that gadoids feed on benthic demersal fish and gobids have been reported in stomach contents of both poor cod and pouting, as well as whiting, especially in juvenile fish (www.ices.dk fish stomach database). The identification of secondary items is a difficult task, usually many eroded otoliths occurring with other prey remains in very good condition suggests that they should be considered as secondary prey. In addition, it is assumed that predators are larger than their prey (e.g., Fung et al., 2013; Pope et al., 1994; Shin et al., 2005); usually with a specific size difference between them ("big fish eat little fish"). Therefore, the assumption that small prey such as gobids might be a secondary item from another larger prey (such as cod), preyed on by a large predator might not be correct. It was not possible to confirm the co-occurrence of gadoid fish and gobies reported by Spitz et al. (2006a) and Santos et al. (2008), however it might be that those prey appeared within the same stomachs.

Tuna-dolphins-seabirds associations have been reported in different areas for many decades, and fishermen have used dolphins and seabirds for locating tuna aggregations (e.g., Green et al., 1971; Northridge, 1984; Scott et al., 2012). These tuna-dolphin associations mainly occur with *Stenella* spp. and *Delphinus* spp. (Northridge, 1984; Ringelstein et al., 2006; Scott et al., 2012). In the eastern tropical Pacific it has been suggested that tuna and dolphin associations might be related to potential high density common food patches and shallow thermoclines (Au and Pitman, 1986; Edwards, 1992; Hall et al., 1999). In the Atlantic Ocean, dolphin-tuna associations have also been reported to be associated with common prey patches in the Azores (Clua and Grosvalet, 2001), the North-East Atlantic (Das et al., 2000; Hall, 1998 and refs there in), Brazil (Sazima et al., 2006), and in the Mediterranean Sea (Hall, 1998). The feeding ecology of albacore tuna has been studied in different areas (Goñi et al., 2011; Hassani et al., 1997; Pinkas et al., 1971; Potier et al., 2004; Pusineri et al., 2005; Rohit et al., 2010;

Vaske et al. 2003), and they appear to feed on crustaceans, followed by pelagic fish (such as anchovy-*Engraulis* spp., Cuvier 1816-, *Trachurus* spp. (Rafinesque 1810), and flyfish -Exocoetidae), and to a lesser extent on mesopelagic fish and cephalopods. In contrast, striped dolphin diet associated with the tuna-fisheries have shown a preference for offshore cephalopods and mesopelagic fish, and in lower numbers with swimming shrimps (this study; Hassani et al., 1997; Perrin et al., 2008; Ringelstein et al., 2006). Similar to Perrin et al. (1973) who worked on spinner dolphins (*Stenella longirostris*, Gray 1828), the diet of striped dolphins in the south west of Ireland seems to be composed of different prey to that of albacore tuna, with the former foraging in deeper water prey species; however, Perrin et al. (1973) also indicated that the differences in diet might rely on the nocturnal/crepuscular behaviour of the dolphin species. Foraging behaviour of striped dolphins has also been investigated in the north west of the Ligurian Sea (Mediterranean Sea) (Gannier 1999; Gordon et al., 2000), where it was suggested that dolphins performed inshore-offshore migrations to take advantage of the availability of the diel vertical migration (DVM) of their prey (Gannier, 1999). Messnier et al. (2012) suggested that seasonal movements of striped dolphins in the North West of the Mediterranean Sea might be reflected in the diet, but it was not possible to investigate this aspect in this study due to the lack of distributional prey data. Spitz et al. (2006) also suggested a shift in diet (from coastal to oceanic prey) as striped dolphins move towards the continental slope. It might be possible that striped dolphin in Irish waters also do this inshore movement; therefore, stranded dolphins might reflect the diet of this species during the day, while the by caught dolphins might reflect a night feeding behaviour following the DVM of mesopelagic prey.

Only one stranded dolphin (SD 1/08) contained mesopelagic prey (lancet fish and silvery pout –*Gadiculus argenteus thori*, Schmidt 1913). This animal also contained 94% of all argentines (*Argentina* spp., Linnaeus 1758) recorded. Silvery pout is considered a mesopelagic fish species inhabiting between 110 and 1,000 m depth and commonly inhabiting the continental slope, however nothing is known about the feeding ecology of this species. Argentines are considered benthopelagic or semipelagic species usually living over the continental shelf and the upper part of the continental slope between 140 and 1400m depth (Cohen, 1984; Fisher et al., 1987; Johannessen and Monstad, 2003). This dolphin also contained *Trisopterus* spp. and whiting/blue whiting group, which might suggest that she was feeding close to the continental slope. The co-occurrence of mesopelagic and more continental shelf prey might further indicate these inshore/offshore migrations detected in the Ligurian Sea (Gannier, 1999). Another hypothesis is that the stranded dolphins might be feeding over the continental shelf but relatively close to the continental slope during the last few days before the stranding event, and they might be constantly travelling onto the continental shelf when they are feeding.

The striped dolphin is one of the species commonly incidentally captured in fishing gear (e.g., Archer and Perrin 1999; Hammond et al., 2008a; Northridge, 1984, 91; Rogan and Mackey, 2007). Despite these interactions, there are very few attempts to estimate food requirements for this species, especially in the Atlantic. The annual food consumption of this species has only been described in the North West of the Ligurina Sea (Laran et al., 2010) with an estimation of about one tonne per year for a density of dolphins between 0.37 and 0.87 individuals per km; however, Lauriano et al. (2010) reported a population of 13,232 dolphins for a density of 0.23 of individuals per km. Laran et al. (2010) reported a striped dolphin density from 0.37 (CV=21.7) in winter to 0.87 (CV=15.2) in summer, and estimated the annual food consumption as 8,372 tonnes; however, if we consider the striped dolphin populations given by Lauriano et al (2010) for the whole Pelagus Sanctuary (13,232 dolphins) the annual food consumption by this species will increase considerably using the Col et al. (2012) equation (~18,917 tonnes). In the Atlantic waters, striped dolphin is mainly an offshore species (Hammond et al., 2008a; Jefferson et al., 2008; Reid et al., 2003). In Irish waters, the estimation of striped dolphin abundance was only obtained for the offshore population (CODA, 2009). However, Hammond et al. (2013) obtained an abundance estimation for the mixed group striped-common dolphin. Potentially, the use of a comparative proportion with offshore populations for these species might overestimate the dolphins in Irish waters and, therefore, overestimate the annual food consumption obtained in this study. The estimation of striped dolphin annual food consumption in this study was obtained using a similar approach to Laran et al. (2010), but using population abundance instead of density of dolphins, as well as the estimated residential pattern for the species (Col et al,. 2012). Most of the studies on food consumption have used population abundance of species (e.g., Col et al., 2012; Kaschner et al., 2006; Trites et al., 1997), and that suggests that the annual food consumption given by Laran et al. (2010) is likely to be underestimated.

Most of the prey found within the diet of striped dolphins in this study was not commercially important. However, there might be a potential direct competition between dolphins and fisheries for the whiting/blue whiting group. On the other hand, the amount of prey consumed by the striped dolphin population inhabiting Irish waters is lower than the landings and stock biomass of whiting reported for the area (ICES catches landings database, www.ices.dk). Kaschner et al. (2006) indicated that the amount of small pelagic fish consumed by small odontocetes might not compromise fisheries activity; which also appears to the case in this area, including the whiting/blue whiting fishery.

Dietary differences between sexes of toothed whale species have been reported in some areas and species (e.g., Santos and Pierce, 2003; Santos et al., 2007); however, other studies have not shown differences (e.g., Niño-Torres et al., 2006; Silva, 1999). Stable isotope analysis on the western Mediterranean population of striped dolphins showed no significant differences between sexes (Gomez-Campos et al., 2011) but size related differences have been found (Messnier et al., 2012), similar to this study. In this species ontogenetic differences in prey, due to the energetic requirements and/or expertise can be expected (e.g., Desportes and Mouritsen, 1993; Gomez-Campos et al, 2011). A high diversity of prey in the diet of striped dolphins was found in both the North West Pacific (Miyazaki et al., 1973, in Spitz et al. 2006a) and in Atlantic European waters (Desportes, 1985; Ringelstein et al., 2006), with different energy contents; similar to the results in this study. Gomez-Campos et al. (2011) suggested that as these animals get older, their ability to catch more prey with high energy content increases and their prey spectrum may narrow. In the Mediterranean Sea, Gomez-Campos et al. (2011) indicated that adult striped dolphins primarily consume sardine (*Sardina pilchardus*, Walbaum 1792), which is a high energy fish species (Spitz et al., 2010); however, in this study no Clupeoid species were identified, and the RDA analysis showed that mature dolphins were feeding on cephalopods, a group, in general, considered to have a low calorific value (Spitz et al., 2010). Very little is known about the biology of most of the mesopelagic fish and cephalopod species identified in this study. Indeed, although some studies have looked at the potential to develop commercial fisheries for mesopelagic fish (Freijser, 2012; O'Leary, 2009), there are no biomass estimates for these species, severely limiting our understanding of their role in the ecosystem and our ability to implement an ecosystem approach to fisheries management. In addition, there is very little information on the chemical or energetic composition of these species. It is clear from the diet of the “offshore” striped dolphins that they are an important component of the diet. Similar results have been obtained for common dolphins caught in the same nets (e.g., Brophy et al., 2009). Whether their occurrence in the diet is because of spatial and temporal overlap, or is a trade off with possibly low energetic food and ease of capture of potentially large prey aggregations, are elements of the work that needs further investigation. A further consideration is that very little is known about the population structure of this species in the North Atlantic. While it seems unlikely that there is population structure according to habitat type (e.g., continental shelf vs “offshore”), based on prey choice, this is also something that also needs further investigation.

As Mendez-Fernandez (2013) and Gannier (1999) noted, striped dolphins were mainly offshore predators but they may carry out incursions onto the continental shelf and feed on some of the prey available there. Further studies on stable isotopes comparing both groups might give more information about these findings, while genetic approaches might give information about population structure.

Chapter 4

FORAGING ECOLOGY OF ATLANTIC WHITE-SIDE DOLPHIN AND SOME INSIGHTS ON THE WHITE-BEAKED DOLPHIN IN IRISH WATERS

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FORAGING ECOLOGY OF ATLANTIC WHITE-SIDE DOLPHIN AND SOME INSIGHTS ON THE WHITE-BEAKED DOLPHIN IN IRISH WATERS

4.1ABSTRACT

Strandings of Atlantic white-sided and white beaked dolphins have been recorded along the Irish coastline for more than 100 years. A total of 43 stomachs (40 Atlantic white-sided dolphins and 3 white-beaked dolphins) were analysed. In addition, one Atlantic white-sided dolphin was by caught, however her stomach was empty. The Atlantic white-sided dolphin prey was found to be composed mainly of gadiforms (85%N), where *Trisopterus* spp. and the whiting/blue whiting group (34%N) were the main prey; Atlantic mackerel was also found to be important in terms of biomass. Most of the consumption of the whiting/blue whiting group coincided with peaks in annual landings of blue whiting. Significant differences were found in the diet between age groups for the main prey groups. Half of the prey items found in the stomachs of white-beaked dolphin were horse mackerel, with a few Gadiformes found. The total annual food consumption of Atlantic white-sided dolphins was estimated to be 26.49×10^3 tonnes, comprising 20.22×10^3 tonnes of whiting/blue whiting and 8.53×10^3 tonnes Atlantic mackerel.

4.2 INTRODUCTION

The Atlantic white-sided dolphin (*Lagenorhynchus acutus*, Gray, 1828) is a sub-arctic and cold temperate Atlantic species (Fig.4.1a), although sightings have been reported as far south as the Gibraltar Strait (Hammond et al., 2008b). Western populations have been well studied (Waring et al., 1999, 2006, 2007, 2011); however, studies on the eastern population have only recently been carried out (DEHLG, 2009; Hammond et al., 2008b). Atlantic white-sided dolphin populations that inhabit European waters have been reported to be larger (MacLeod, 2004) than the western populations (Waring et al., 2013); however studies on the structure of the western populations have been better studied (Waring et al., 1999, 2006, 2007, 2011, and references therein). Strandings of this species are reportedly more common on U.S. and Canadian coasts (Ewing et al., 2002; Truchon et al., 2013; Waring et al., 2006, 2011, 2013), than on the European coasts (CSIP reports (http://ukstrandings.org/csip-reports/; CRMM reports http://crmm.univ-lr.fr/index.php/fr/communication/bulletins-rapports; IWC progress reports), possibly as a result of habitat preferences. While the western populations inhabit more coastal areas, over the continental slope (Waring et al. 2011), the eastern populations seem to prefer deeper habitats, in waters greater than 100-200m depth (CODA, 2009; Hammond et al., 2013; Ó Cadhla et al., 2004; Wall et al., 2013; Weir et al., 2001). In Ireland, this species has been reported to have a North West distribution (Fig. 4.2a), mainly occurring in offshore waters with more than 200m depth (Wall et al., 2013).

White-beaked dolphin (*L. albirostris*, Gray, 1846) distribution overlaps with that of the Atlantic white-sided dolphin, but extends further North into subarctic waters (Fig. 4.1b). Its distribution in Europe is mainly central and north of the North Sea up to Norway (Reeves et al., 1999b); however, strandings of this species have also been reported to be common in the southern North Sea and in the English Channel (Brereton et.al, 2010; Reeves et al., 1999b). In Ireland, strandings and sightings are scarce (Fig. 4.4b), with only a few sightings recorded on the northwest coast (Wall et al., 2013), and along the continental slope (Ó Cadhla, et al., 2004). In contrast to the Atlantic white-sided dolphin, this species appears to preferentially use inshore waters (Reeves et al., 1999b; Reid et al., 2003; Weir et al., 2001).

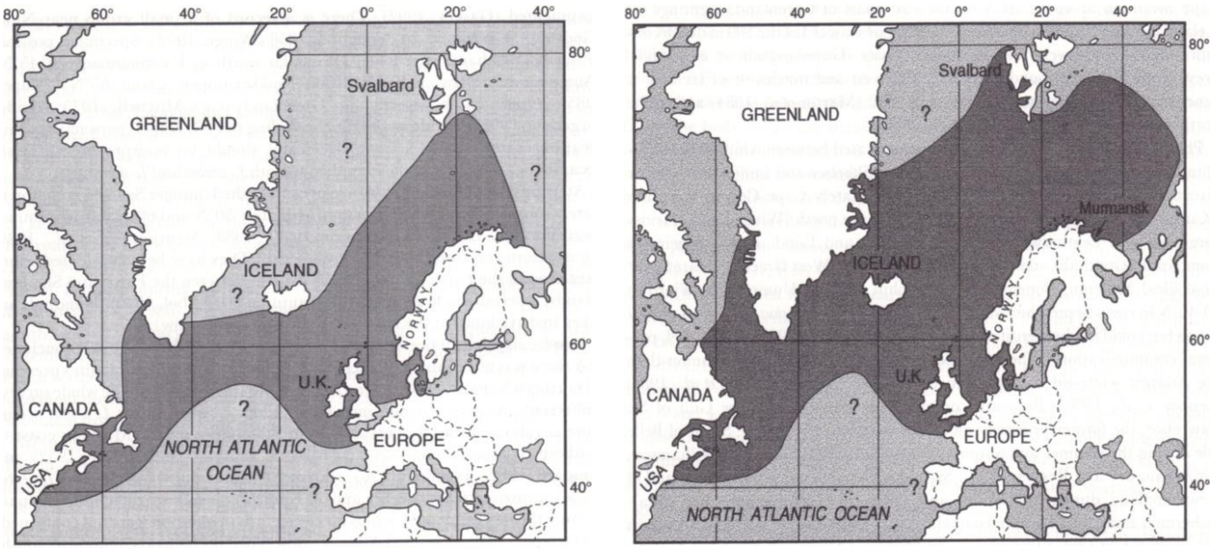

Figure 4.1. a) Atlantic white sided dolphin distribution (Reeves et al. 1999a), and b) white-beaked dolphin distribution (from Reeves et al. 1999b). Black shadows show the normal distribution; question marks correspond to unusual distribution of the species.

Relative abundance of Atlantic white-sided and white-beaked dolphins in European waters have been estimated through the multinational dedicated sighting surveys, SCANS II (Hammond et al., 2013) and CODA (CODA, 2009); however, specific studies have been carried out in smaller areas like the West Outer Hebrides (Macleod, 2004), British Isles (Northridge et al., 1995), and the Rockall Trough (Ó Cadhla et al., 2004). MacLeod (2004) estimated that the Atlantic white-sided dolphin population abundance in the West Outer Hebrides was 21,371 (CV=0.54, and density of 0.39 dolphins/km^2), while Ó'Cadhla et al. (2004) estimated 5,490 individuals (CV=0.43, and density of 0.046 dolphins/km^2) in the Rockall Trough. It is possible that the population studied by Ó Cadhla et al. (2004) might be part of the population reported by MacLeod (2004) due to the proximity of both areas. During the SCANS II survey, sightings of this dolphin species were too low to obtain a population abundance estimation, and they were included with white-beaked dolphins (Hammond et al., 2013); this low number of sightings is consistent with that reported by Reid et al. (2003) who suggested that Atlantic white-sided dolphins are usually in deep waters and along the shelf edge. On the other hand, both Ó Cadhla et al. (2004) and Reid et al. (2003) pointed out that this species is rarely seen south and south west of Ireland; but, Couperus (1997a) recorded that at least 153 Atlantic white-sided dolphins were by caught in trawlers targeting Atlantic mackerel (*Scomber scombrus*, Linnaeus, 1758), horse mackerel (*Trachurus trachurus*, Linnaeus, 1758) and blue whiting (*Micromesistius poutassou*, Risso, 1827) south west of Ireland, and Scans I (Hammond et al., 2002) estimated a population of 833 (C.V.=1.02) *Lagenorhynchus* spp. (Gray, 1846) in the Celtic Sea. Atlantic white-sided dolphins have also been reported to occur south of Ireland, in the south Irish Sea and in the Bay of Biscay (Evans et al., 2003 and refs. therein).These discrepancies in sightings and abundance estimation between authors makes it difficult to raise food consumption to a population level. In contrast, there is no estimate of white-beaked dolphin abundance in Irish waters (Ó Cadhla et al., 2004; Wall et al., 2013), and SCANS I (Hammond et al., 2002) and SCANS II (Hammond et al., 2013) surveys give values for both species of *Lagenorhynchus* spp. (Gray 1846) combined; suggesting that numbers of this species are likely low in this area.

Incidental capture of Atlantic white-sided dolphins has been recorded by different types of fisheries suggesting at least seasonal use of the waters, with possibly inter-annual differences (e.g., Couperus, 1997a; Northridge, 1991). Along the North American coast, by catch has been reported in gillnets, and different types of trawl fisheries (Waring et al., 1999, 2006, 2007, 2011, 2013). In European waters, Atlantic white-sided dolphin has been reported to be by caught mainly by trawlers (Northridge, 1991; Couperus, 1997a; Morizur et al., 1999) targeting horse mackerel. By-catch of white-beaked dolphin has also been reported on both sides of the Atlantic in similar gear types (Couperus, 1997a; Northridge, 1991; Northridge et al., 1997; Reeves et al., 1999b).

Dietary preferences of Atlantic white-sided dolphins on the west of the Atlantic have been widely studied in the last century (e.g., Craddock et al., 2009; Gaskin, 1992; Schevill, 1956; Seltzer and Payne, 1988; Weinrich et al., 2001), while diet studies of the eastern populations have been carried out more recently (Couperus, 1997a; Das et al., 2003a, 2003b; Desportes, 1985; Evans, 1980; Morizur et al., 1999). The main prey found in the stomachs of dolphins by caught in the Dutch trawler fishery was Atlantic mackerel (Couperus, 1997a), but other studies also reported pelagic prey (horse mackerel, Atlantic mackerel, Atlantic herring –*Clupea harengus*, Linnaeus 1758) within the diet of this species (Berrow and Stark, 1990; Jonsgård and Nordli, 1952; Morizur and Antoine, 2003; Morizur et al., 1999). White-beaked dolphins have been reported to prefer Gadiformes prey species (e.g., Canning et al., 2008; Jansen et al., 2010; Reeves et al., 1999b), although other inshore/coastal species are also reported.

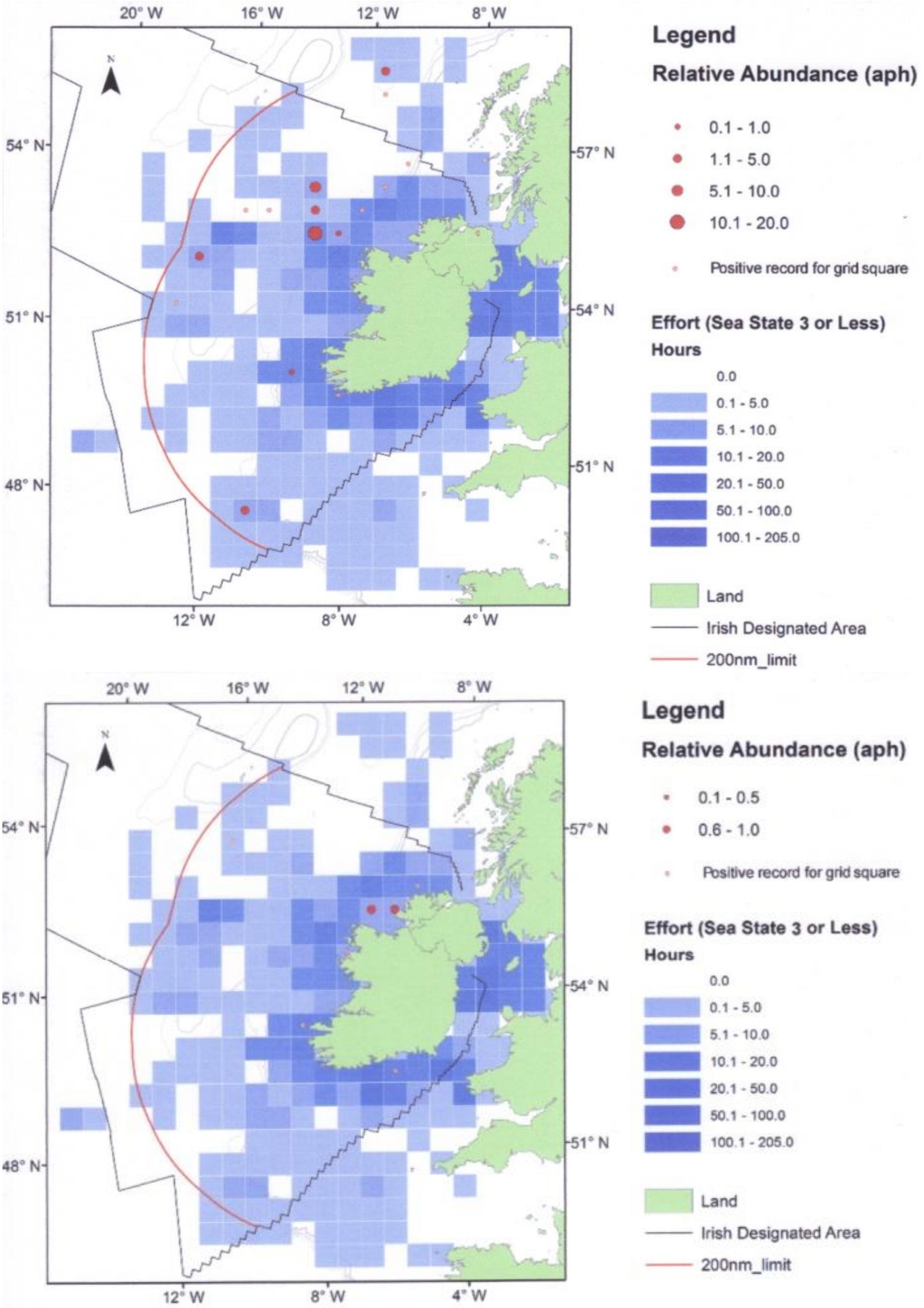

Figure 4.2. Relative abundance and distribution of white-sided (top) and white-beaked (bottom) dolphins in Irish waters from 2005 to 2011. Relative abundance was expressed as animals recorded per survey hour (aph) (from Wall et al., 2013)

Both species are classified as ‘least concern’ by the IUCN (www.iucnredlist.org) and both are listed in Annex A of the European Council Regulation (338/97), included in CITES Appendix II and in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS). Both are listed in Annex IV of the European Habitats Directive.

This is the first study of the diet of Atlantic white-sided dolphin and white-beaked dolphins in Irish waters, and the estimation of annual consumption in the area. These results will enhance our knowledge of the feeding ecology of these species, and will help in our understanding of their ecological requirements.

4.3 MATERIAL AND METHODS

4.3.1 Study area and sample composition

Atlantic white-sided dolphins (WSD) have been recorded stranded in Ireland since 1876. Since 1990, a number of stranded individuals were dissected by UCC staff and research students and sample collection was performed following the standard protocol of the European Cetacean Society (Kuiken and García Hartmann, 1993). Animals were measured, sexed and when the animals were in good condition additional samples were collected. Digestive tracts from only sixteen dolphins from single stranded events mostly on the west and north of Ireland were recovered (Fig 4.3). A total of three females, twelve males and one unknown stranded along West and North West of Ireland were analysed (Fig. 4.3., Table 4.1). They were classified as adults (A) when body length was over 250cm for males and 220cm for females (Jefferson et al., 2008); however, there were four male dolphins with a body length of 240-250cm and they were classified as separately (A-J). Dolphins with a body length below 220cm were classified as juveniles (J) including subadults.

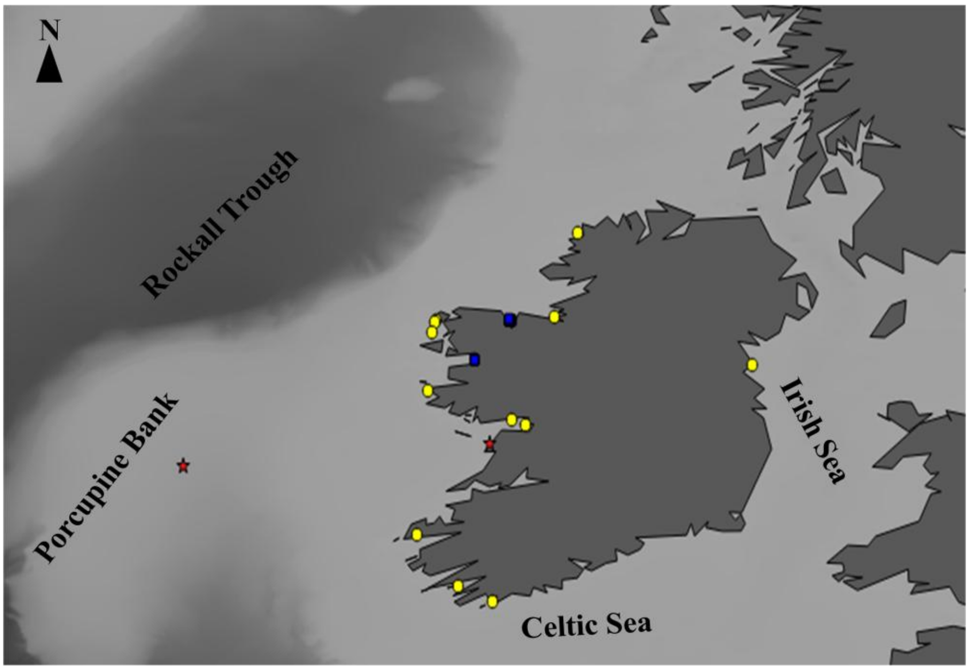

Figure 4.3. Atlantic white-sided mass stranding [(blue squares), single event strandings (yellow circles), and classified as by-caught (red stars)] and white-beaked dolphin (green circles) strandings in Ireland used in this study.

Table 4.1-. Data on stranded and by caught Atlantic white-side dolphin (WSD) and white-beaked dolphin (WBD) in Ireland for which stomach contents were analysed (N=18, N=3 respectively); # code of the animal was lost (UNK: unknown). Jan: January, Feb: February, Mc: March, Ap: April, My: May, Jn: June, Jul: July, Oct: October. M: male, F: female, WHG-WHB: whiting-blue whiting; TRX: *Trisopterus* spp.; MAC: Atlantic mackerel; HOM: horse mackerel. § These dolphins contained other type of prey items. ♦ Empty stomachs.

Code	**Year**	**Month**	**Sex**	**Length (cm)**	**Estimated weight (kg)**	**Location of stranding**	**Size of the main prey (minimum and maximum total length, mm)**				
							WHG-WHB	**TRX**	**MAC**	**Mesopelagic fish**	**HOM**
WSD 10	1990	Mc	M	244	80.8	Mweenish Island, Galway	-	-	190.0-260.0 (n=8)	-	-
WSD 14	1990	Mc	M	265	98.4	Omey Island, Galway	178.2	66.4-319.7 (n=2)	310.0-360.0 (n=3)	-	-
WSD 1/94	1994	Jan	M	247	83.2	Silver Strand, Galway	-	81.3-118.0 (n=3)	-	95.6-156.2 (n=39)	-
WSD 2/94	1994	Ap	M	255	89.8	Baltimore, Cork	-	-	270.0-330.0 (n=5)	63.6-212.2 (n=40)	-
WSD ROSS 1§	1994	Sep	M	185	41.8	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 2	1994	Sep	M	274	106.5	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 3♦	1994	Sep	F	236	74.6	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 4	1994	Sep	F	230	70.2	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 5	1994	Sep	F	241	78.5	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 6	1994	Sep	M	258	92.3	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 7	1994	Sep	M	266	99.3	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 8	1994	Sep	F	170	34.2	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 9♦	1994	Sep	F	253	88.1	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 10	1994	Sep	F	221	63.8	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 11	1994	Sep	M	270	102.9	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 12	1994	Sep	M	250	85.6	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 13	1994	Sep	M	170	34.2	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 14	1994	Sep	F	221	63.8	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 15♦	1994	Sep	F	218	61.8	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 16	1994	Sep	M	249	84.8	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 17	1994	Sep	F	158	28.7	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 18	1994	Sep	M	256	90.6	Killala Bay, Donegal	-	-	-	-	-
WSD ROSS 19	1994	Sep	M	256	90.6	Killala Bay, Donegal	-	-	-	-	-
WSD 1/96	1996	Jn	F	279	111.2	Geedore Bay, Donegal	256.8-349.8 (n=2)	158.6-225.0 (n=35)	-	-	-

Table 4.1-. *Continue*

Code	**Year**	**Month**	**Sex**	**Length (cm)**	**Estimated weight (kg)**	**Location of stranding**	**Size of the main prey (minimum and maximum total length, mm)**				
							WHG-WHB	**TRX**	**MAC**	**Mesopelagic fish**	**HOM**
WSD 25/96♦	1996	Ag	F	137	20.4	52º46'N/13º08'W	-	-	-	-	-
WSD 1/97	1997	Mc	M	182	40.2	Alihies Bay, Cork	195.2-294.4 (n=5)	-	-	55.0-164.8 (n=47)	-
WSD 3/98♦	1998	My	M	250	85.6	Clogher Head, Louth	-	-	-	-	-
WSD 4/98♦	1998	My	M	223	65.2	Castlebellighan, Louth	-	-	-	-	-
WSD M1	1998	Oct	M	169	33.7	Kilmeena, Mayo	89.3-171.7 (n=33)	78.5-141.2 (n=2)	-	-	-
WSD M2	1998	Oct	F	230	70.2	Kilmeena, Mayo	100.2-260.3 (n=29)	276.7	-	118.9	-
WSD M3	1998	Oct	M	168	33.2	Kilmeena, Mayo	38.5-162.9 (n=8)	-	-	-	-
WSD M4	1998	Oct	F	231	70.9	Kilmeena, Mayo	-	29.1-84.7 (n=40)	223.2-339.3 (n=11)	-	-
WSD M5	1998	Oct	M	242	79.3	Kilmeena, Mayo	-	30.7-56.9 (n=4)	-	-	-
WSD a/99♦	1999	Oct	M	245	81.6	Marbell Hill, Donegal	-	-	-	-	-
WSD 1/00	2000	Mc	M	170	34.2	Doolin, Clare	100.7-327.2 (n=107)	-	495.3	102.4-141.6 (n=6)	-
WSD 1/02§	2002	Feb	M	143	22.6	Mullet Peninsula, Mayo	-	-	-	-	-
WSD 2/02	2002	Feb	M	258	92.31	Mullet Peninsula, Mayo	-	-	-	-	-
WSD 1/04§	2004	Jan	F	176	37.12	Strandhill, Sligo	-	-	-	-	-
WSD 1/05	2005	Jul	F	236	74.7	Blacksod Bay, Mayo	-	120.4-132.9 (n=3)	-	-	-
WSD 1/06	2006	Jul	M	241	78.5	Dingle Bay, Kerry	61.8-391.7 (n=26)	25.7-74.9 (n=187)	-	-	-
WSD O3§#	NA	NA	NA	NA	NA	NA	-	-	-	-	-
WBD 2/93	1993	My	F	239	76.9	Camp, Kerry	85.8-105.3 (n=2)	-	-	-	183.1-215.9 (n=6)
WBD 1/96	1996	Ap	M	198.5	49.4	Mullet Peninsula, Mayo	-	-	711.8	-	90.2-117.8 (n=3)
WBD 1/04§	2004	Jan	M	215	59.8	Achill Island, Mayo	-	-	-	-	-

One stranded Atlantic white-sided dolphin was classified as by caught based on some net marks present on his body and a rope attached to the fluke. Additionally, one Atlantic white-sided dolphin was by caught, however her stomach was empty

In addition, two mass strandings occurred in Ireland in the 1990s. In 1994, 19 Atlantic white-sided dolphins stranded in Killala bay (Co. Mayo) at the end of September (Rogan et al. 1997a). On the 28th October 1998, another mass stranding occurred in Cleggan Strand (Kilmeena, Co. Mayo) (Rogan et al. 2002); where five animals were found and stomach contents were recovered. The full digestive tracts were analysed.

Since 1901, 33 White-beaked dolphins (WBD) have been recorded stranded along the Irish coast (Appendix IV). Dolphins stranded mainly along the west, and North West of Ireland, however a few strandings have been recorded close to Cork (Co. Cork). A total of six dolphins were dissected by UCC staff and research students, and only three were found to contain food remains: a pregnant female and two juvenile males (Table 4.1)

4.3.2 Prey identification and quantification of diet

Prey items were recovered using the techniques described in Chapter 2, and size and weight was estimated using back calculation regressions (Appendix I); when whole undigested fish were found, the standard length of the prey was measured.

Digestion coefficient factors for most of the prey species were applied (Grellier and Hammond, 2006; Tollit et al., 1997) (see Chapter 2, Section 2.3.3). For those species for which digestion coefficient factors were not available and otoliths presented considerable erosion, values from otoliths similar in shape and robustness were used.

Digestion coefficient factors obtained from both Grellier and Hammond (2006) and Tollit et al. (1997) were applied and differences were investigated using Wilcoxon Signed Rank statistics, using the R Statistical Software (R Development Core Team, 2009, www.r-project.org). No digestion coefficient factors were applied to bones as low numbers of prey were identified through bones and they were recovered in relatively good condition.

The importance of individual prey species/taxa in each stomach was evaluated in terms of occurrence, number and summed estimated weight, using the three standard indices (frequency of occurrence, %F; percentage by number, %N; percentage by reconstructed weight, %W). Also Index of Relative importance (IRI) was used to measure the importance of each prey (Hyslop, 1980) (see Chapter 2, Section 2.3.3).

4.3.3. Annual food consumption and statistical analysis

The annual food consumption rate for the Atlantic white-sided dolphin population in Irish waters was applied in two different ways; firstly using the food consumption (C) equation provided by Col et al. (2012), and secondly using the Pierce et al. (2007) food consumption equation (see Chapter 2, Section 2.3.5)

No abundance estimate was calculated from the SCANS II multinational survey of Atlantic white-sided dolphins for Irish waters due to the low number of sightings. A combined abundance of both Atlantic white-sided dolphin and white-beaked dolphin (*Lagenorhinchus* spp) was estimated for the Q block (Fig 1.2a) of 7,736 (CV=0.29) for the combination of. On the other hand, the multinational survey carried out in offshore waters (CODA, 2009, Fig 1.2b) did not provide any value for this dolphin species. O'Cadhla et al. (2004) reported that the Atlantic white-sided dolphin population estimation in Rockall Trough, the Hatton Bank and the Rockall Bank was 5,490 (CV=0.43). In contrast, MacLeod (2004) estimated that the Atlantic white-sided dolphin in West Outer Hebrides was 21,371 (CV=0.54). In this study, the population provided by MacLeod (2004) was used.

The average weight of Atlantic white-sided dolphins was estimated using the length information of the total number of white-sided dolphins stranded in Ireland whose stomach contents were analysed (n=37) (Appendix III).

The food consumption of the main prey items was compared with the average landings during the study period (1990-2010). Landings data of Atlantic mackerel and blue whiting were obtained from ICES (FishStats+, www.ices.dk) for the Divisions VIa, VIb, VIIb, VIIc, VIId, VIIf, VIIg, VIIh, VIIj2 and VIIk in the FAO area 27 (Fig. 1.16) to compare the annual consumption of these dolphin species with commercial fisheries. Gadidae species were grouped in the same way as previously described in the diet analysis (Chapter 2). Mesopelagic fish included all Myctophiformes, and silvery pout (*Gadiculus argenteus thori*, Schmidt. 1913).

The analysis examining possible differences in diet relating to age was carried out in two ways: firstly the three age-groups were kept separate (adult (A), adult-juvenile (A-J), and juvenile (J)), and secondly two age-groups were considered, where the A-J were combined with the adult group. Comparison of the diet between adult and juvenile dolphins was investigated using the Fisher Exact Test and Chi-square Test using prey occurrence and Mann-Whitney U and Wilcoxon rank test when examining differences in prey weight. Other comparisons such as season and sex were not carried out due to the small sample size. Comparison of the diet between individuals involved in the mass strandings and single strandings were not possible due to the small sample size. All analyses were carried out using the R Statistical Software (R Development Core Team, 2009, www.r-project.org).

4.4. RESULTS

4.4.1. Atlantic white-sided dolphin

4.4.1.1 Study area and sample composition

A total of 133 Atlantic white sided dolphins have been reported to have stranded in Ireland since 1876 (Appendix III, Fig. 4.4), with the majority of these strandings occurring along the South West, West and North West of Ireland. In addition, another dolphin was incidentally caught in a drift net targeting albacore tuna (*Thunnus alalunga,* Bonnaterre 1788). Strandings in Ireland showed an increase from 1989 with several peaks until the present day; however the 1994 and 1998 mass strandings of eighteen and five dolphins increased the amount of reported dolphins, respectively. Strandings recorded in 1989 and 1990 made up 17% of the total strandings of this species in Ireland, while 50% of the strandings were reported during these two years over the full decade; in contrast, 35% of the total strandings of Atlantic white-sided dolphin were recorded from 2000 to present. Two peaks of strandings occurred during the year, the first one in March and April, and the second one in September and October (Fig. 4.5).

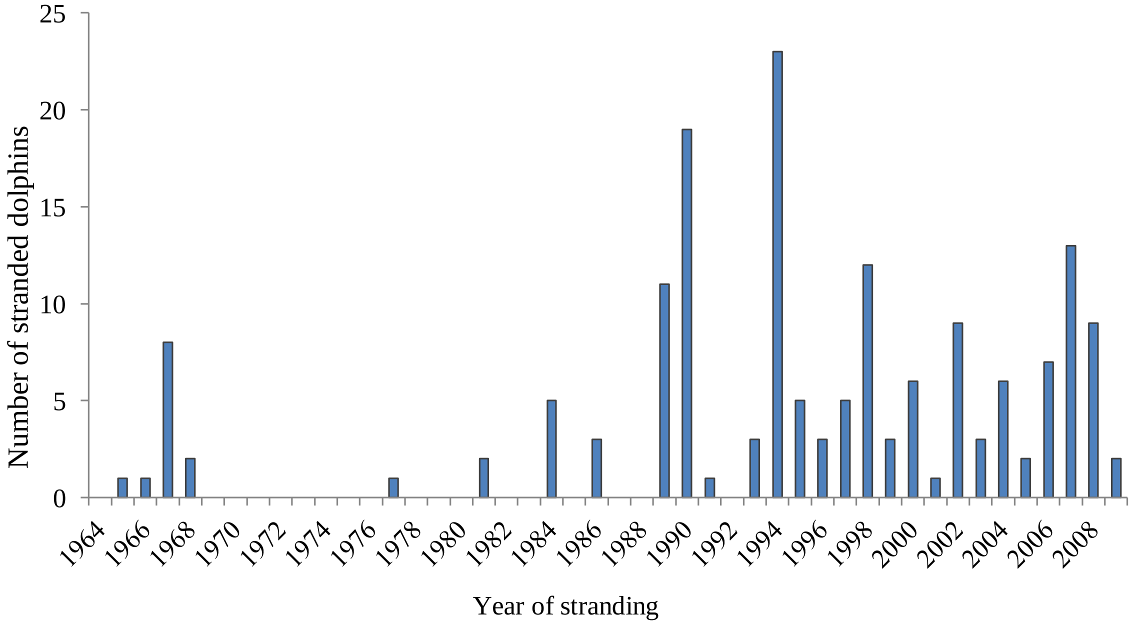

Figure 4.4. Annual strandings of Atlantic white-sided dolphin in Ireland (1876-2009) Mass strandings occurred in September (18 dolphins) and October (5 dolphins)

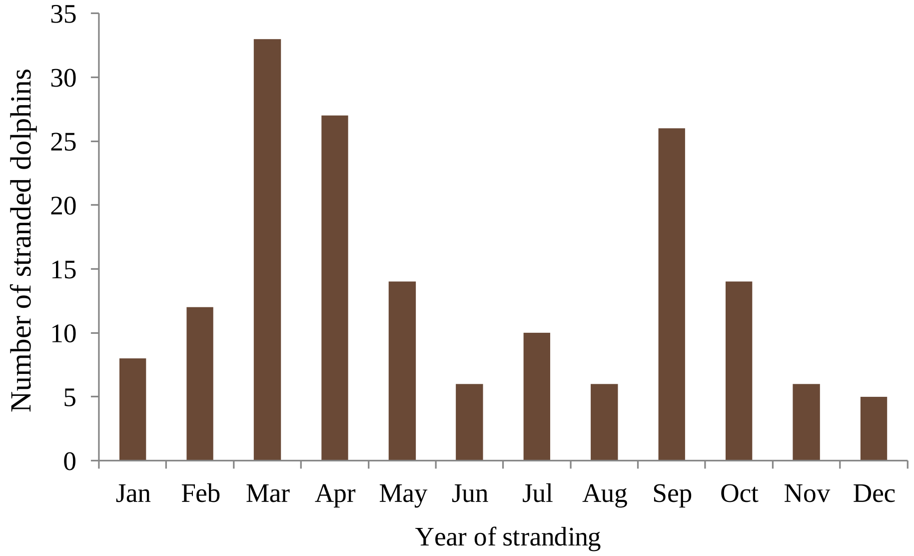

Figure 4.5. Monthly distribution of the strandings of Atlantic white-sided dolphins in Ireland (1965-2009). Mass strandings occurred in September (18 dolphins) and October (5 dolphins)

A total of 41 stomachs of Atlantic white-sided dolphins stranded on the Irish coasts were analysed, and seven stomachs were empty (Fig. 4.3, Table 4.1). The composition of the dolphins that presented empty stomachs where two adult and three juvenile males, and one adult and one juvenile female.

Twenty five out of 40 were males, 14 were females and one unknown; however, the ratio of the mass strandings was similar (4♀:5♂), while there were more males than females within the reminder of the stranded dolphins (Table 4.1). The size of dolphins ranged from 143cm to 274cm in males and from 158cm to 279cm in females. Following Reeves et al. (1999a) and Jefferson et al. (2008) seven males and four females were defined as juveniles (J), however one of the juveniles was pregnant and it was considered as an adult (A) (Table 4.1).

4.4.1.2. Prey identification and quantification of diet

A total of 810 prey items were identified, with teleost fish (n=758) making up 93.6% by number and 98.4% by weight (Table 4.2). The majority of prey was identified to genus level (83.2%, n=674), and fish prey were identified mainly by otoliths (97.76%), while only 17 fish (2.24%) were identified using skeletal structures. At least 15 fish taxa were identified belonging to eight families. Gadiformes species comprised the most important taxonomic group (10844.53 IRI) occurring in more than 75% of the diet (84.9% by number, 75.5% by weight); *Trisopterus* spp. (Rafinesque, 1814) was the most common prey species in the diet (47.4%F, 34.2%N) and within the Gadiformes (69.2%F, 41.2%N), but the biomass occurrence was very low (13.1%W and 17.3% respectively) in comparison with other groups. Whiting/blue whiting group was the second most common prey type occurring in the diet (42.1%F, 33.6%N) and within the Gadiformes (61.5%F, 62.9%N), however the percentage of biomass was larger (49.6%W and 65.6%W respectively). Pelagic prey species (mainly Atlantic mackerel and Atlantic herring -*Clupea harengus,* Linnaeus 1758) was the next most important group (906.52 IRI); however, they were less important in terms of number (3.7%N). Mesopelagic fish was found to be important when silvery pout was included in the group (26.3%F, 16.4%N, 570.3 IRI) (Table 4.2).

Cephalopods were found in half of the stomachs with remains, but the number (6.2%) and biomass (1.6%) were very low. The most important cephalopods found were pelagic squid (*Loligo* spp. -Lamarck, 1798-, ommastrephids, etc), occurring in 26.3% of the stomachs (4.9%N, 161.4 IRI) (Table 4.2).

The estimated weight of prey items after applying the digestion coefficient factors increased 2.3 times (22.9 kg) when using Grellier and Hammond (2005) values, and 2.8 times (31.3 kg) from the original estimated weight when using Tollit et al. (1997) values. Wilcoxon Rank test showed that total estimated biomass consumed by dolphins differed significantly between the original biomass estimation and the biomass estimated after applying both coefficient factors ($p<<0.05$); however, biomass did not differ significantly between the prey biomass estimation after applying Grellier and Hammond (2005) and Tollit et al. (1997) digestion coefficient factors ($p>>0.05$).

Table 4.2- Prey species identified from stranded Atlantic white-sided dolphins in Irish coasts (n=19). Each prey are shown as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W) and index of relative importance (IRI). Length of prey is total length for fish and dorsal mantle length for squid (in mm). * All *Argentina* spp. were assumed to have same size and weight although only one otolith was suitable for measuring.

Prey species	**Range length (mm)**	**Av.length (mm)**	**Range weight (grams)**	**Av.weight (grams)**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**
Osteichthyes										
Clupeiformes										
Clupea harengus	262.51	-	134.67	-	5.26	1	0.12	134.67	0.34	2.43
Osmeriformes										
Argentina spyraena	188.62	-	63.82	-	5.26	3	0.37	191.47	0.48	4.48
Argentina spp*	213.15-214.44	213.79	96.10-98.06	97.08	5.26	2	0.25	257.98	0.65	4.71
Myctophiformes										
Notoscopelus elongatus	149.69	-	23.03	-	5.26	1	0.13	23.03	0.06	0.95
Notoscopelus spp.	63.60-150.91	109.17	1.27-23.66	8.83	10.53	27	3.33	238.28	0.60	41.38
Diaphus spp.	104.98	-	7.23	-	5.26	1	0.13	7.23	0.02	0.75
Unidentified Myctophid	55.02-118.90	72.09	0.76-24.56	3.95	10.53	10	1.24	39.47	0.10	14.04
Gadiformes										
Micromesistius poutassou	61.77-349.81	222.49	4.36-344.53	77.88	31.58	191	23.58	14,640.98	36.75	1,905.30
Merlangius merlangus	89.28-481.55	178.15	6.92-1,117.68	93.66	26.32	45	5.56	4,214.70	10.58	424.63
M. merlangus/M. poutassou	38.51-307.49	131.58	0.58-214.38	34.17	31.58	36	4.44	888.53	2.23	210.19
Pollachius spp.	213.95	-	165.04	-	5.26	1	0.12	2.64	0.01	0.69
Pollachius spp/*M .aeglefinus*	125.48-314.53	183.50	9.89-307.88	87.02	10.53	15	1.85	1,305.2	3.28	53.98
Trisopterus esmarki	78.45	-	2.54	-	5.26	1	0.12	2.54	0.01	0.68
T. luscus/T.minutus	216.35-276.73	246.54	98.05-269.48	183.76	10.53	2	0.25	367.52	0.92	12.31
Trisopterus spp.	25.70-319.68	74.50	0.13-437.39	18.79	42.11	274	33.83	4,834.18	12.14	1,935.3
Gadiculus argenteus thori	72.13-212.15	122.69	2.37-114.38	18.98	21.05	94	11.61	1,784.37	4.48	338.62
Raniceps raninus	161.00	-	62.12	-	5.26	1	0.13	62.12	0.16	1.47
Unidentified Gadidae	50.56-443.01	213.96	0.75-865.66	165.04	15.79	12	1.48	1,980.5	4.97	101.89
Perciformes										
Scomber scombrus	190.00-495.30	295.43	63.04-1,031.71	341.32	31.58	29	3.58	8,191.05	20.56	762.44
Atheriniformes										
Atherina spp.	146.65-151.71	149.18	20.42-21.13	20.78	5.26	2	0.25	41.55	0.10	1.85
Unidentified fish	NA	NA	NA	NA	21.05	10	1.24	NA	NA	NA

Table 4.2 *Contin.*

Cephalopods										
Sepiolida										
Unidentified sepiolids	19.35-20.77	20.02	1.81-3.12	2.47	10.53	25	3.09	61.79	1.16	34.12
Theuthida										
Loligo spp.	198.76	-	186.79	-	15.79	3	0.37	186.79	0.47	13.25
Unidentified Ommastrephidae	NA	NA	10.94-46.90	31.48	10.53	10	1.14	314.82	0.79	21.32
Brachioteuthis rissei	50.47	-	3.64	-	5.26	1	0.13	3.64	0.01	0.70
Unidentified squid	NA	NA	NA	NA	5.26	1	0.13	NA	NA	NA
Octopoda										
Octopus spp.	NA	NA	10.34-24.71	17.52	5.26	2	0.25	35.05	0.09	1.76
Unidentified octopuses	NA	NA	24.50	-	5.26	1	0.13	24.50	0.07	0.97
Unidentified cephalopod	NA	NA	NA	NA	21.53	7	0.86	NA	NA	NA
Crustacean	NA	NA	NA	NA	5.26	2	0.25	NA	NA	NA
TOTAL					**19**	**810**		**39,835.22**		

Length of fish prey varied; the estimated length of gadoid species ranged from 26 to 481 mm (Table 4.2); where the larger species occurring were the haddock/pollack/saithe group (Fig. 4.6b), followed by the whiting/blue whiting group (Fig.4.6a). The third main fish group was *Trisopterus* spp. with an average size of 75mm (Table 4.2). Most of whiting (84%) found were below the minimum landing size (MLS, 270mm); however 91% of blue whiting were above the maximum length at maturation of the species (150mm). Within the whiting/blue whiting group, 76% of the prey length was estimated to be below 150mm, while only one prey item was larger than 270mm.

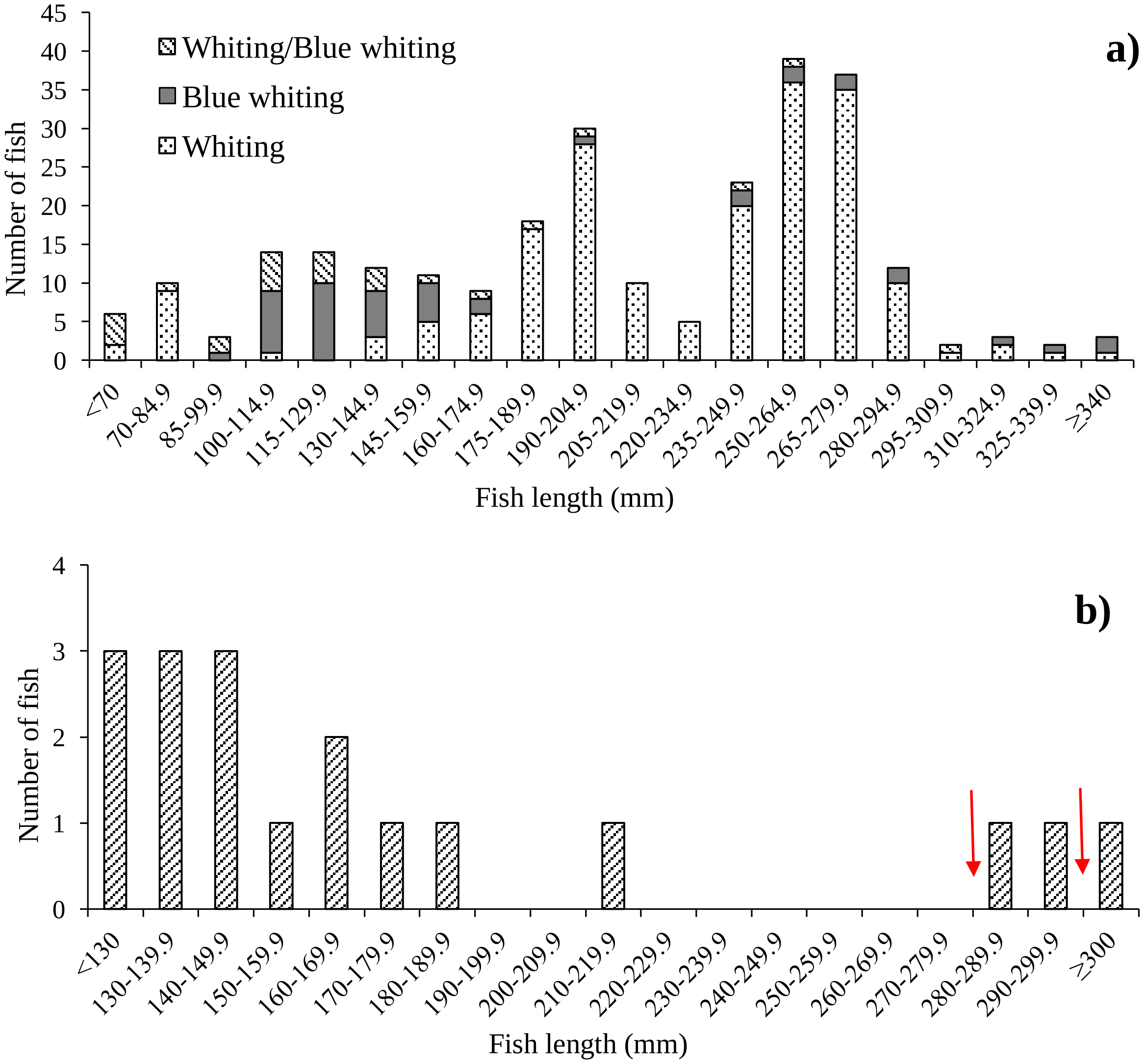

Figure 4.6. Estimated length (mm) for, a) blue whiting and whiting prey items, and b) pollack, saithe and haddock found in Atlantic white-sided dolphin stomachs. MLS (arrows) for whiting, pollack, saithe and haddock are 270 mm, 300mm, 350mm, and 300mm respectively. There is no blue whiting MLS in this region, however 150mm is the maximum maturity length (Froese and Pauly, 2009)

Most of the *Trisopterus* spp. (85%) were found below their length at sexual maturity (130mm and 150mm for *T.esmarkii* (Nilsson, 1850) and *T.minutus* (Linnaeus, 1758) respectively, and 250mm for *T.luscus* (Linnaeus, 1758), Froese and Pauly, 2013) (Fig. 4.7a). Myctophids was another important group in terms of numbers (Fig.4.7b), and most of the silvery pout (67.0%) were above the common length reported for this species (Froese and Pauly, 2013).

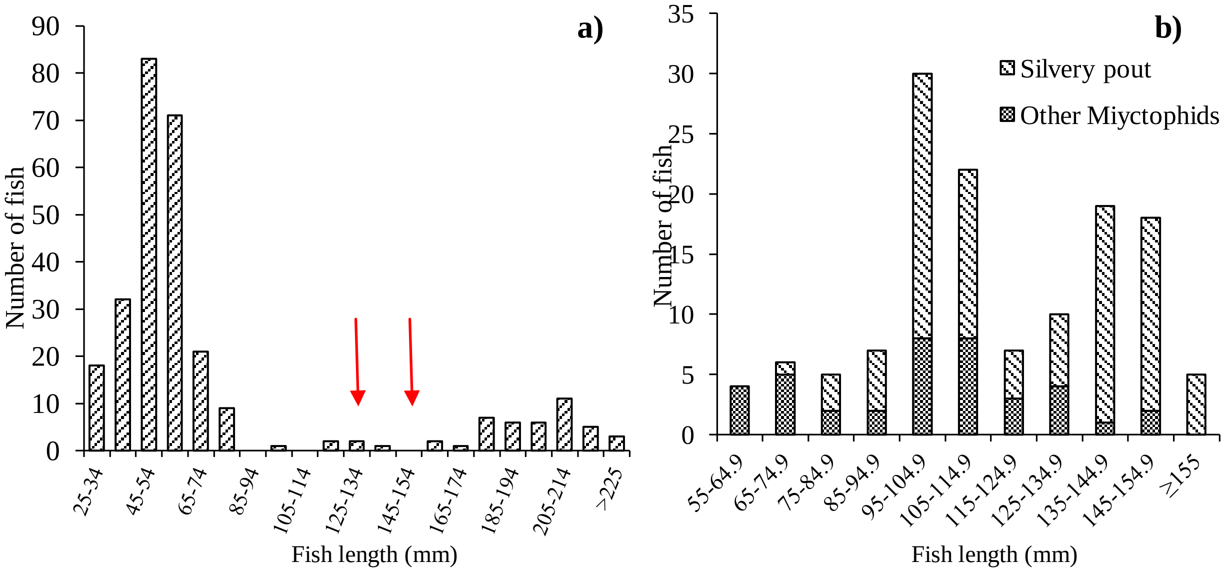

Figure 4.7 Estimated lengths (mm) for a) *Trisopterus* spp., and b) myctophids found in Atlantic white-sided dolphin stomachs. There is no MLS data available for these species; maximum maturity length for Norway pout, poor cod and bib are 130mm, 150mm and 250mm respectively. There are no data available for maturity length of silvery pout. Froese and Pauly (2009)

Most of the other myctophids were identified as *Notoscopelus* spp. (Günther, 1864) and their maximum size is similar to silvery pout; considering the common length of 100mm for silvery pout, 46.2% were above this size. Also, only one fish identified within the group of haddock/pollack/saithe was over the MLS for all species. The opposite is true for Atlantic mackerel (Fig. 4.8) with 96% of the fish found were over marketable size (200mm).

Cephalopods occurred in 47% of the stomachs but their importance was small (6% by number and only 1.5% by weight, Fig. 4.9). Five different species were identified, belonging to different families. The most important cephalopods were the pelagic cephalopods, occurring 80%N and 90%W (Table 4.2). The most abundant cephalopods, *Sepiola* spp. (Leach, 1817) and *Ommastrephes* spp. (d'Orbigny, 1834), were found in two stomachs where one of them only contained cephalopods and the other one comprised mostly blue whiting. Two crabs were also found but could not be identified to species level (Table 4.2).

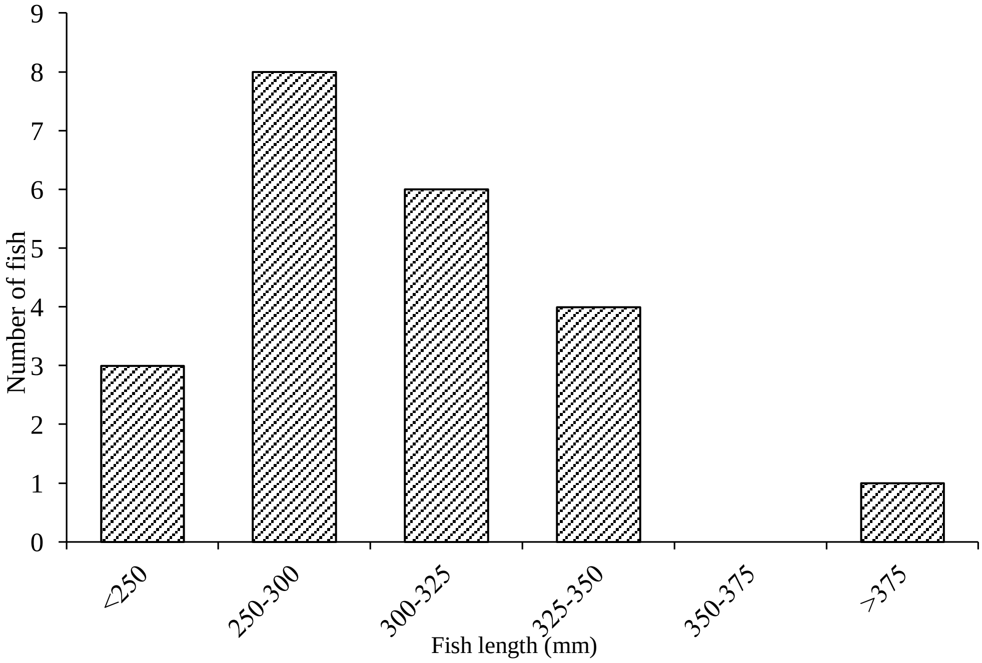

Figure 4.8. Estimated length (mm) for Atlantic mackerel prey items found in Atlantic white-sided dolphin stomachs. MLS for Atlantic mackerel is 20cm.

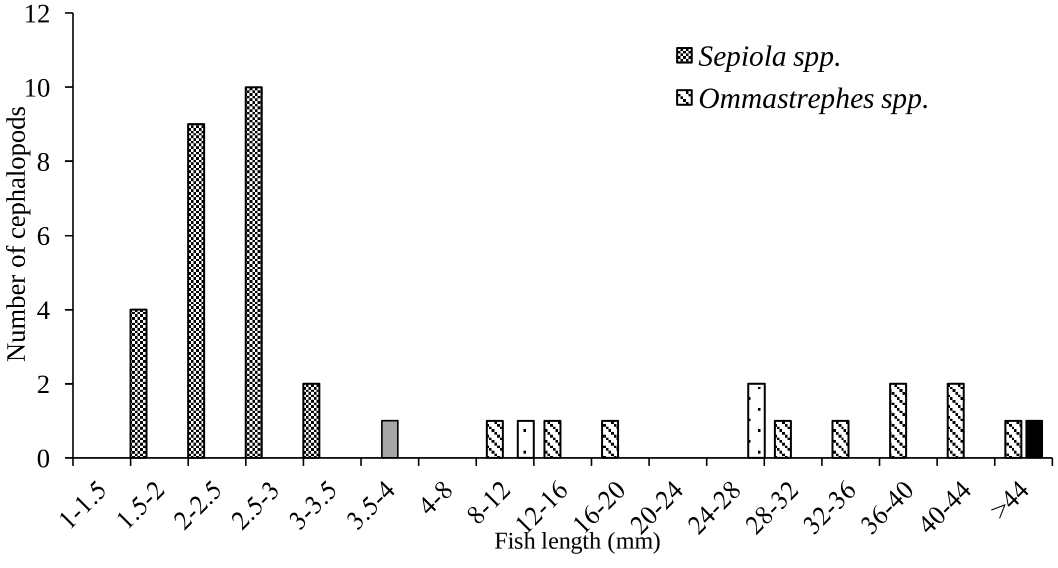

Figure 4.9. Estimated weight (g) for cephalopod prey found in Atlantic white-sided dolphin stomachs

Diet information of the Atlantic white-sided dolphin mass stranding that occurred in 1994 was reported by Rogan et al. (1997a); they found that 17 out of the 19 dolphins contained remains identified as *Trisopterus* spp., Atlantic herring, horse mackerel, an argentine (*Argentina* spp. -Linnaeus, 1758), and squid beak; also two amphipods were found in one of the stomachs. However, analysis of the other mass stranding event

Table 4.3- Prey species identified from the mass stranding of Atlantic white-sided dolphins in Kilmeena (Co. Mayo, Ireland) on the 28th October 1998 (N=5). Each prey are shown as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W) and index of relative importance (IRI). Length of prey is total length for fish and dorsal mantle length for squid (in mm).

Prey species	**Range length (mm)**	**Av.length (mm)**	**Range weight (grams)**	**Av.weight (grams)**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**
Osteichthyes										
Myctophiformes										
Notoscopelus spp.	118.9	-	24.5	-	20	1	0.63	24.5	0.27	17.9
Gadiformes										
Micromesistius poutassou	140.1-209.9	170.1	11.2-344.5	127.1	40	14	8.8	1652.4	18.1	1072.8
Merlangius merlangus	89.3-165.4	130.3	6.9-37.4	20.4	60	32	20	651.4	7.1	1627.4
M. merlangus/M. poutassou	38.5-260.3	117.1	0.6-162.0	23.1	60	24	15	532.0	5.8	1249.0
Pollachius spp	58.4	-	2.6	-	20	1	0.6	2.6	<0.0	13.1
Pollachius spp/*M .aeglefinus*	125.5-314.5	183.5	9.9-307.9	87.0	40	15	9.4	1305.2	14.3	946.0
Trisopterus esmarki	78.5	-	2.5	-	20	1	0.6	2.5	<0.0	13.1
T. luscus/T.minutus	276.7	-	269.5	-	20	1	0.6	269.5	3.0	71.4
Trisopterus spp.	29.1-141.2	69.1	0.2-51.8	22.1	60	45	28.1	766.5	8.4	2190.5
Raniceps raninus	161.00	-	62.12	-	20	1	0.6	62.12	0.7	26.1
Unidentified Gadidae	50.56-138.6	98.4	0.75-30.7	15.2	40	2	1.9	45.6	0.5	95.0
Perciformes										
Scomber scombrus	223.2-339.3	280.5	188.0-657.9	383.0	20	11	6.9	3829.6	41.9	975.1
Unidentified fish	NA	NA	NA	NA	60	9	5.6	NA	NA	NA
Cephalopods										
Unidentified squid	NA	NA	NA	NA	20	1	0.6	NA	NA	NA
Unidentified cephalopod	NA	NA	NA	NA	20	1	0.6	NA	NA	NA
TOTAL					**5**	**160**		**9144.1**		

showed that dolphins analysed were feeding mainly on Gadiformes (85.5%N, 57.9%W, 14347.5 IRI), especially on whiting/blue whiting (43.8%N, 31.0%W, 4485.7 IRI), followed by *Trisopterus* spp. (Table 4.3). Atlantic mackerel was also important in the diet of these dolphins in terms of biomass.

4.4.1.3. Annual food consumption and statistical analysis

The estimated weights of the animals used in this study ranged between 33 and 111 kg (Table 4.1). Using an average estimated weight of the dolphins in this study (67.5kg, SE=6.3), and considering the population estimation of Atlantic white-sided dolphins for the West Outer Hebrides (21,371 (CV=0.54), Macleod, 2004), the annual food consumption using the Col et al. (2012) equation was estimated to be 26,496.3 tonnes when using the average weight of the dolphins with stomach contents, however when using the proportion of prey consumption the result was 1.3 times lower in both cases (Table 4.4)

	No Weighting	E Weighting	D Weight
Whiting/blue whiting	20,220.6	11,280.9	24,949.3
Trisopterus spp.	5,329.8	7,906.6	3,052.6
Atlantic mackerel	8,527.1	9,835.6	6,475.5
Mesopelagic fish	2,142.9	4,016.0	1,921.7
Other prey	4,575.8	7,757.1	4,397.1
Total	40,796.2	40,796.2	40,796.2

Table 4.4. Annual food consumption of the main prey of Atlantic white-sided dolphin not rescaled (No weighting), after applying equal weighting (E Weighting), and after applying the weighting related to the body weight of the animal (D Weighting) (Pierce et al., 2007). Results are in tonnes.

The annual food consumption of the main prey groups (whiting/blue whiting, *Trisopterus* spp., mesopelagic fish (including silvery pout), and Atlantic mackerel) was estimated using the Pierce et al. (2007) equation (Table 4.4). Differences were found when applying both stomach weighting and dolphin weight in the equation. In the whiting/blue whiting case, equal weighting of stomachs reduced the estimation of annual food consumption, but dolphin estimated weight adjustment increased the annual food consumption. On the other hand, in the other three groups, the estimation of annual food consumption increased when equal weighting adjustment was used, but decreased when dolphin estimated weight was applied.

The amount of whiting/blue whiting fish consumed by the dolphins in this study increased at the same time that the landings for these two species increased (Fig. 4.10). The other commercial species (Atlantic mackerel) decreased, while landings showed a slow decrease over the time period for both of the commercial species groups (whiting/blue whiting and Atlantic mackerel).

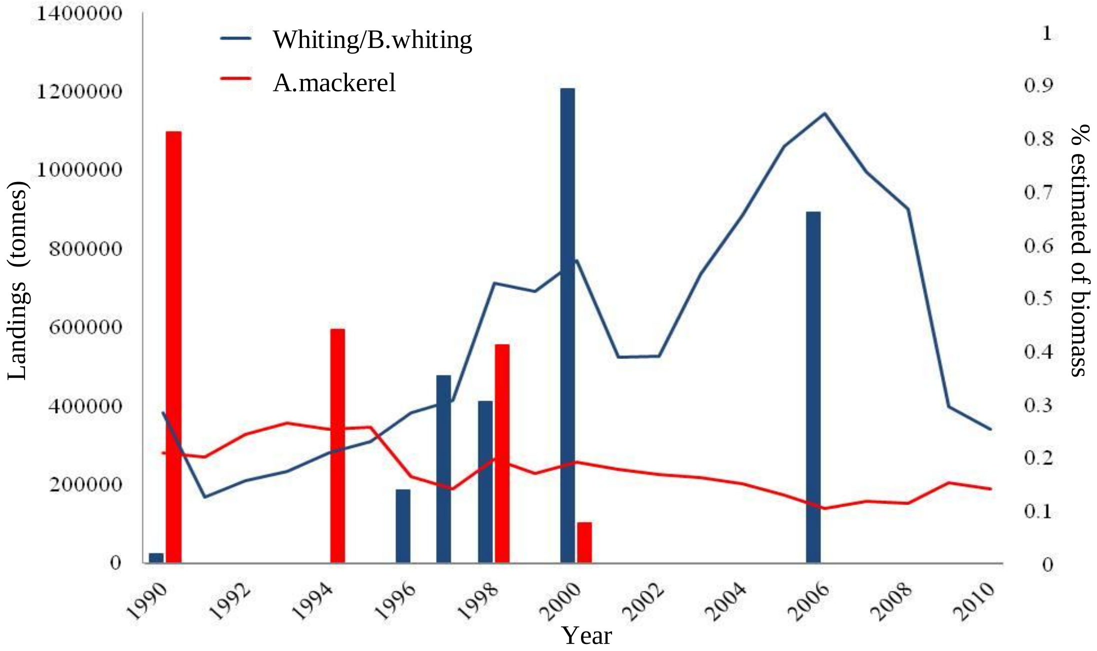

Figure 4.10. Landings (lines) and percentage of estimated biomass (columns) of the main commercial prey consumed (whiting/blue whiting and Atlantic mackerel) by Atlantic white-sided dolphins in this study. Left Y axis is landings in tonnes (FishStats+, www.ices.dk) and right Y axis is percentage of estimated biomass.

For diet comparison among the different dolphin age categories, prey was grouped by the main prey species consumed and the rest of the items were grouped as others (OTH) (Table 4.5). However, only two *Trisopterus* spp. prey were found in juvenile dolphin stomachs and in this case this prey was included within "other-OTH" group.

5 prey groups		4 prey groups	
WHX	Whiting and blue whiting	WHX	Whiting and blue whiting
TRX	All *Trisopterus* spp.	TRX	All *Trisopterus* spp.
MES	All mesopelagic fish	MAC	Atlantic Mackerel
MAC	Atlantic Mackerel	OTH	Rest of species
OTH	Rest of species		

Table 4.5. List of prey categories used in the statistical analysis

Juvenile (J) dolphins' diet was comprised mainly of whiting/blue whiting group (63.5%N), followed by mesopelagic prey (15.7%), but *Trisopterus* spp. group only made up 0.6%N of the diet of all juvenile dolphins, and Atlantic mackerel occurred in low numbers too (1.8%N). On the other hand, adults (body length over 240cm were considered- A-J and A) showed a preference for *Trisopterus* spp. (57.9%N) followed by mesopelagic fish (16.8%N), and whiting/blue whiting group (12.2%N). Atlantic mackerel prey occurred in 6.1%N of the stomachs.

A significant result was found for all comparisons carried out. Fisher Exact test showed differences in diet among the three age-group (A, J, A-J) of dolphins when using the number of prey classified in five groups (Fisher Exact, $p<0.005$) and four prey groups (Fisher Exact, $p<0.005$) (Table 4.5); similar results were found when dolphins were grouped in two age-groups ($\chi2=262.16$, $p<0.005$ using five prey categories, $\chi2=281.16$, $p<0.005$ using four prey categories). Differences between dolphin age-groups were also found when using reconstructed biomass of prey; Kruskal-Wallis test showed a significant difference between J, A, and J-A group when prey was classified in five ($H=79.46$, $p<0.005$) and four ($H=60.10$, $p<0.005$) categories; also, Mann-Whitney-U test showed a significant difference in the mean biomass of the diet for both five ($U=200750$, $p<0.005$) and four ($U=176846$, $p<0.005$) prey categories.

4.4.2. White-beaked dolphin:

A total of 33 white-beaked dolphins have been reported since 1901 stranded along the Irish coasts (Appendix IV). All dolphins were reported from the West, and North West of Ireland. A total of six dolphins were dissected by UCC staff and research students, however only three contain food remains: a pregnant female and two juvenile males (Table 4.1).

4.4.2.2. Prey identification and quantification of diet

A total of 18 prey items were found, with more than 50% of the prey items identified as horse mackerel; however, six of these were found in only one stomach (WBD 2/93, Table 4.6). In addition, two small blue whiting (<10cm of length), a large *Pollachius* spp., and a large Atlantic mackerel were found. In the stomach of the white-beaked dolphin stranded in 2004, only a squid beak and a shrimp were found (Table 4.6).

Table 4.6- Prey species found in three stomachs of white beaked-dolphins Stranded in Ireland.

Prey species	**N**	**Av.weight (grams)**	**Av.length (mm)**
Osteichthyes			
Gadiformes			
Micromesistius poutassou	2	8.24	191.04
Pollachius spp.	1	2806.19	710.54
Unidentified Gadoid	1	3.73	66.57
Perciformes			
Scomber scombrus	1	3366.39	70.56
Trachurus trachurus	9	49.25	170.40
Unidentified fish	1	NA	NA
Cephalopods			
Unidentified Cephalopod	2	NA	NA
Crustaceans			
Unidentified shrimp	1	NA	NA
Total	18	6627.81	

4.5. DISCUSSION

4.5.1 Atlantic white-sided dolphin

The feeding preferences of the Atlantic white-sided dolphin has been widely studied in the western Atlantic during the last century (e.g., Craddock et al., 2009; Gaskin, 1992; Schevill, 1956; Seltzer and Payne, 1988; Weinrich et al., 2001); however, dietary studies on the eastern populations are more recent (Canning et al., 2008; Couperus, 1997a; Das et al., 2003a, 2003b; Desportes, 1985; Evans, 1980). Although this species appears to be more abundant in European waters (MacLeod, 2004) than in North American waters (Waring et al., 2011), the preference for coastal waters by the latter might be one of the reasons (Evans, 1980) for more reported strandings in the western (Ewing et al., 2002; Waring et al., 2006, 2011; Truchon et al., 2013) than in the eastern Atlantic (CSIP reports (http://ukstrandings.org/csip-reports/); CRMM reports (http://crmm.univ-lr.fr/index.php/fr/communication/bulletins-rapports); IWC progress reports).

Most of the strandings reported in Ireland occurred during the 90s (Appendix III), where a large mass stranding involving eighteen animals (Rogan et al., 1997a) occurred. Strandings were mainly reported during March and April. It has been suggested that this dolphin species is highly affected by fisheries interactions (Couperus, 1997a; Reeves et al., 1999a; Waring et al., 1999, 2006, 2007, 2011), in particular in the Atlantic mackerel and horse mackerel fishery (Berrow and Rogan, 1997; Couperus, 1997a; Morizur et al., 1999), as well as for the fishery targeting sardine species (Morizur and Antoine, 2003). In Irish waters, Atlantic mackerel, horse mackerel and blue whiting fisheries operate during the late winter and spring months, and almost 60% of the dolphins reported with signs of incidental capture were stranded during the months of March and April.

Dietary insights into the east Atlantic white-sided dolphin are scarce, and the only information about this species in Ireland has been reported by Rogan et al. (1997a), from the mass stranding in Killala Bay (Co. Mayo) in 1994, and Berrow and Stark (1990). Rogan et al. (1997a) reported that the main species were *Trisopterus* spp., but also Atlantic herring and horse mackerel remains were found. In contrast, Berrow and Stark (1990) indicated that one of the dolphins that stranded in Omey Island (Co. Galway) was feeding recently on Atlantic mackerel. Most of the dolphins studied contained *Trisopterus* spp., whiting/blue whiting, and Atlantic mackerel within their main prey. *Trisopterus* spp. has been found as an important prey item in a number of different difference marine mammal species around Ireland (Chapter 3, 5 and 6; Kavanagh et al. 2010; Gosch et al., 2014).

Within the three *Trisopterus* species, Norway pout is the smaller species and the only one that usually feeds within the pelagic ecosystem (Cohen et al. 1990), while the other two (Poor cod and Bib) are usually benthic feeders and also gregarious (Cohen et al. 1990). Atlantic white-sided dolphin are usually distributed along the continental shelf in Ireland (CODA, 2009; Ó Cadhla et al., 2004; Hammond et al., 2013; Wall et al., 2013); furthermore, most of the *Trisopterus* spp. prey found within the stomachs were smaller than 10cm length (after applying the digestive correction factors); these two circumstances indicate that the main *Trisopterus* spp. occurring was probably Norway pout. Norway pout is considered to be an important fish for a number of marine vertebrates (e.g., Brown and Pierce, 1998; Hammond et al., 1994; Santos et al., 2004), and fisheries exist for this species in the North of the North Sea (ICES, 2012a). In Ireland, a large amount of *Trisopterus* spp. was reported by Rogan and Berrow (1996) in the diet of harbour porpoises; however, there is not a specific fishery targeting this group of fish.

Whiting and blue whiting species are hard to identify when their otoliths are broken or eroded, and in many cases they have to be grouped together (e.g., Santos et al. 2001c, 2007). Although only 13% of the otoliths within this group were difficult to identify to species taxonomic level, the presence of either whiting or blue whiting within each stomach was not enough to assume which of the species was present, with the exception of the stranded dolphin WSD 1/00, where blue whiting was identified in 159 out of 168 remains and no whiting remains were found. This dolphin was also found with a rope around its tail, and the cause of death was reported to be due to incidental capture. It is interesting to draw attention to the differences in diet between those animals stranded in the North Sea and those outside the North Sea; in the former area Atlantic white-sided dolphins have been reported to feed mainly on whiting, while outside the North Sea blue whiting seemed to be the main prey item (Evans, 1980; ASCOBANS). Blue whiting is distributed mainly along the continental shelf in the Eastern North Atlantic (O'Donnell et al., 2011) and overlaps with Atlantic white-sided dolphin distribution (CODA, 2009; Hammond et al., 2013; Ó Cadhla et al., 2004; Wall et al., 2013); however, in the North Sea there are no large aggregations of blue whiting and whiting seems to be specially aggregated in some areas where studies have been carried out (Loots et al., 2010). Couperus (1997b) and Desportes (1985) found that blue whiting was the main prey item in stomachs of by caught dolphins south west Ireland and stranded dolphins around the Bay of Biscay, respectively. It is probable that Atlantic white-sided dolphins along the Irish coasts might feed on blue whiting rather than whiting, as the former is a high abundance pelagic species in the area with higher energy content (Spitz et al. 2010).

Some studies have reported that Atlantic white-sided dolphins also feed on Atlantic mackerel, horse mackerel, and Clupeoids (Jonsgård and Nordli, 1952; Berrow and Stark, 1990; Couperus, 1997a; Morizur et al., 1999; Morizur and Antoine, 2003). Atlantic mackerel is a gregarious pelagic fish species (Collette and Nauen, 1983) widely distributed along the continental shelf and slopes of Irish waters (Reid et al., 1997), overlapping with the distribution of the Atlantic white-sided dolphin population. Couperus (1997a) suggested that Atlantic white-sided dolphins might be attracted by schools of Atlantic mackerel, however his study was based on by caught dolphins in the Atlantic mackerel and horse mackerel fishery operating South West of Ireland.

Most of the dolphins in this study presented with whiting/blue whiting and mackerel in their stomachs, but only one of the dolphins stranded within the months that those fisheries were operating: 97% of the diet of that animal comprised whiting/blue whiting group and Atlantic mackerel prey. Berrow and Stark (1990) also reported a white sided dolphin that stranded in March 1990 to be feeding on Atlantic mackerel with an average size of 35.3cm. Low numbers of by caught Atlantic white sided dolphins has been reported in the summer fisheries targeting albacore tuna (Rogan and Mackey, 2007). Albacore tuna feeds mainly on Atlantic saury (*Scomberesox saurus*, Walbaum 1792), mesopelagic fish, and blue whiting (Goñi et al., 2011; Pusineri et al., 2005), and Atlantic white-sided dolphins caught in those fisheries might be targeting the same prey.

The forth main group of prey found in the diet was made up of mesopelagic fish, including silvery pout. It is not surprising that this species is feeding on deep offshore prey with nycthemeral behaviour. Das et al. (2003a) indicated using stable isotope analysis that Atlantic white-sided dolphin in Ireland showed a preference for an offshore diet, and mesopelagic fish, blue whiting and mackerel are usually found offshore, in deeper waters.

In general, most of the blue whiting and Atlantic mackerel identified were estimated to be over the minimum landing size (MLS, www.ices.dk) (85% and 95% respectively). However, only 15% of the whiting was estimated to be larger than the MLS. *Trisopterus* spp. does not have a minimum landing size in the area, and it was found that 85% of this type of prey was smaller than the maturity length of any of the three species.

Digestive coefficient factors have been developed for diet studies (Grellier and Hammond, 2006 and Tollit et al., 1997) based on pinnipeds scats, as the degree of erosion of otoliths is usually high once the remains pass through the whole digestive system. When diet studies are carried out analysing stomach contents, otoliths and bones might be in good condition and the use of digestion coefficient factors may not be necessary. However, otoliths found within the digestive tracts of Atlantic white-sided dolphins and white-beaked dolphins stranded in Ireland were highly eroded; therefore digestion coefficient factors were applied to estimate size and weight of the prey ingested. The digestive coefficient factors given in Grellier and Hammond (2006) were applied, as they gave values for most of the prey found within these species' diet. The identification of bones improves the findings of the diet of the animals (e.g., Fernandez et al., 2009; Gosch et al., 2014; Hernandez-Milian and Rogan, 2011; Santos et al.; 2007); however, the application of digestive coefficient factors to bones over-estimates both the size and biomass (Bowen, 2000) and therefore these were not applied to bones. When both bones and otoliths from the same prey species were identified within the same sample and the bones were much eroded, otoliths were chosen to reconstruct the diet.

Food consumption studies are a good tool to use to examine the potential relationships between marine mammals and fisheries. A number of models for the estimation of annual food consumption have been developed (e.g., Antonelis and Perez, 1984; Col et al., 2012; Pierce et al., 2007; Trites et al., 1997). Most of the models require similar information; however, Col et al. (2012) included a residential population coefficient that should be considered for those species that are less migratory. A recent study on Atlantic white-sided dolphin population structure (Banguera-Hinestroza et al., 2014), found that both the western Atlantic and the westernmost European populations did not show genetical differences suggesting a certain degree of connectivity between both sides of the Atlantic; therefore, the residential ratio applied to the western populations was used in this study also. The annual food consumption using the Col et al. (2012) equation resulted in an estimate that was 1.3 times lower than the sum of the annual consumption estimated using the Pierce et al. (2007) equation. The residential ratio for the eastern populations has not been independently calculated and it could be higher than the one given by Col et al. (2012). Applying a residential value of 0.90 (similar to common dolphins), the estimation of annual consumption increases the food consumption provided by the other models. Although Col et al. (2012) is a simple model that can be used when diet information of marine mammals is not available in the area, a more realistic approach is to use models that include diet information. However, diet information is usually obtained from animals stranded or incidentally captured in fishing nets, depending on the type of animals (age, sex, area) being studied. Caution should be taken when using the Pierce et al. (2007) approach using equal weighting and dolphin weight adjustments as information about the population structure in Irish waters is lacking; the implementation of a residency ratio in their equation might give a better idea of the annual consumption of marine mammals, in particular of those fish species that fisheries are also targeting.

It is interesting that the percentage of *Trisopterus* spp., Atlantic mackerel, and mesopelagic fish increased when the equal weighting adjustment was applied, while the whiting/blue whiting group showed a decrease. This may be a reflection of a larger diverse diet of dolphins that feed on whiting/blue whiting, while those dolphins feeding on other prey were found to prey on a lower diversity of species and might be species-specific feeders. Some studies indicate that some individual and/or group feeding specializations may occur in some dolphin species (e.g., Jansen et al., 2010; Mann et al. 2008; Patterson, 2012; Pusineri et al., 2007); it is possible that some of the animals tend to feed in particular prey depending on the age, as was found in white-beaked dolphins in the North Sea by Jansen et al. (2010). Further research on the diet of this species is necessary, combining stable isotopes, fatty acid analysis, and stomach content analysis to further investigate feeding specializations.

There are two peaks in blue whiting fisheries landings during the study period, coincident with the times when more whiting/blue whiting prey were prevalent in dolphin’s stomachs. The peak in 2000 corresponds with the juvenile dolphin considered by caught, while the 2006 dolphin did not have any evidence of incidental capture. By catch of Atlantic white-sided dolphin within the blue whiting fishery has only been reported by Couperus (1997b), and only one animal was involved. In contrast, Atlantic mackerel show a decreasing trend over the time and mackerel in the diet only occurred in one stomach after 2000 (it is not shown in the figure as it was not possible to estimate its size as the otolith was broken), likely reflecting decreasing prey availability.

Despite the low sample size, significant differences were found for the different “age” categories in this study. This result should not be surprising as in other dolphin species feeding partitioning exists (e.g., Jansen et al., 2010; Santos, 1998; Santos et al., 2007). These differences are due to a higher incidence of Atlantic mackerel and *Trisopterus* spp. in adult dolphins (A and A-J), while cephalopods occurred mainly in juvenile/immature dolphins. Juvenile/immature dolphins (J) have a higher energy requirement than adults, however in our study adults were feeding on prey with high energy content such as Atlantic mackerel. On the other hand, the average number of prey items ingested by juveniles was much higher (55.3 prey) than in adults (39.5 prey), and the juvenile group might be feeding on more prey to obtain the necessary energy for their metabolism. However, the sample size of this study is very low, and a larger sample size is necessary, as well as information from other techniques, such as stable isotopes and fatty acid analysis, to confirm these results.

4.5.2 White-beaked dolphin

The white-beaked dolphin is scarce in Irish waters (Northridge et al., 1997; Wall et al., 2013), and strandings are very rare (Appendix IV). It is interesting that the majority of the dolphins were immature, possibly reflecting a dispersion of juveniles out of their normal distributional range.

White-beaked dolphin diet has been extensively studied elsewhere (e.g., Canning et al., 2008; Fall, 2011; Jansen et al., 2010; Reeves et al., 1999a and references therein). Most of the information about the diet of this species indicates a preference for Gadiformes prey, although other prey items were also identified such as cephalopods, Atlantic mackerel and flatfish (Reeves et al., 1999b and references there in). Fall (2011) found that white-beaked dolphins in the Barents Sea were associated with blue whiting, cod and capelin (*Mallotus villosus*, Müller 1776). Horse mackerel was only identified in small numbers in dolphins stranded in Scotland (Canning et al., 2008), and both of the dolphins in this study contained a high percentage of this prey in their stomachs. At the time of these strandings, the horse mackerel fishery was operating, and one of the dolphins (WBD 1/96, Table 4.1) presented evidence of incidental capture; the main prey of this dolphin was horse mackerel (66.6% of the prey). Although white-beaked dolphins showed a preference for gadoids, some differences might occur depending on the areas and the availability of particular prey (Canning et al., 2008; Jansen et al., 2010); this may explain why these two dolphins were mainly feeding on horse mackerel. The low percentage of recovery of this species in Ireland (only 4% of animals were recovered for post mortem examination) makes it difficult to investigate their feeding behaviour. However, this species was also reported to be affected by different gillnet fisheries (Read, 1994), and interactions between this fisheries and white-beaked dolphin will be worthy of investigations, such as those targeting mixed demersal fisheries.

Further studies are necessary to understand the ecology of the white-beaked dolphin in Irish waters. Both the collection of stomach contents and biopsy sampling will be important tools to describe the diet of this species.

Chapter 5

FORAGING ECOLOGY OF BOTTLENOSE DOLPHIN

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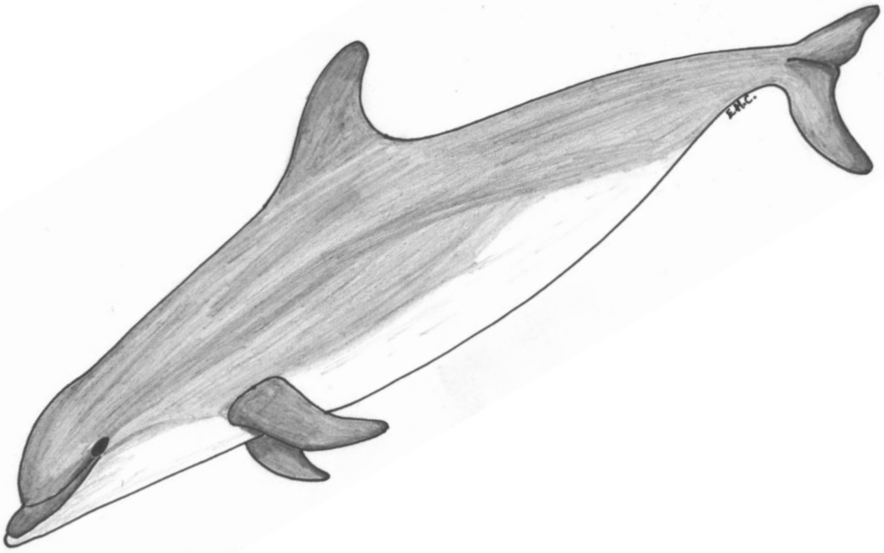


CHAPTER 5

FORAGING ECOLOGY OF BOTTLENOSE DOLPHIN IN IRISH WATERS

5.3 Material and Methods

5.4 Results

5.1 ABSTRACT

The stomach contents of eleven Bottlenose dolphins (*Tursiops truncatus*) stranded in Ireland and one incidentally caught in fishing nets were examined. Ten of the eleven samples originated from dolphins that stranded on the west coast between 1999 and 2012 while the remaining dolphin was caught in a drift net targeting albacore tuna. Ten of the stomachs examined contained food remains, mainly fish bones and otoliths but cephalopod and crustacean remains were also found. The main prey items identified from the stomach contents were gadoid fish of the haddock-pollack-saithe group, followed by whiting-blue whiting and *Trisopterus* spp. A total of 37 prey taxa were identified from the stomachs suggesting that bottlenose dolphins have a broad diet in this region. Some of the animals were genetically assigned to a distinct population of unknown geographic origin; their stomach contents suggest that these animals might be foraging on the continental shelf and close to the shelf edge. Significant differences were found in the stomach contents of dolphins that had stranded alive when compared with those that were found dead, with the former feeding more on pelagic species. Differences were also found in the diet between male and female dolphins, males consumed a wider variety of prey items than females. Annual consumption rates for the coastal bottlenose dolphin population in Irish waters are estimated to be around 1,190 metric tonnes.

5.2 INTRODUCTION

The Bottlenose dolphin (*Tursiops truncatus*, Montagu1821) is considered one of the most cosmopolitan marine mammal species, distributed in all temperate and tropical waters around the world, in both neritic and pelagic zones (Caldwell and Caldwell 1972; Hammond et al. 2012; Fig. 5.1). Most of the bottlenose dolphin population studies are concentrated in coastal waters. However, offshore/pelagic populations also occur, and in the North West Atlantic differences between inshore and offshore/pelagic dolphins have been recorded based on morphology, genetic structure, trophic ecology and behaviour (Hoelzel et al., 1998; Jefferson et al., 2008; Natoli et al., 2005; Wells and Scott, 1999).

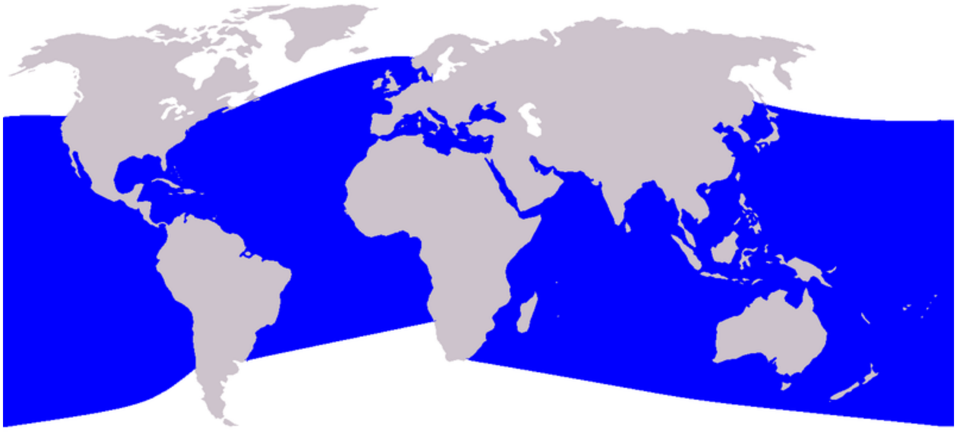


Figure 5.1. Adapted from the Wikimedia Commons file "Image: Cetacean range map Bottlenose Dolphin.png". http://commons.wikimedia.org/wiki/File:Cetacea_range_map_Bottlenose_Dolphin.png

In the North East Atlantic, two multinational dedicated sighting surveys SCANS-II (Hammond et al., 2013) and CODA (CODA, 2009), have recently been carried out and have provided abundance estimates and distribution data of bottlenose dolphins for the shelf waters and oceanic region, respectively. In addition, year-round sightings and photo-identification studies have helped to identify residential coastal groups, and in some cases local abundance has been estimated. In Europe, one such group has been described in the Moray Firth, Scotland (Wilson et al., 1997) and further resident groups have been described in Ireland in the Shannon Estuary (Ingram, 2000), the Galician Rías (NW Spain) (Fernández et al., 2011b) and the Sado Estuary in Portugal (Harzen, 1998). Although in European waters no morphological differences between "coastal" and "offshore populations" have been reported, some genetic and diet differences have been reported (Fernandez, et al. 2010; Hoelzel et al., 1998; Louis et al., 2014; Natoli et al., 2005).

In Ireland, this species is mainly concentrated along the west (Englund et al., 2007; Ingram et al., 2001; O'Brien et al., 2009) and south coasts (Berrow et al. 1996, 2012; Ingram and Rogan 2003; Wall and Murray, 2009), but has also been reported in more offshore waters (Hammond et al., 2013; Wilson and Berrow 2006). In the Irish Sea, bottlenose dolphins mainly inhabit Cardigan Bay (Evans et al., 2003), although there has been an increase in sightings along the Irish coast possibly suggesting a change in habitat use (www.iwdg.ie). A study on population structure of bottlenose dolphins in Ireland suggested the presence of at least three genetically distinct populations (Mirimin et al., 2011). The most studied population inhabits the outer Shannon estuary and Cork Harbour, with a total estimation of 120-130 individuals in the Shannon estuary (Ingram, 2000; Berrow et al., 2012). The second population is formed by dolphins that seem to range more widely, using a large, but as yet undetermined stretch of the coast, including areas off Connemara (Galway) and Mayo but also showing some site fidelity (Fig 5.2, Ingram et al., 2009). Photo-identification studies have been able to match individuals sighted both in Ireland and Scotland (O'Brien et al., 2009; Robinson et al., 2012) and Ireland and Cornwall (Ryan et al., 2010), suggesting that some of these animals range widely and are likely part of the "inshore" population described by Louis et al. (2014).

The third population (of unknown origin) is only known from stranded individuals (Fig 5.2, Mirimin et al., 2011), and is characterised by high genetic variability suggesting that they may be part of a wider ranging "pelagic" population, possibly with an offshore distribution. In addition, Parsons et al. (2002) found more genetic similarities between Moray Firth and Cardigan Bay bottlenose dolphin populations than with animals on the West Scotland. A recent study by Louis et al. (2014) suggested that there may be two ecotypes in the North East Atlantic bottlenose dolphin, one with a coastal distribution and another one more pelagic.

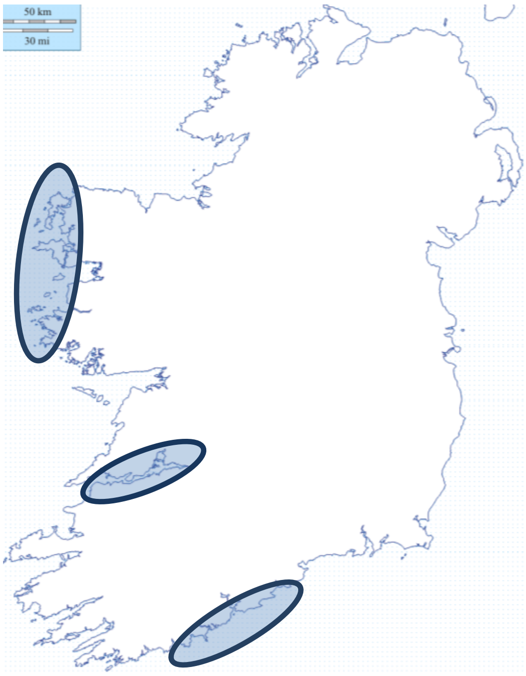


Figure 5.2. Location of the sampling sites of the coastal bottlenose dolphin populations (after Mirimin et al., 2011)

Although this species is relatively accessible because of the partially coastal distribution and site fidelity, the trophic ecology of the bottlenose dolphin is still difficult to study; biopsy samples for stable isotopes analysis, for example, requires expertise and expensive resources (e.g., boats). On the other hand, stomach content analysis from stranded dolphins requires long time periods of collecting animals. Strandings of this species rarely occur and when the animals appear they are usually in an advanced decomposition level, and samples are not suitable for further analysis. Information on the diet of bottlenose dolphins in the NE Atlantic has been mainly obtained by the examination of stomach contents of stranded and by-caught individuals with data available from Scotland (Santos et al., 2001c), NW Spain (Santos et al., 2007) and France (De Pierrepont et al., 2005; Spitz et al., 2006b). Only a few notes on bottlenose dolphin diet have been published on individual animals stranded in Ireland (Hernandez-Milian and Rogan, 2011; Nash, 1974; O'Brien and Berrow, 2006). In general, results from these studies indicate a broad diet with many demersal and pelagic prey items as described in the diet of the species along the Atlantic coasts of Scotland, France and Spain.

Stable isotope analyses have also been used to investigate feeding ecology and habitat use of this species in the NE Atlantic (Fernández et al., 2011; Mendez-Fernandez et al., 2012; Rogan et al., 2011). Results from the combined approach of genetic, stable isotope and stomach contents analysis carried out by Fernández et al. (2011b) confirmed the existence of bottlenose dolphin population structuring in Galicia (NW Spain).

Bottlenose dolphins in Ireland are protected under the Wildlife Act (1976) and amendments and they are also listed under Annex II of the EU Habitats Directive. This Directive requires Member States to designated Special Areas of Conservation (SAC) for the species and assesses the species status based on the best available information. Improving our knowledge of the feeding ecology of a species/population can help us to understand its ecological requirements and inform conservation efforts and future management plans.

The aim of this chapter is to describe the feeding ecology of bottlenose dolphins stranded in Ireland and to try to identify the diet of the third population identified in Mirimim et al. (2011). Also, the annual food consumption of the species is estimated in order to investigate the potential interactions with fisheries and examine the food requirements of this species. This information is also used in a mass-balance model (Ecopath) of the Irish Sea and is used to examine prey overlap with other marine mammal species (Chapter 7).

5.3 MATERIAL AND METHODS

5.3.1 Study area and sample composition

Stranded bottlenose dolphins in Ireland have been recorded systematically for over 150 years (Appendix V). Dolphins were measured, sexed and dissected, following the standard protocol of the European Cetacean Society (Kuiken and García-Hartmann, 1993). From 1999 to 2011 only five males and five females stranded in reasonable condition, to obtain the digestive tracts, along the South West, West and North West coasts of Ireland (Fig. 5.3, Table 5.1). In addition, three bottlenose dolphin carcasses were by caught (Table 5.1, Appendix V) in drift nets targeting albacore tuna (*Thunnus alalunga*, Bonnaterre 1788), but the digestive tract of only one of them was recovered. Digestive tracts were analysed following the methodology presented in the Chapter 2.

Five of the individuals sampled were characterised genetically in a former study (see Mirimin et al. 2011) as belonging to the "3rd population" of unknown origin and one was assigned to the Shannon/Cork population (Table 5.1).

Figure 5.3. Map showing the locations of stranded and by-caught bottlenose dolphins used in this study. Two females stranded on the same beach

Table 5.1-. Data on stranded and by-caught bottlenose dolphins in Ireland for which stomach contents were analysed (N=11); # indicates live strandings.ST = 3^{rd} population of unknown origin, SH = Shannon (from Mirimin et al., 2011) and * stable isotope samples, ND = not determined, BY = By-caught. Season: W: Winter, Sp: Spring, S: Summer, A: Autumn. Estimated dolphin weight was calculated using Kastelein et al. (2002) formula (Chapter 2). HAD/POL/POK: haddock/pollack/saithe; WHG/WHB: whiting-blue whiting; TRX: *Trisopterus* spp.; HKE: European hake; HOM: horse mackerel; FLX: flatfish; COE: conger eel; SCL: *Scyliorhinus* spp.; PSQD: pelagic squid (*Teuthowenia megalops* and *Brachioteuthis* spp). § In this animal only there were only two otoliths of European hake. BND 1/01 & BND 2/01 did not present prey items in their guts.

Code	Pop.	Year	Season	Sex	Length (cm)	Estimated weight (kg)	Location of stranding	Size of the main prey (minimum and maximum total length, mm)								
								HAD/POL/POK	WHG/WHB	TRX	HKE	HOM	FLX	COE	SCL	PSQD
BND 1/99#	ST	1999	W	Male	309	396.8	Ballydonegan Co. Cork	-	-	-	-	-	-	-	-	60-168 (N=32)
BND 2/99	ND*	1999	S	Male	330	543.7	Lahinch Co.Clare	568	173-298 (N=3)	59-240 (N=7)	-	183-202 (N=2)	170-433 (N=12)	479-673 (N=11)	380-570 (N=12)	58-73 (N=4)
BND 1/01#	ST	2001	S	Male	340	631.7	L. Swilly Co.Donegal	-	-	-	-	-	-	-	-	-
BND 2/01	SH*	2001	S	Female	320	467.9	Doonbeg Co.Clare	-	-	-	-	-	-	-	-	-
BND 3/01	ST	2001	A	Female	288	289.6	Ventry Co.Kerry	339-1,143 (N=38)	176-699 (N=6)	122-136 (N=2)	765-1,262 (N=12)	188-350 (N=29)	380	-	-	-
BND 1/02	ND	2002	S	Female	280	256.8	Doonbeg Co.Clare	-	194-269 (N=3)	-	-	-	-	-	-	-
BND 1/05	ST*	2005	S	Female	287	285.3	Doonbeg Co.Clare	580	-	268-495 (N=11)	319-560 (N=3)	101-366 (N=6)	242	-	-	-
BND 2664#	ND	2005	Sp	Male	295	321.7	Aran Islands Co.Galway	133-518 (N=14)	102-216 (N=13)	-	-	-	-	-	-	-
BND 3241#	ST	2008	A	Male	310	402.8	Rossaveel Co.Galway	342-921 (N=4)	115-223 (N=26)	78-321 (N=10)	688	-	92	656-701 (N=4)	-	-
BND 3617§		2011	Sp	Female	300	346.7	Kilkee, Co. Clare	-	-	-	623-711 (N=2)	-	-	-	-	-
BND 1/12#	ST	2012	Sp	Female	280	256.8	Pilmore Co. Cork	380	513-561 (N=2)	-	390-672 (N=9)	189	-	-	-	-
JB T3H6 (BND 1/96)	BY*	1996	S	Female	-	-	51 18 99N 13 01 38W	-	-	-		-	-	-	-	38 (N=1)

5.3.2 Prey identification and quantification of diet

Identification of all fish, cephalopod and crustacean prey remains was carried out following the methodology described in Chapter 2 (Section 2.3.2).

During the digestion process, prey remains suffer different degrees of erosion depending on the type and robustness of the structure (see Tollit et al. 1997 and Grellier and Hammond 2006); digestion coefficient factors were therefore applied when necessary as described in Chapter 2 (Section 2.3.3).

Although digestion coefficient factors were only applied to otoliths, those digestion coefficient factors published by both Tollit et al. (1997) and Grellier and Hammond (2006) were applied to investigate if these coefficient factors significantly increased the total biomass consumed, and to examine the differences in both factors using Wilcoxon Signed Rank test (R Statistical Software, www.r-project.org). No digestion coefficient factors were applied to bones, as bones recovered from the stomachs were in relatively good condition.

The importance of individual prey species/taxa in each stomach was evaluated in terms of presence/absence (%F), number (%N) and summed estimated weight (%W).

5.3.3. Annual food consumption and statistical analysis

The annual food consumption was primarily estimated using the Col et al. (2012) equation (eq. 2.5 in Chapter 2), and the Pierce et al. (2007) equation (eq. 2.12 in Chapter 2). The number of bottlenose dolphins (N) in the area (Block R, Fig 1.2a) was estimated to be 313 (CV=0.81) dolphins (Hammond et al., 2013). Average adult body mass for the species has been reported to be between 220-500kg (www.cms.int); the average weight (360kg) was used to estimate the annual food consumption using the Col et al. (2012) equation (eq. 2.5 in Chapter 2). The annual food consumption was also estimated using the average weight of stranded dolphins in Ireland and the dolphins estimated body weight used in the dietary analysis (Appendix V). Comparisons between the two estimations were carried out.

Comparison of food consumption and average landings during the study period of the main prey groups were investigated. Landings data were obtained from ICES (www.ices.dk) for the ICES sub-division VIIb, VIIg and VIIj2, in the FAO area 27 (Fig. 1.16). Landings information for the Gadidae species were grouped together in the same way as was done in the diet analysis. All flatfish were grouped together, as were the cephalopods.

Live strandings may occur when an animal is disorientated or sick and possibly not familiar with the coastal area, while the dead strandings are likely to be from coastal animals (Simmonds, 1997). Comparison of the main prey items found in the diet between dolphins stranded alive and dolphins considered stranded dead and between sexes were investigated using Chi-square tests. Other comparisons such as among seasons and between areas were not carried out due to the small sample size. All analyses were carried out using R Statistical Software (www.r-project.org).

5.4. RESULTS

5.4.1. Study area and sample composition

Strandings of bottlenose dolphins in Ireland are infrequent, with a total of 90 animals being recorded in the period ranging from 1999 to 2011 (Appendix V). Only 13% (n=12) of the reported carcasses were recovered for post-mortem examination.

In total, five animals stranded alive, six stranded dead and one was by-caught. Five of the eleven dolphins studied were males while seven were females. However, only digestive tracts of ten out of twelve bottlenose dolphins analysed contained prey items (Fig. 5.1). Half of the dolphins with food contents stranded alive and four were male. Length of the animals ranged from 295 to 340 cm in males and 280 to 320 cm in females. The two dolphins that presented with empty stomachs were the largest male (340cm) and female (320cm), and the latter was genetically assigned to the Shannon population. Only one of the bottlenose dolphins was recovered from the north west of Ireland, the remainder stranded in the west or south west of the country.

5.4.2. Prey identification and quantification of diet

Three hundred and thirty three prey items were identified from the digestive tracts examined, with 96.4% of all items being identified to at least genus level (Table 5.2). The number of fish identified using both bones and otoliths was 8.2% higher than using otoliths alone, and four species (*Scyliorhinus* spp. (Blainville, 1816), salmon (*Salmo salar*, Linnaeus 1758), rockling (*Phycis* spp., Walbaum 1792) and ling (*Molva molva*, Linnaeus 1758) were identified using other skeletal structures. Fish occurred in 88.9% of the stomachs, but made up 82.4% of the diet by number and 98.9% by weight. At least 26 fish taxa were identified belonging to 22 families; Gadiformes species comprised 54.1% by number (76.8% by weight, n=187), flatfish made up 4.3% by number (0.9% by weight, n=15), dogfish (*Scyliorhinus* spp.) and conger eel (*Conger conger*, Linnaeus 1758) made up 3.5% by number (1.1% by weight, n=12) and 4.3% by number (16.0% by weight, n=15), respectively; horse mackerel (*Trachurus trachurus*, Linnaeus 1758) made up 12.4% by number (2.0% by weight, n=41) (Table 5.2).

Table 5.2- Prey species identified from stranded and by-caught bottlenose dolphins in Irish coasts and waters (N=9). Each prey are shown as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W), and index of relative importance (IRI) and re-scaled to a maximum value of 100. Length of prey is total length for fish and dorsal mantle length for squid.

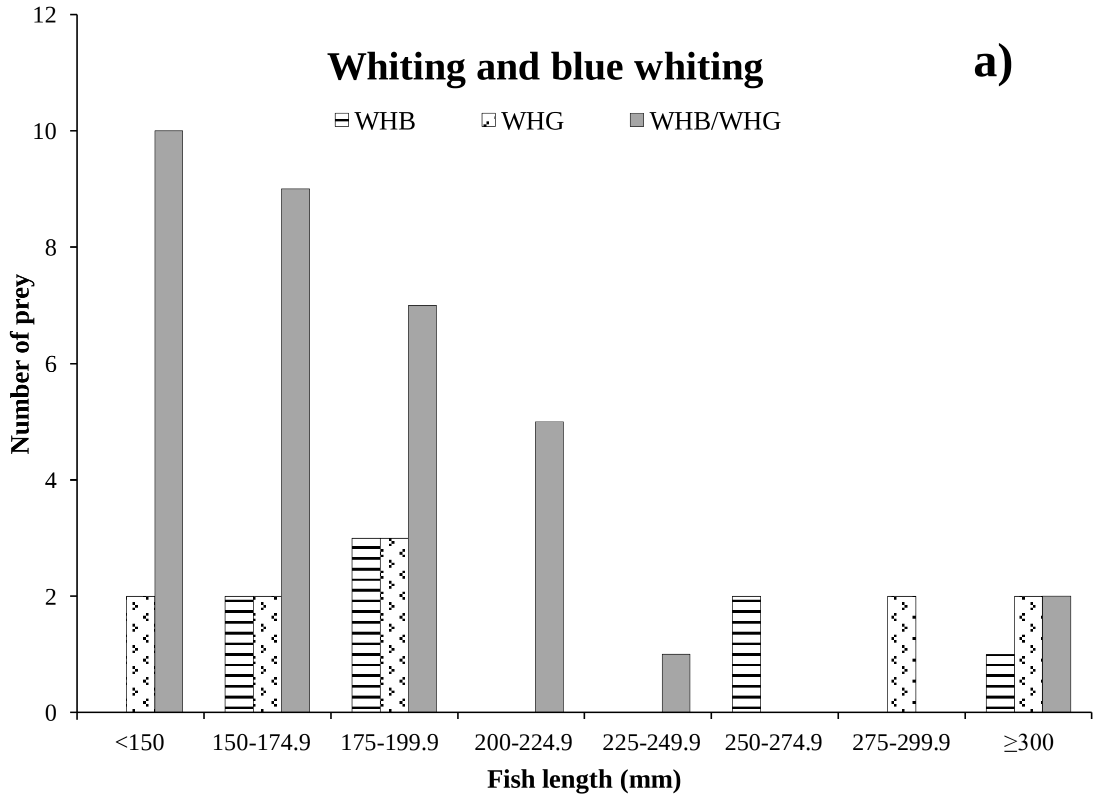
Prey species	**Range length (mm)**	**Av.length (mm)**	**Range weight (grams)**	**Av.weight (grams)**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**
Chondrichthyes										
Scyliorhinus spp.	380.2-570.0	465.3	188.1-641.4	358.1	10	12	3.5	4,297.1	1.1	45.3
Egg capsule of *Scylorhinus* spp.	53.0	NA	NA	NA	10	1	0.3	NA	NA	NA
Osteichthyes										
Anguilliformes										
Unidentified Eel	570.3	NA	290.5	NA	10	1	0.3	290.5	3.6	5.3
Conger conger	478.8-700.7	603.3	3,428.4-5,017.4	4,319.9	20	15	4.3	64,798.0	16.0	406.0
Salmoniformes										
Salmon salar	521.4-574.7	548.0	1,542.7-2,125.9	1,834.3	10	2	0.6	3,668.6	0.9	14.8
Gadiformes										
Micromesistius poutassou	173.3-414.5	229.3	173.3-4,958.5	1,085.2	30	8	2.3	8,681.3	2.1	133.5
Merlangius merlangus	118.7-699.2	271.6	16.0-4,051.8	552.0	30	11	3.2	6,071.9	1.5	140.3
M. merlangus/M. poutassou	102.0-561.4	188.1	9.7-1,583.6	104.2	30	34	9.8	3,542.2	0.9	321.0
Melanogrammus aeglefinus	339.0-698.0	467.5	385.9-4,262.1	1,267.5	30	17	4.9	21.547.1	5.3	306.6
Pollachius virens	594.4-1,142.7	808.5	1,659.7-11,353.5	4,562.3	10	11	3.2	50,185.1	12.4	155.4
P. pollachius	424.0-1,040.6	712.2	698.0-11,953.4	4,745.2	20	11	3.2	52,196.9	12.9	320.8
Pollachius spp	342.2-921.3	544.0	390.7-6,424.0	1,971.6	20	6	1.7	11,829.5	2.9	93.0
Pollachius spp/*M .aeglefinus*	133.2-629.4	292.6	27.1-2,188.1	495.5	10	14	4.1	6,936.9	1.7	57.6
Trisopterus esmarki	58.6-94.5	73.4	1.0-4.0	2.1	10	3	0.9	6.3	0.0*	8.7
T. luscus	197.0-320.6	243.8	85.7-491.0	210.3	2	6	1.7	1,261.9	0.3	40.9
Trisopterus spp.	78.9-495.2	211.0	3.2-1,642.1	238.2	30	21	6.1	4,287.5	1.1	213.8
Gadiculus argenteus thori	59.7-123.8	96.5	2.9-18.1	10.1	10	3	0.9	30.4	0.0*	8.8
Unidentified Gadidae	217.8-283.6	250.7	112.4-240.3	176.4	30	3	0.9	352.7	0.1	28.6
Phycis spp.	287.3	287.3	249.3	249.3	10	2	0.6	498.6	0.1	7.0
Molva molva§	248.8-1,814.2	673.3	125.5-50,690.7	6,307.4	40	10	2.9	63,074.1	15.5	737.1
Merluccius merluccius	319.2-1,262.1	706.4	234.3-12,854.4	3,012.3	30	27	7.8	81,332.0	20.0	1,391.9

Table 5.2 Cont.	**Range length**	**Av.length**	**Range weight**	**Av.weight**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**
Perciformes										
Trachurus trachurus	101.0-366.2	257.3	6.9-481.7	188.3	40	43	12.4	7,908.2	2.0	575.0
Scomber scombrus	655.0	655.0	4,586.1	4,586.1	10	1	0.3	4,586.1	1.1	14.2
Unidentified Gobiidae	70.9	70.9	3.3	3.3	10	1	0.3	3.3	0.0*	2.9
Atheriniformes										
Atherina presbyter	126.4	126.4	13.1	13.1	10	1	0.3	13.1	0.0*	2.9
Myctophiformes										
Unidentified Myctophidae	62.9	62.9	27.0	27.0	10	1	0.3	27.0	0.0*	3.0
Pleuronectiformes										
Platichthys flesus	171.4-417.0	323.1	110.7-636.1	416.8	20	3	0.9	1,250.5	0.3	23.5
Pleuronectes platessa	439.2	439.2	995.0	995.0	10	1	0.3	995.0	0.3	5.3
Limanda limanda	242.3	242.3	144.3	144.3	10	1	0.3	144.3	0.0*	3.3
Hippoglossoides platessoides	91.5-307.8	222.8	4.6-247.2	111.6	20	7	2.0	780.9	0.2	44.3
Scophthalmus rhombus	259.7	259.7	233.8	233.8	10	1	0.3	233.8	0.1	3.5
Solea solea	239.8-315.0	277.4	127.6-313.4	220.5	10	2	0.6	441.0	0.1	6.9
Unidentified fish	NA	NA	NA	NA	20	4	1.2	NA	NA	NA
Cephalopods										
Theuthida										
Loligo spp.	215.7-252.7	238.8	232.7-359.7	311.1	30	3	0.9	933.3	0.23	32.9
Alloteuthis spp.	77.5	75.4	6.5	6.5	10	1	0.3	6.5	0.0	2.9
Todarodes sagittatus	NA	NA	NA	NA	10	1	0.3	NA	NA	NA
Illex spp./*Todaropsis* spp.	233.4	228.6	363.2	363.2	10	1	0.3	363.2	0.1	3.8
Unidentified Ommastrephidae	NA	NA	10.3	10.3	10	1	0.3	10.3	0.0*	2.9
Brahioteuthis riisei	38.5-124.4	69.7	2.0-18.5	69.7	30	17	4.9	119.3	0.0*	148.3
Gonatus spp.	122.8-210.2	232.0	47.3-254.7	132.0	10	8	2.3	1,055.6	0.3	25.7
Teuthowenia megalops	95.4-168.2	131.8	11.0-47.8	27.3	10	20	5.8	409.1	0.1	58.8
Octopoda										
Octupus vulgaris	NA	NA	107.8-359.7	242.8	20	5	1.5	1,097.2	0.3	34.3
Eledone cirrhosa	84.7-138.4	111.5	130.0-551.1	340.6	10	2	0.6	681.1	0.2	7.5
Unidentified cephalopod	NA	NA	NA	NA	20	2	0.6	NA	NA	NA
Crustacean	NA	NA	NA	NA	10	1	0.3	NA	NA	NA
TOTAL	**38.5-1,151.1**	**351.5**	**2.0-8,611.1**	**1,188.7**	**10**	**346**		**40,5946.8**		

Five Gadiformes species (whiting, blue whiting, pollack –*Pollachius pollachius,* Linnaeus 1758–, saithe –*P. virens,* Linnaeus 1758–, and haddock) occurred in over 60% of the stomachs (32.3% by number and 39.7% by weight). Although the degree of erosion of the otoliths of these five species was medium-low, they were difficult to identify to species level especially in two stomachs, and resulted in the groupings whiting/blue whiting and pollack/saithe/haddock for further analysis. These prey items were in better condition in the remaining stomachs to be able to identify them to species level in most of the cases. All groups made up 60% of the stomachs containing fish prey; however, whiting and blue whiting made up 15.3% by number and 4.5% by weight, and *Pollachius* spp. and the haddock group presented 17.1% by number and 35.2% by weight. The other two gadiforms were *Trisopterus* spp. (Rafinesque, 1814) which occurred in more than a third of the animals (8.7% by number, 1.4% by weight), and European hake (*Merluccius merluccius,* Linnaeus 1758), which only occurred in three stomachs (7.8% by number, 20% by weight).

The estimated weight of food consumed by these individuals was 169.4kg in total. After applying the digestion correction factors, this value increased by a factor of 2.4 (equivalent to 236.6kg) when using the correction factors published in Grellier and Hammond (2006) and 2.2 times (199.4kg) using the Tollit et al. (1997) values. Biomass increased significantly (Wilcoxon Rank test, $p<0.005$) after applying both sets of correction factors; however, there was no significant difference between the derived biomass estimates when both coefficient factors were applied.

Length of fish prey consumed varied within the Gadiformes group. The estimated length for gadoid species ranged from 113 to 1,143 mm in the haddock/saithe/pollack group (Fig. 5.2b), and between 102 and 699 mm in the whiting-blue whiting group (Fig. 5.2a); however, the size of about 50% of these two groups was below the length at sexual maturity (www.fishbase.org). *Trisopterus* spp. ranged in length from 59 to 495mm, but 33% of the fish were smaller than 130 mm (the maximum length at sexual maturity for Norway pout (*T. esmarkii*, Nilsson 1855) is 110-150mm, and for Poor cod (*T. minutus*, Linnaeus, 1758) is 130 mm, www.fishbase.org) (Table 5.2).



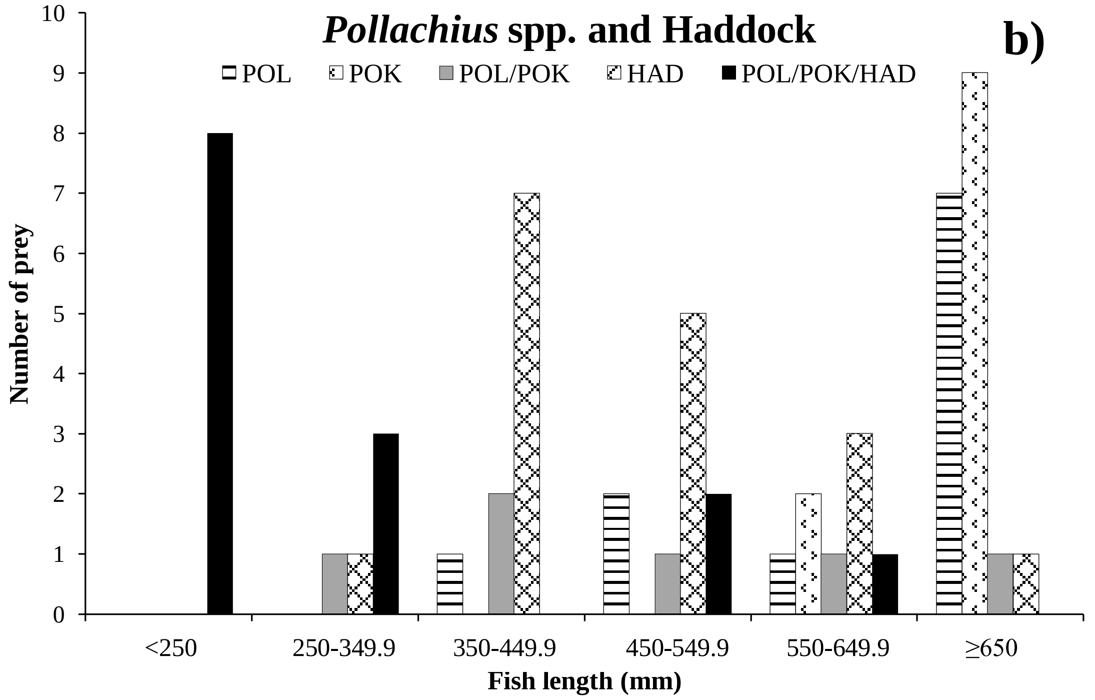


Figure 5.2. Estimated size for a) blue whiting (WHB) and whiting (WHG) prey items, and b) pollack (POL), saithe (POK) and haddock (HAD). MLS for whiting, pollack, saithe and haddock are 27cm, 30cm, 35 cm, and 30cm, respectively. There is no blue whiting MLS in this region, however 14cm is the MLS for north west of Iberian Peninsula.

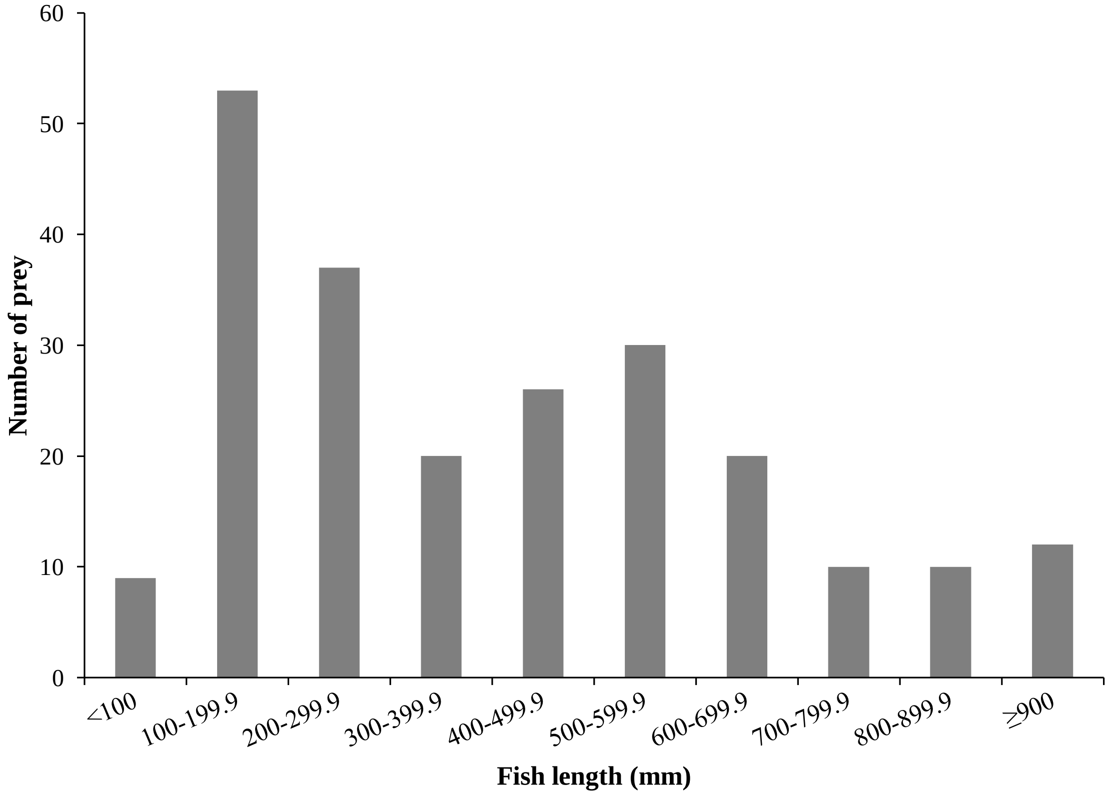


Figure 5.3. Estimated size for all the main fish prey groups combined

Almost 50% of the reconstructed Gadiformes fish size were found to be below 30cm (Fig. 5.3), which is considered to be below the minimum landing size (MLS) for a few marketable Gadidae species (e.g., whiting and blue whiting) for the area (Fig. 5.2b) (www.ices.dk). In contrast, saithe, pollack and haddock were found to be larger than the MLS, as was European hake.

Although 12% of the horse mackerel (*Trachurus trachurus*, Linnaeus 1758) estimated size was found below MLS (15cm, www.ices.dk), maturity length has been reported to be over the MLS (23.9cm, www.fishbase.org) and 33% of the horse mackerel were below the sexual maturity length.

The Cephalopoda group was the second main prey group found in the diet, occurring in 61% of the stomachs but its importance was relatively small (17.6% by number and only 1.2% by weight). Ten species within six families were identified and oceanic cephalopods made up 15.6% by number (n=54), however 78.8% of this group was found in only one stomach (Table 5.1 and 5.2). Within the cephalopod prey category, the most abundant were the oceanic cephalopods *Teuthowenia megalops* (Prosch, 1849)

(32.8% by number, 8.8% by weight), *Gonatus* spp. (Gray, 1849) (13.1% by number, 22.6% by weight), and *Brachioteuthis riisei* (Steenstrup, 1882) (27.9% by number, 2.6% by weight) (Fig. 5.4). However, these oceanic species mainly occurred in one of the stranded dolphins and in the by caught individual. At least another four species of squid were identified within two families, Loliginidae (7.4% by number and 32.4% by weight), and Ommastrephidae (5.6% by number and 12.9 by weight). The coastal cephalopods were mainly octopuses; the main species was *Octopus* spp. (Cuvier, 1797) (8.2% by number, 23.5% by weight), and *Eledone cirrhosa* (Lamarck, 1798) (3.3% by number, 14.6% by weight). Most of the cephalopod prey size ranged from 58 to 180 mm (80.9%) mantle length (ML) and weighed less than 130g (79.3%).

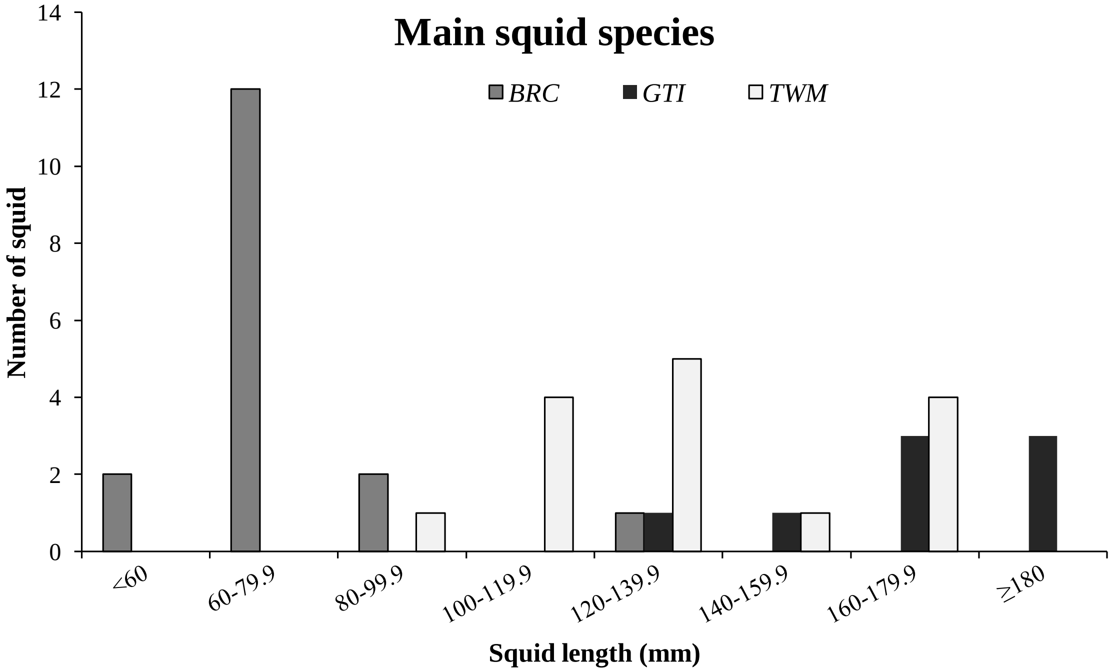


Figure 5.4. Estimated size of the main squid prey (BRC: *Brachioteuthis riisei*, GTI: *Gonatus* spp., TWM: *Teuthowenia megalops*)

Only one crustacean was found and it was not possible to identify it to a lower taxonomic level (Table5.2).

Five bottlenose dolphins were identified as belonging to the 3rd population of unknown origin (Mirimin et al., 2011) and their stomach contents presented a variety of species from coastal (e.g. Octopuses and Conger eel in BND 3241) to oceanic pelagic prey (e.g.

T. megalops and *M. poutassou*, BND 1/99 and BND 3/01, respectively) (Table 5.2), suggesting a wide ranging habitat use for this population.

5.4.3. Annual food consumption and statistical analysis

The estimated weights of the dolphins used in this study ranged from 257 to 632 kg (Table 5.1). The annual food consumption based on the Col et al. (2012) equation (eq. 2.5, Chapter 2) using the average estimated weight (381.8kg, SE= 37.0) of individuals with food remains in their stomachs, and the bottlenose dolphin population estimate from SCANS II for Block R was 1,194 metric tonnes (Table 5.3). The average estimated bottlenose dolphin weight reported by UNEP/CMS (Convention on the Conservation of Migratory Species of Wild Animals, www.cms.int) was similar to the average dolphin weight estimated in this study and, therefore, similar annual food consumption was obtained of 1,148 metric tonnes. The annual food consumption estimated using the average weight of all the bottlenose dolphins stranded in Ireland was 1,187 metric tonnes.

	Ŵsam	Ŵstra	ŴCMS
C (tonnes)	1,193.8	1,187.0	1,148.4
Range (tonnes)	297.5-4,081.9	286.2-4,619.2	295.8-4,774.5

Table 5.3. Annual food consumption calculated using Col et al. 2012 (tonnes) equation for the average weight estimated for the bottlenose dolphin containing food items (Ŵsam), average weight of all individuals stranded in Ireland (Ŵstr), and average weight reported by www.cms.int (ŴCMS). And annual food consumption ranges for the minimum and maximum bottlenose dolphin population value in the area.

The annual food consumption for the main groups of prey was estimated using the Pierce et al. (2007) equation (eq. 2.12 in Chapter 2; Table 5.4). The two main prey-group categories in terms of biomass changed when equal weighting was applied and while saithe/pollack/haddock group decreased in importance, Whiting/Blue whiting group increased (Table 5.4); pelagic squid also increased when equal-weighting was applied. Only European hake and octopuses increased and decreased respectively, when both adjustments (equal weighting and dolphin weighting) were applied.

	No Weighting	E Weighting	D Weight
Whiting/blue whiting	35.6 (<0.0)	81.49 (<0.0)	29.77 (<0.0)
Pollack/Saithe/Haddock	329.0 (1.5)	116.69 (0.8)	272.65 (1.8)
Trisopterus spp.	8.7 (0.2)	19.24 (0.4)	10.11 (0.2)
European hake	59.4 (0.8)	141.13 (0.9)	159.59 (1.0)
Horse mackerel	12.1 (<0.0)	9.62 (<0.0)	15.47 (<0.0)
Flatfish	5.6 (<0.0)	4.25 (<0.0.)	4.33 (<0.0)
Pelagic squid	4.49 (0.1)	80.24 (1.3)	4.0 (0.1)
Octopuses	2.75 (0.2)	2.31 (0.1)	2.20 (0.1)
Total	**409.11**	**454.97**	**498.13**

Table 5.4. Annual food consumption (tonnes) of the main prey of bottlenose dolphin without rescaling (No weighting), after applying equal weighting (E Weighting), and after applying the weighting related to the body weight of the animal (D Weighting). Percentage of diet related to landings is in brackets.

When comparing food consumption and landings in Ireland of the main prey groups, all prey groups are consumed on a very small scale (Fig. 5.5, Table 5.4); with the consumption of *Pollachius* spp./haddock, hake and squid equating to around 1% of the reported landings.

Significant differences were found in prey occurrence between the two stranding categories (dead and alive) ($\chi2=27.9$, $p<0.005$) and between sex ($\chi2= 97.8$, $p<0.005$). While 47.9% of the prey items found in live-stranded dolphins were identified within the Gadidae family (haddock, pollack, saithe, blue whiting, whiting and *Trisopterus* spp.), followed by cephalopods (35.2%), and Atlantic hake (12.8%); only 5.4% of the prey were cephalopods in the dead stranded dolphins, with a further 36.8% comprising the three main Gadidae groups, 11.8% eels and dogfish, and 6.9% flatfish species. Females fed on 43.5% of the three main groups of gadoids, followed by horse mackerel (27.9%), and Atlantic hake (17.7%); males also fed on the three main groups of gadoids (39.7%), cephalopods and eels/dogfish were also found to be important prey items (28.6% and 13.6% respectively).

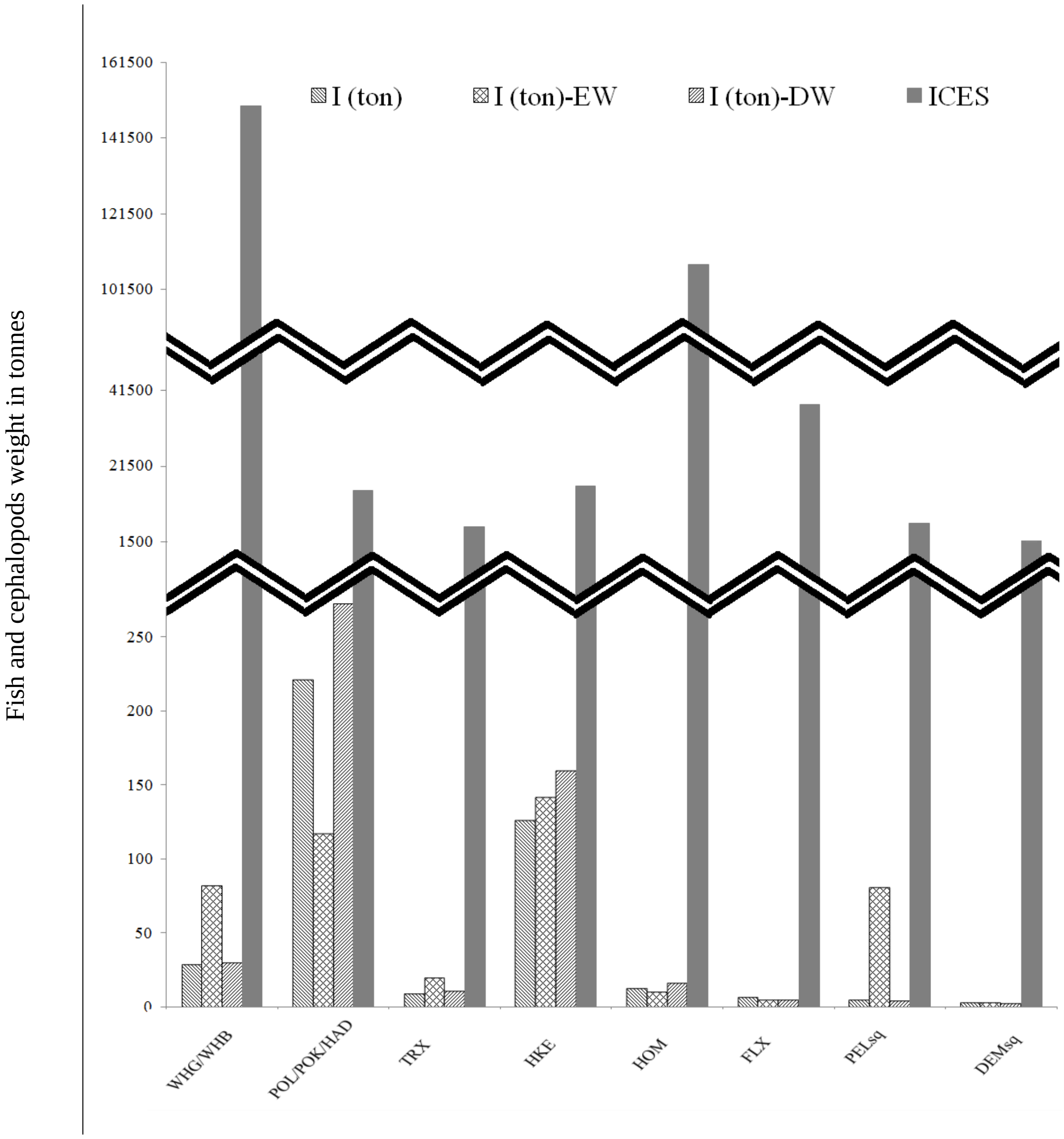


Figure 5.5. Landings and estimated consumption of the main prey groups for the coastal population in Ireland. Estimations were calculated using percentage of weight (Ingestion-I), equal weighting percentage (Ingestion-Weighted, I-EW), and weighting related to the body weight of the dolphin (Ingestion-Dolphin, I-DW). Landings were obtained using the available data from ICES (www.ices.dk, ICES-landings). WHG/WHB: whiting/blue whiting, POL/POK/H: *Pollachius* spp./haddock, TX: *Trisopterus* spp., HKE: European hake; HOM: horse mackerel, FLX: flatfish, PELsq: pelagic squid, DEMsq: octopuses.

5.5. DISCUSSION

Little is known about the diet of bottlenose dolphins in the NE Atlantic primarily due to the small amount of data available; however some published information from stomach contents is available (De Pierrepont et al., 2005; Hernandez-Milian and Rogan, 2011; Santos et al., 2001c, 2007; Spitz et al., 2006b). The paucity of data is partly because the recovery of this species is relatively infrequent. Carcasses are usually found in an advanced state of decomposition, the extended coastline together with the remoteness of some locations, and the loss of the carcass with the next tide before examination, all contribute to a relatively low sampling rate (only 12% were recovered for post-mortem examination, Appendix V).

Bottlenose dolphins have been described as generalist predators feeding mainly on pelagic fish and squid prey (e.g., Barros and Wells, 1998; Barros et al., 2000; Lopez, 2009; Walker et al., 1999). In Europe, studies on bottlenose dolphin diet, also based on the analysis of stomach contents of stranded and by-caught individuals, have reported a wide variety of prey, including demersal species and pelagic prey (Santos et al., 2001c, 2007; Spitz et al., 2006b). In Scotland, bottlenose dolphins (n=9) were reported to feed mainly on whiting, followed by saithe and cod (Santos et al., 2001c). In France (n=25), the main Gadiformes species consumed was European hake, followed by blue whiting and *Trisopterus* spp. (Spitz et al., 2006b). Off North West Spain (n=82) bottlenose dolphins preyed mainly on blue whiting and hake (Santos et al., 2007) and in the western Mediterranean (n=15) predominately on European hake (Blanco et al., 2001).

Although the sample size is small, results from this study are consistent with previous studies. Bottlenose dolphins stranded along the South-West and West of Ireland are eating a mixture of pelagic and demersal fishes, predominately Gadiformes species such as the pollack/saithe/haddock followed by the whiting-blue whiting group and *Trisopterus* spp. (Table 4.2). Interstingly, a saithe of 80cm (~5kg) has been identified in regurgitation from a solitary bottlenose dolphin in Galway Bay (collected by Conor Ryan). In general, the main prey items could be considered benthic or benthopelagic species, suggesting a feeding activity in coastal or relatively shallow waters. However, the presence of mesopelagic fish and squid species in the stomachs of dolphins from the

“3rd population” and a by-caught dolphin might suggest that they are foraging either in more oceanic waters and/or at deeper depths (bottlenose dolphins are capable of diving to depths deeper than 450m, Klatsky et al., 2007).

Horse mackerel was also reported in the diet of bottlenose dolphin in French waters (Spitz et al., 2006b), but the size range consumed was larger in dolphins stranded in Ireland. Most of the horse mackerel (95.2%) occurred in dolphins that were classified within the “3rd population”. West and South West Irish waters are included within area VII of the ICES areas, and this area is reported to be an important area for migration and a spawning area for pelagic fish species such as Atlantic mackerel and horse mackerel (Abaunza et al., 2008; MI, 2010; Uriarte and Lucio, 2001).

The occurrence of conger eels in the diet of bottlenose dolphins from European waters was previously reported from animals stranded along the Spanish coasts, both from the NW of Spain and the Mediterranean coast (Blanco et al., 2001; Santos et al., 2007), but not further North. Although conger eels seemed to be important in terms of weight in this study, they mainly occurred in a single dolphin. The occurrence of conger eel could be related to individual prey preferences or foraging strategy.

Small elasmobranchs have been found to occur in the diet of bottlenose dolphin from the NW Atlantic (e.g., Jenkins, 1932(in Gunter, 1942); Barros and Wells, 1998; Gannon and Waples 2004). However, within European waters dogfish has only previously been reported in the diet of the Mediterranean Monk Seal (*Monachus monachus*, Hermann, 1779) (Pierce et al., 2011). Dogfish are one of the most common small elasmobranchs species around the Irish coast and the landings in Ireland are around 2000 ton per year (Central Statistics Office Ireland 2010) mainly by recreational fisheries. They are also caught and discarded from bottom-set gillnets. The occurrence of this species at different stages of digestion in one dolphin accompanied by other unusual prey species (Hernandez-Milian and Rogan, 2011), suggested that the dolphin might be feeding in an area where dogfish are locally abundant. Previously, Nash (1974) reported on a single bottlenose dolphin in Ireland that contained dogfish in its oesophagus which he considered to have caused the death of the dolphin by chocking. However, the importance of elasmobranchs in the diet of dolphins is difficult to quantify due to their relatively high digestibility and identification of elasmobranch fishes is only possible by direct feeding observation or when the stranded animal was feeding very recently.

The occurrence of salmon in the diet is also of note. Although only it was found in one stomach, movement of bottlenose dolphins into the Shannon Estuary following the salmon run has been suggested as one of the reasons for an increase in bottlenose dolphins in the Shannon estuary over the late spring - summer months (Ingram, 2000). Direct observations of bottlenose dolphins feeding on salmon have also been reported in the Shannon Estuary (along with garfish -*Belone belone*, Linnaeus 1761- Ingram, 2000; Emer Rogan *pers. comm.*) and in Cork Harbour (Ryan et al., 2010) and, therefore, salmon might be more prevalent in the diet than was found in this study.

In general, the estimated size of 50% of Gadiformes was below the Minimum Landing Size (MLS) established for the different species (www.ices.dk). *Pollachius* spp./haddock group and European hake eaten by bottlenose dolphins were estimated to be above the MLS, while the opposite was true for whiting-blue whiting group and *Trisopterus* spp. Most of the items that were not identified to species level in *Pollachius* spp./haddock group were estimated to be below 280mm after applying correction factors, and 300mm is considered the MLS for the smallest species: haddock.

Underestimation of prey size using otoliths and bones recovered from digestive tracts that have suffered acid digestion has been considered a potential source of bias in studies of prey consumption by marine mammals (e.g., Grellier and Hammond, 2006; Tollit et al., 2003; Wijsma et al., 1999). In an attempt to quantify the degree of erosion that fish otoliths from different species suffer in their passage through the digestive system, a number of studies have been carried out on captive seals, although no comparable information is available for cetaceans. These coefficients were applied to the data and differences in the biomass were obtained. Estimation of biomass of prey consumed increased 300% in some groups such as gadoids (e.g., pollack, saithe and haddock) and hake and 200% in Atlantic mackerel and European plaice.

However, it is likely that these correction factors over-estimated the biomass, as prey remains had not been subjected to digestion in the entire digestive tract (which is the case in pinniped feeding trials) and most otoliths were recovered from the 1st stomach of the dolphins, where only mechanical digestion takes place. The identification of bones in marine mammal diet studies to improve our understanding of feeding ecology has only recently been commonly used (e.g., Brown and Pierce, 1997; Fernandez et al. 2009; Gosch et al., 2014; Pierce et al., 1991; Santos et al. 2007). Working with stomach contents, it is important to identify all skeletal structures as not all bones/otoliths are exposed to the digestion process and in some cases it is likely that only part of the prey was taken (e.g., when taken from a net or a hook). In this study, for example, using a combination of bones and the more usual otolith approach, an additional four fish species (European eel -*Anguilla anguilla* Linnaeus 1758, *Salmo* spp. -Linnaeus, 1758-, common dab -*Limanda limanda*, Linnaeus 1758-, dogfish) were identified from bones that would not have been identified if using otoliths alone.

The prey diversity indicates that the diet of bottlenose dolphin is composed mainly of locally available prey species, as suggested previously by Barros and Odell (1990). Indeed, complementary stable isotopes analysis carried out on bottlenose dolphins in Irish coastal waters showed differences in diet among the different populations (Rogan et al. 2011). Rogan et al. (2011) reported a low $\delta^{13}C$ in animals that were feeding mainly on demersal prey, while animals with high $\delta^{13}C$ preyed on pelagic prey. Also, results from $\delta^{34}S$ confirmed the suggestion that some animals are estuarine feeders, while others are neritic and there might be another group feeding further offshore within the oceanic area (BND 1/96, Table 4.1). Walker et al. (1999) studied stable isotopes in bottlenose dolphins in the NW Atlantic, and found that coastal dolphins were mainly fish feeders while offshore ones were mainly squid feeders. The by-caught dolphin examined in this study had pelagic squid prey in its stomach and stable isotopes analysis showed a high $\delta^{34}S$ value (Rogan et al., 2011); suggesting that this animal might be related to a more oceanic population. The majority of prey items from the stomach contents of animals that are genetically classified as belonging to the third population indicate that these animals were foraging on the continental shelf and close to the shelf edge, suggesting that these animals represent a community that feeds in the neretic zone. Reconstructing diet from stomach content analysis of dead dolphins has obvious caveats associated with it, but in this case stable isotopes (Rogan et al., 2011) and genetic analysis re-enforced the results that the bottlenose dolphin are feeding on locally available species.

Significant differences were found in the diet of male and female dolphins in this study, something that has been reported in other areas (e.g., Blanco et al., 2001; Santos et al., 2007), however the sample size here is very small. Santos et al. (2007) investigated the diet of dolphins related to cause of death (by-caught dolphins vs. unknown and other causes) and found no significant differences in the diet. In this study, only one animal was by-caught and only offshore-pelagic squid was found in its digestive tract, but a third of the animals stranded alive. In the literature, live strandings have often been associated with disorientation, non-familiar habitat and illness and with animals that likely have not been feeding normally. Therefore differences in diet might be expected between this group and the remaining samples. In this study, live-stranded dolphins were mainly feeding on gadoids and cephalopods, while dead-stranded dolphins were found to have greater prey diversity. It is also possible that live strandings could comprise individuals that usually reside in a more oceanic/neritic type habitat; however the variety of prey from these animals does not reflect this.

Indeed, of the animals sampled and where genetic origin is known, five individuals were identified as belonging to the third population in Irish waters of unknown origin. From the stomach contents, it appears that these animals are feeding on species that can occur both in coastal waters and on the continental shelf; these results suggest that the 3rd population might be inhabiting or feeding on the continental shelf or slope.

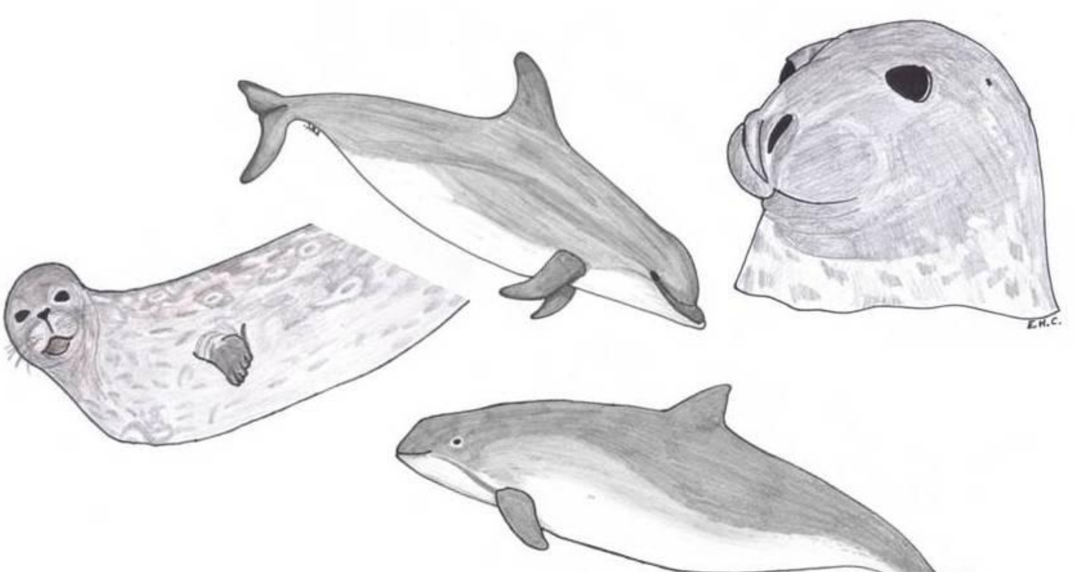
A few studies have estimated food consumption by marine mammal populations (e.g. Barlow et al., 2008; Col et al. 2012). Barlow et al. (2008) investigated the accuracy of different average daily ratio models to calculate the annual food consumption in marine mammals; they found that the approach adopted by Trites et al. (1997) was the most similar one to their model for wild cetaceans. However, these authors do not consider migration/residential patterns. Bottlenose dolphin in Irish waters present a complex structure with resident and highly mobile populations (Mirimin et al. 2011), and the residency ratio suggested by Col et al. (2012) of 0.66 is likely applicable in this study area. Dolphin body mass estimation obtained in published literature was calculated using different studies around the world; those studies are often of smaller animals than the ones inhabiting Irish coastal waters and therefore the annual consumption is likely to be underestimated. Kastelein et al. (2002) obtained a body mass estimation studying 16 captive bottlenose dolphins that ranged from 220-280cm length (seven males and nine non-pregnant and non-lactating females) and found that the asymptotic growth occurred at 270cm. In our study all of the animals were larger than 270cm. Kastelein et al. (2002) suggested that dolphins between 155-225kg might consume between 2-4% of their body mass per day. Using 4% of body mass as a metric for consumption, the mean annual food consumption estimation in Irish coastal waters is around 1,190 metric tonnes. As captive dolphins are expected to have lower consumption rates (Barlow et al. 2008) it might be expected that the annual food consumption of bottlenose dolphin in Irish coastal waters might be higher. On the other hand, Kastelein et al. (2002) fed the dolphins mainly with high energy prey and, therefore dolphins might have consumed more than 4% of their body size than in the wild. Interestingly, the annual consumption of this species in Ireland showed that competition with fisheries might not be strong; considering that all animals in this study were adults and therefore annual food consumption is likely to be overestimated. Although consumption of pollack and saithe was found to be high, more than 80% of this prey was consumed by the animal stranded in 2001 when landings of these species were the highest during the period (~3000-4000 tonnes for saithe, ~6,000 tonnes for pollack and ~12,000 tonnes for haddock), suggesting that this animal was feeding on species that were highly abundant.

The information obtained through these studies helps to understand the individual diet preferences and foraging behaviour of the species, because prey-species identification can be done to species-taxonomic level; this information is important for abundance estimation for some fish stocks where surveys might underestimate biomass (e.g. Boyd and Murray, 2001; Bowen et al., 2006). But it is also valuable information for ecosystem functioning studies using mass-modelling simulations such as Ecopath with Ecosim (www.ecopath.org).

Foraging behaviour of bottlenose dolphin is difficult to assess due to the small sample size that usually is available and the complexity of the population structure. Larger sample size is necessary to confirm these results as well as using a combination of other techniques (e.g. stable isotopes). However, the information obtained in this study provides a starting point to understand the foraging behaviour of bottlenose dolphin in Irish waters.

Chapter 6

FORAGING ECOLOGY OF COASTAL MARINE MAMMALS IN IRISH WATERS



CHAPTER 6

FORAGING ECOLOGY OF COASTAL MARINE MAMMALS IN IRISH WATERS

6.3 Material and Methods

6.4 Results

6.1 ABSTRACT

Four marine mammal species regularly inhabit Irish coastal waters: harbour seal, grey seal, bottlenose dolphin, and harbour porpoise. In this chapter, the dietary preferences and potential diet overlap is investigated. A total of 73 stomachs (66 harbour porpoises and 10 bottlenose dolphins) and 235 scats (132 grey seal and 103 harbour seal samples) with prey remains were analysed. A minimum of 4,239 prey items were identified from 54 fish species and nine cephalopod species. For all predator species, Gadiformes were recorded in more than 50% of the samples, and *Trisopterus* spp. was the main gadoid prey identified, occurring between 33% (harbour seals) and 52% (grey seals) of the time. Apart from the Gadiformes prey, some predator specialization was noticed with both species of seals feeding mainly on benthopelagic species, while cetaceans preyed more upon pelagic prey species. The total annual food consumption for the coastal species was estimated at 22,509.32 tonnes, but differences between important prey groups were found among the predators. Explanatory multivariate analysis (redundancy Analysis) indicated significant relationships between prey species and their predators; dragonets and sandeels appear to be important for harbour seals, salmonids for grey seals, clupeids for harbour porpoises and hake and large demersal prey for bottlenose dolphins. Discriminant analysis also showed a potential overlap in the diet of both seals, and notably, overlap with harbour porpoises, however they seem to feed on different fish sizes.

6.2 INTRODUCTION

Dolphins and seals are species of marine predators inhabiting a large diversity of habitats, from coastal waters to offshore areas; dietary studies of these animals are usually carried out analysing stomach contents of carcasses stranded on beaches or by caught in nets and collecting seal scats at haul out sites (see Chapter 1).

For the purposes of this study, only two species of cetaceans were considered coastal based on sightings close to the coast (e.g., Berrow et al., 2008; Ingram, 2000; Leeney, 2007). Bottlenose dolphins (*Trusiops truncatus*, Montagu 1821) are widely distributed (Chapter 4; Caldwell and Caldwell 1972; Hammond et al. 2012), and most of the studies carried out on this species are on coastal populations (e.g., Hoelzel et al., 1998; Jefferson et al., 2008; Natoli et al., 2005; Wells and Scott, 1999). Harbour porpoises (*Phocoena phocoena*, Linnaeus 1758), are a less conspicuous and shy coastal species occurring in sub polar and temperate waters of the North Hemisphere (Figure 6.1; Hammond et al., 2008c). Few studies suggested that the Atlantic subspecies might differ genetically between populations (Fontaine et al., 2007; Fontaine et al., 2010; Rice, 1998a and refs. therein); in addition, Fontaine et al., (2007) suggested that some genetic structure of harbour porpoise populations in European waters may be due to habitat characteristics as well as specialised foraging ecology in local areas.

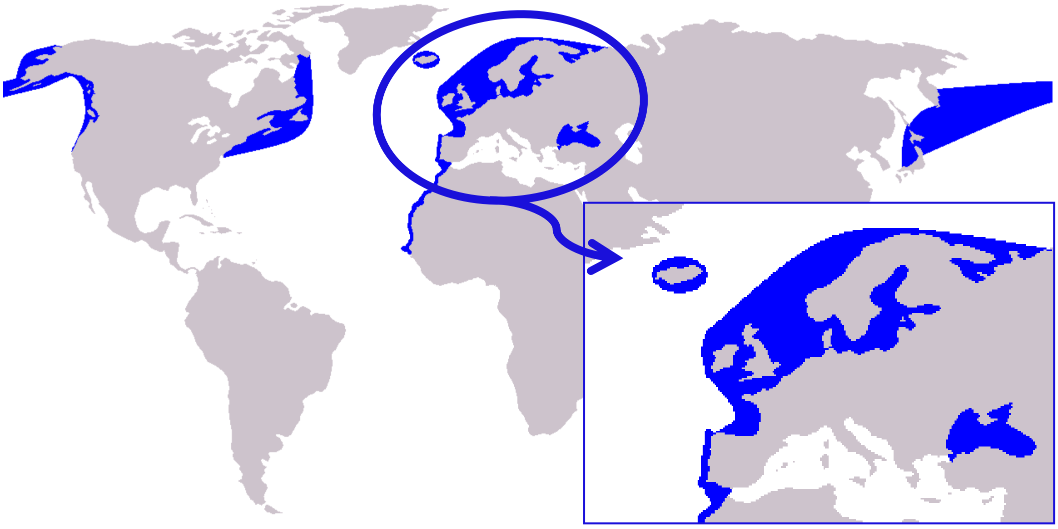


Figure 6.1. Harbour porpoise distribution. Adapted from the Wikimedia Commons file "Image: Cetacea range map Harbour Porpoise.PNG ".http://commons.wikimedia.org/wiki/File: Cetacea_range_map_Harbour_Porpoise.png

Two seal species are normally found on the Irish coast: harbour seals (*Phoca vitulina vitulina*, Linnaeus 1758) and grey seals (*Halichoerus grypus*, Fabricius 1791). The former is distributed throughout the temperate and sub polar and polar waters of the Northern Hemisphere, and *P.v.vitulina* is the subspecies inhabiting Eastern Atlantic coasts (Figure 6.2, Rice, 1998a). They are relatively common in bays, estuaries, and intertidal areas where they aggregate at haul out sites (Thompson and Härkönen, 2008a). The distribution of grey seals is narrower, inhabiting the cold temperate and sub polar waters of the Atlantic, and the Eastern population is mainly concentrated around the U.K. and Ireland (Figure 6.2; Rice, 1998a). This species usually hauls out on remote islands and exposed coast lines where human disturbance is relatively low (Thompson and Härkönen, 2008b).

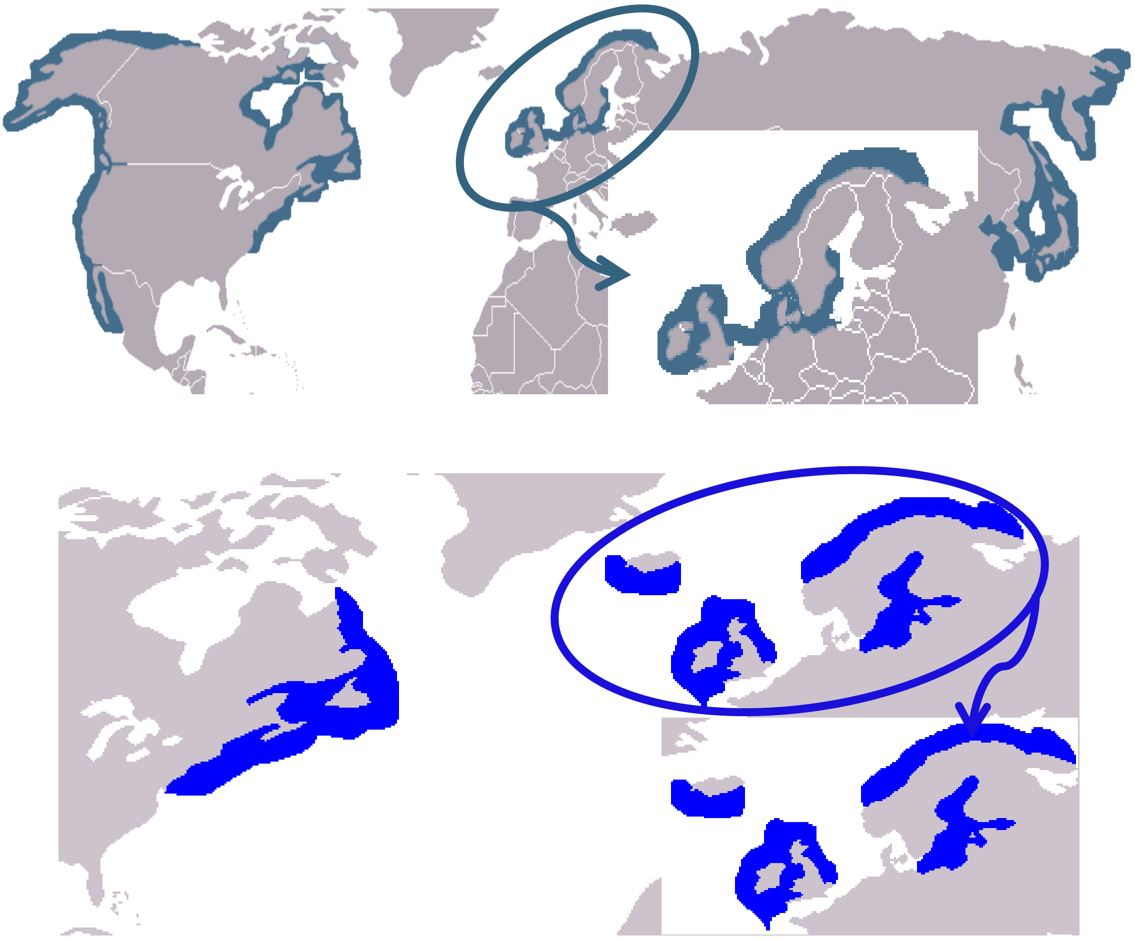


Figure 6.2. Distribution maps of harbour (top) and grey (bottom) seals. Adapted from the Wikimedia Commons file "Image: Seehund (Phoca vitulina) world rad.png", and "Image:Distribution of the grey seal.png". http://commons.wikimedia.org/wiki/File:Seehund_(Phoca_vitulina)_world_rad.png (top) http://commons.wikimedia.org/wiki/File: Distribution_of_the_grey_seal.png (bottom)

Abundance estimates are available for the two cetacean species from two multinational dedicated sighting surveys SCANS-II (Hammond et al., 2013) and CODA (CODA, 2009); however, some area-specific, smaller scale studies have been also carried out for both species (Ingram, 2000; Leeney, 2007; Berrow et al., 2008, 2011). Abundance estimation of both species of seals have been carried out on an *ad-hoc* basis in the Republic of Ireland since the 1970s (Kiely et al., 2000; Lyons, 2004), but the first comprehensive study on seal population abundance was carried out in 2003 for harbour seals (Cronin et al. 2004), and 2007 for grey seals (Ó Cadhla and Strong, 2007).

Interactions between marine mammals and fisheries, and in particular marine mammal by-catch, have been reported around the world (e.g., Bearzi, 2002; Northridge, 1984; 1991), and in Irish waters (Couperus, 1997b; McCarthy, 1985; Rogan and Mackey, 2007; Tregenza et al., 1997). Competition between marine mammals and commercial fisheries has been also reported (e.g., Lopez, 2003; Pierce et al., 2010; Ridoux et al., 2007; Santos et al., 2007). Estimations of annual food consumption of fish targeted by local fisheries is one approach which can be used to assess the level of this interaction through diet studies of both incidentally caught and stranded animals (e.g., Couperus, 1997b; Hassani et al, 1997; Philpot, 2001; Santos and Pierce, 2003; Silva, 1999).

All these predators share the same geographic habitat (Hammond et al., 2013; Rice, 1998a), and therefore feeding overlap might occur. Spitz et al. (2006b) found that bottlenose dolphins and harbour porpoises in the Bay of Biscay presented a partial overlap although porpoises fed mainly on small schooling prey while bottlenose dolphin preferred large demersal prey as well as cephalopods. Dietary seal studies in Ireland are scarce (Gosch et al., 2014; Kavanagh et al., 2010; Philpot, 2001), and results show a preference for small demersal/benthic prey by harbour seals (Kavanagh et al., 2010), while grey seals prey on larger demersal Gadoid species (Gosch et al., 2014; Philpot, 2001).

Both cetacean species are classified as ‘least concern’ in the IUCN Red list, and are included in Annex A of the European Council Regulation (338/97) and in the Appendix II of CITES. They are also listed in Annexes II and IV of the Habitats Directive and included in the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS). Harbour and grey seals are also classified as ‘least concern’ in the IUCN Red list, and are included in Annexes II and V of the Habitats Directive. Annex II listing under the Habitats Directive means that Special Areas of Conservation must be designated for these species.

The aim of this work is to investigate the different dietary patterns of the four coastal marine mammal predators in Irish waters and estimate the annual food consumption of the main prey species. The dietary information has also been used to build up the Ecopath model of the Irish Sea presented in the Chapter 7, as they were considered to be the main top predators in the Irish Sea. Potential competitive interactions among the species were explored.

6.3 MATERIAL AND METHODS

6.3.1 Study area and sample composition

Bottlenose dolphin and harbour porpoises stranded in Ireland (Appendix V and VI) were attended and when possible post mortem examination were carried out by UCC staff and research students following the standard protocol of the European Cetacean Society (Kuiken and García Hartmann, 1993). Length of the animals was recorded as well as sex. Digestive tracts of twelve bottlenose dolphin (Chapter 5, Table 5.1) and 67 harbour porpoises (Appendix VI) were recovered for dietary analysis. Seal scats were collected at three different haul-out sites. During the period of 2006-2007, scat sampling of harbour seals from the south west of Ireland was carried out to investigate the diet of this species in Ireland, combined with fatty acid analysis (Kavanagh et al., 2010). Grey seal scats were collected predominately from one of the most important haul out and breeding areas on the south west of Ireland (Blasket’s Islands, Co. Kerry) (Gosch et al., 2014).

Boness et al. (2002) indicated that average length at sexual maturity of male bottlenose dolphins is slightly bigger than females (263cm and 250cm, respectively). Lockyer (1995) reported that in porpoises, females are bigger than males, with the average length at sexual maturity being 140cm for females and 130cm for males. Body length for adult harbour seal ranges from 160cm to 190cm (Burns, 2002), whereas grey seals are larger, ranging from 165 to 230cm (Bonner, 1981). The average weight of harbour seals is 97.5kg (Burns, 2002), while Bonner (1981) estimated that grey seal body weight for adults was 233 kg for males and 155 kg for females; for the purpose of this study the average of female and male weight (194kg) was used.

6.3.2 Prey identification and quantification of diet

Identification of all fish, cephalopod and crustacean prey remains was carried out following the methodology outlined in the Chapter 2 (Section 2.3.2).

Digestion coefficient factors given by Grellier and Hammond (2006) were applied to otolith measurements used to reconstruct lengths and weights in both species of cetacean when it was necessary, and in harbour seals (Chapter 2, Section 2.3.3). No correction factors were applied for grey seals as more than 20% of their diet was identified using hard structures other than otoliths. Other hard structures also undergo the digestion process, however no digestion coefficient factors are available for bones in the literature and therefore the reconstructed diet is likely underestimated in these species.

The diet quantification of the four species was evaluated using three standard indices (frequency of occurrence, %F; percentage by number, %N; percentage by reconstructed weight, %W), and the Index of Relative importance (IRI), as described in Chapter 2 (Section 2.3.4).

6.3.3. Annual food consumption and statistical analysis

Annual food consumption was estimated for all predator species. In the case of the bottlenose dolphin and the harbour porpoise, weight estimations were calculated from the length recorded during the dissections using the equations detailed in Chapter 2 (Section 2.3.5, eq. 2.7 and 2.10 respectively). Seal weight was assumed using the average weight of adult harbour seals (97.5kg) given by Burns (2002) and adult grey seals (195kg) given by Bonner (1981). Abundance estimation for the two cetacean species were taken from Hammond et al. (2013) for two survey areas during the SCANS II survey (Fig 1.2a), blocks R (south, west and north of Ireland) and block O (Irish Sea). In block R it was estimated that there were 313 (CV=0.81) bottlenose dolphin and 10,716 (CV=1.14) harbour porpoises, and in block O 235 (CV=0.75) bottlenose dolphins and 15,230 (CV=0.35) harbour porpoises. O'Cadhla et al. (2007) gave an estimated population of 5,343 grey seals in the Republic of Ireland. Cronin et al. (2004) gave an abundance estimation of 4,153 harbour seal for the whole island (Republic of Ireland and Northern Ireland).

General annual food consumption for all predators was estimated using the Col et al. (2012) equation (eq. 2.5), and the equation given by Pierce et al. (2007) (eq. 2.12, Chapter 2, Section 2.3.5) was used to estimate specific prey annual consumption; three main groups of gadoids were considered separately from the rest of the gadoids, the whiting (*Merlangius merlangus,* Linnaeus 1758) and blue whiting (*Micromesistius poutassou,* Risso 1827) group, the haddock (*Melanogrammus aeglefinus,* Linnaeus 1758), pollack (*Pollachius pollachius,* Linnaeus 1758) and saithe (*P.virens,* Linnaeus 1758) group, and *Trisopterus* spp. (Rafinesque, 1814) group. Clupeids, horse mackerel (*Trachurus trachurus,* Linnaeus 1758), Atlantic mackerel (*Scomber scombrus,* Linnaeus 1758), and garfish (*Belone belone*, Linnaeus 1761) were grouped as pelagic species; the remaining fish species and crustaceans were grouped as demersal species and Cephalopods were grouped and considered separately. The adjustment used in Pierce et al. (2007) considering the predator weight was used for seals, using the average weight of the seals given in the literature.

Data were checked for normality using an Anderson-Darling test. Discriminate analysis (DA) was used to investigate similarities in the diet of four marine mammal species. DA is an ordination technique that can be used to address prey-assemblage data using *a priori* groups. Redundancy analysis (RDA) was used to investigate associations between predators (response variables) and the different prey groups (explanatory variables). Monte Carlo permutation test (n=4,999 permutations) was used to test the statistical significance of the explanatory variables, and point-vector biplots were displayed (see Zuur et al., 2007). All tests were carried out in the R environment (www.r-project.org) using the MASS package (http://www.stats.ox.ac.uk/pub/MASS4/; Venables and Ripley, 2002) for the DA and the vegan package (http://vegan.r-forge.r-project.org) for the RDA.

6.4. RESULTS

6.4.1. Study area and sample composition

A total of 90 bottlenose dolphins (Appendix V, Chapter 5), have been recorded stranded and by caught in Ireland since 1990, however only 12 dolphins were recovered for post mortem examination (Chapter 5, Figure 5.2). A total of 189 harbour porpoises have been recorded by UCC stranded and by caught in Ireland since 1993, but only 67 were recovered for post mortem examination (Figure 6.3). Sex ratio of bottlenose dolphins was 5♂:7♀, while 30 males, 31 females, and six individuals of undetermined sex was the composition of the harbour porpoises dissected. Two bottlenose dolphins and one harbour porpoise digestive tracts were empty (Table 5.1); two porpoises only had milk in their stomachs and one contained debris (plastic and feathers) (Table 6.3), and these were excluded from the analysis. A female bottlenose dolphin was recovered from drift nets targeting albacore (Table 5.1), while twelve (five males and seven females) harbour porpoises were recovered stranded with signs of interaction with fisheries or were known by-catch, recovered from fishing vessels. Bottlenose dolphin length ranged from 295 to 340 cm in males and 280 to 320 cm in females, and harbour porpoises ranged from 86 to 163cm in males and from 105 to 172cm in females. While the bottlenose

Figure 6.3. Map showing the locations of stranded porpoises. Green stars are considered by caught porpoises, the yellow stars is a live stranding, and red stars are stranded porpoises.

dolphins studied stranded mainly on the west coast of Ireland (Figure 5.3), harbour porpoises stranded along all Irish coasts (Figure 6.3), but predominately from the south and east coasts. All bottlenose dolphins examined were considered adults based on the length of the animal, while ten male and eighteen female harbour porpoises were considered adults based on length of the animal (Lockyer et al., 2001).

A total of 235 seal scats were used in this study; 103 were collected from two haul out sites of harbour seal colonies in west Cork and Galway (Figure 6.4; Kavanagh, 2008), and 132 grey seal scats were collected from the main beach of the Blasket's Islands (Co. Kerry, Figure 5.5)

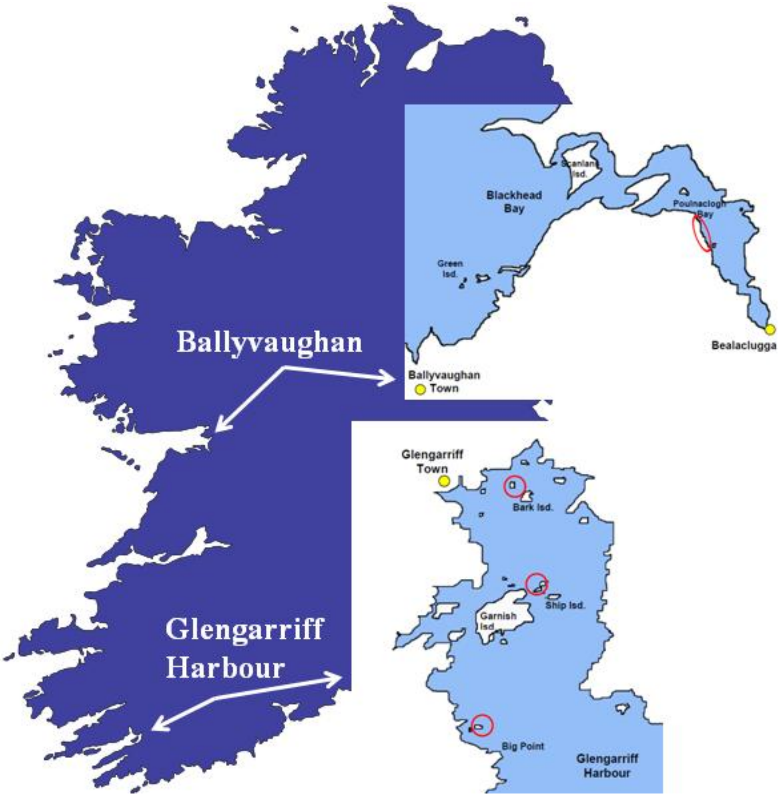


Figure 6.4. Map showing the sampling sites for the harbour seals (Adapted from Kavanagh, 2008)

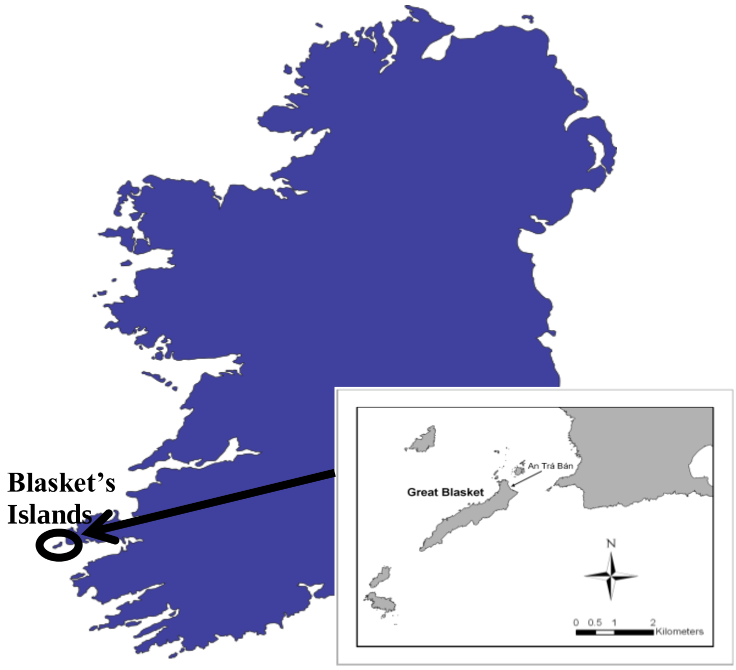


Figure 6.5. Map showing the sampling site for the grey seal (Adapted from Gosch et al., 2014)

6.4.2. Prey identification and quantification of diet

Sixty nine prey species were identified across the four predators (Table 5.2 -Chapter 5-, Tables 6.3, 6.4 and 6.5), with the prey diversity lower in harbour porpoises (n = 22) than in the other species (bottlenose dolphins n = 38, harbour seal n = 39, grey seal n = 42). Identification of prey to at least genus taxonomic level was achieved for 81% of the 4,239 prey items, and the total estimated biomass was 704.33kg for fish and 8.545kg for cephalopods. Gadiformes (excluding European hake -*Merluccius merluccius*, Linnaeus 1758) was the most commonly recorded prey type (49.9%N, 44.9%W) with *Trisopterus* spp. being the most commonly recorded prey type by number (25.0%) but comprising a very small percentage of biomass (3.2%). The incidence of pelagic prey (including blue whiting) was 9.2% by number and 21.4% by biomass. The rest of the prey were considered demersal or benthic; within this group flatfish occurred 33.1% by number but they contributed little in terms of biomass (4.9%). Despite this general overview, each predator was preying on a range of different prey species (Table 5.2 -Chapter 5, Tables 6.3, 6.4 and 6.5).

Table 6.1- Prey species identified from stranded and by caught harbour porpoises on Irish coasts (N=66). Each prey is represented as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W), and index of relative importance (IRI). Length of prey is total length for fish and dorsal mantle length for squid. * considering the stomach with debris, # considering no empty stomachs. Length is given in mm and weight in grams

Prey species	F	F%	N	N%	W	W%	IRI	Length range	Average length	Weight range	Average weight
Osteichthyes											
Anguilliformes											
Anguilla anguilla	1	1.6	1	0.1	NA	NA	NA	NA	NA	NA	NA
Clupeiformes											
Clupea harengus	21	33.3	73	4.3	54,957.1	38.7	1434.5	30-669	249	0.5-7499.6	820.3
Sprattus sprattus	6	9.5	39	2.3	971.0	0.7	28.6	37-253	134	0.2-168.7	24.9
Unidentified Clupeids	10	15.9	40	2.4	1,995.8	1.4	60.0	208-436	194	7.0-1,109.3	133.1
Gadiformes											
Micromesistius poutassou	3	4.8	7	0.4	2,447.7	1.7	10.2	87-264	162	26.9-1,093.9	349.7
Merlangius merlangus	23	36.5	184	10.9	12,106.4	8.5	710.4	67-422	191	3.0-669.5	87.1
Melanogrammus aeglefinus	7	11.1	50	3.0	10,753.3	7.6	117.1	150-438	266	25.5-905.4	215.1
Pollachius spp	3	4.8	6	0.4	170.5	0.1	2.3	75-209	138	2.9-74.8	28.4
Gadus morhua	1	1.6	1	0.1	225.6	0.2	0.4	303	-	225.6	-
Trisopterus spp.	29	46.0	709	42.1	3,243.5	2.3	2044.3	29-275	82	0.2-250.7	4.6
Gadiculus argenteus thori	1	1.6	1	0.1	25.9	0.0*	0.1	24	-	25.9	-
Phycis spp.	2	3.2	2	0.1	8.0	0.0*	0.4	61-527	224	2.8-1,423.5	156.8
Unidentified Gadidae	28	44.4	420	25.0	52,377.0	36.9	2748.2	61-527	224	2.8-1,423.5	156.8
Merluccius merluccius	2	3.2	2	0.1	340.0	2.2	1.1	128-325	227	93.0-247.0	170.0
Perciformes											
Trachurus trachurus	3	4.8	33	2.0	292.1	0.2	10.3	85-155	109	3.9-28.2	9.7
Scomber scombrus	1	1.6	1	0.1	1,842.8	1.3	2.2	593	-	1842.8	-
Argentina spp.	2	3.2	2	0.1	95.3	0.1	0.6	139-196	167	22.4-72.9	47.6
Unidentified Gobiidae	1	1.6	7	0.4	6.8	0.0*	0.7	16-46	27	0.3-3.2	1.0
Ammodytidae	6	9.5	13	0.8	125.8	0.1	8.2	66-252	173	0.4-20.9	18.0
Pleuronectiformes											
Pleuronectes platessa	1	1.6	1	0.1	35.6	0.0*	0.1	163	-	35.6	-
Unidentified fish	5	7.9	10	0.6	NA	NA	NA	NA	NA	NA	NA
Cephalopoda											
Unidentified cephalopod	9	14.3	35	2.1	NA	NA	NA	NA	NA	NA	NA
Miscelaneous											
Crustacean	6	9.5	30	1.8	NA	NA	NA	NA	NA	NA	NA
Echinoderms	1	1.6	4	0.2	NA	NA	NA	NA	NA	NA	NA
Seaweed	2	3.1	2	0.1	NA	NA	NA	NA	NA	NA	NA
Feathers *	1	1.6	2	0.1	NA	NA	NA	NA	NA	NA	NA
Plastic *	2	3.1	5	0.3	NA	NA	NA	NA	NA	NA	NA
Other	2	3.2	2	0.1	NA	NA	NA	NA	NA	NA	NA
Milk #	2	3.0									
TOTAL	**63**		**1,682**		**14,2020**						

Table 6.2 Prey species identified from harbour seal scats collected on the west coast of Ireland (N=103). Each prey is represented as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W), and index of relative importance (IRI). Length of prey is total length (mm) for fish and dorsal mantle length (mm) for squid; weight is given in grams

Prey species	**F**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**	**Length range**	**Average length**	**Weight range**	**Average weight**
Osteichthyes											
Anguilliformes											
Conger conger	3	2.9	4	0.3	1,741.3	2.6	8.5	158-789	498	32.0-805.1	260.0
Anguilla anguilla	1	1.0	1	0.1	127.4	0.2	0.3	435		127.4	
Cepola rubescens	3	2.9	6	0.5	212.4	0.3	2.3	243-676	351	12.9-119.2	35.4
Clupeifomres											
Clupea harengus	9	8.7	14	1.1	2,996.0	4.5	48.7	73-420	278	2.8-639.6	214.0
Salmoniformes	2	1.9	2	0.2	430.5	0.7	1.6	189-278	233	181.9-248.5	215.2
Gadiformes											
Micromesistius poutassou	5	4.9	5	0.4	114.4	0.2	2.7	170-289	219	3.0-72.3	22.9
Merlangius merlangus	12	11.7	34	2.7	4,800.5	7.2	114.6	155-509	247	24.3-1,352.2	141.2
Melanogrammus aeglefinus	1	1.0	1	0.1	51.3	0.1	0.2	185		51.3	
Pollachius spp	5	4.9	7	0.6	1,666.0	2.5	14.8	239-618	431	113.4-2,300.3	900.7
M.aeglefinus/Pollachius spp.	4	3.9	8	0.6	1,614.7	2.4	11.8	219-345	267	51.2-399.2	201.8
Trisopterus esmarkii	4	3.9	4	0.3	43.2	0.1	1.5	111-138	125	6.9-14.9	10.8
Trisopterus luscus	4	3.9	9	0.7	1,296.5	1.9	10.3	102-260	186	13.8-221.0	144.1
Trisopterus minutus	4	3.9	6	0.5	128.7	0.2	2.6	117-163	137	12.2-37.1	21.5
T.luscus/T.minutus	17	16.5	70	5.5	3,064.6	4.6	165.7	59-258	143	3.1-205.6	43.8
Trisopterus spp.	21	20.4	34	2.7	1,291.1	1.9	93.4	56-242	144	1.0-150.0	34.2
Ciliata mustela	8	7.77	41	3.2	4,340.25	6.50	75.3	136-967	233	179.2-516.7	367.8
Gaidropsaurus vulgaris	1	1.0	3	0.2	1,103.4	1.7	1.8	267-382	334	179.2-516.7	367.8
Molva molva	1	1.0	1	0.1	942.8	1.4	1.5	594		942.8	
Unidentified Gadidae	7	6.8	11	0.9	4,383.6	6.6	50.4	139-433	321	31.0-811.1	398.5
Merluccius merluccius	3	2.9	4	0.3	282.4	0.4	2.1	158-287	198	30.1-172.3	70.6
Perciformes											
Trachurus trachurus	10	9.7	16	1.3	4,281.9	6.4	74.4	83-556	197	3.6-1,903.0	267.6
Scomber scombrus	2	1.9	2	0.2	677.9	1.0	2.3	136	-	16.0	-
Callionymus spp.	25	24.3	155	12.1	8,431.0	12.6	599.3	55-64	160	0.9-2,208.3	54.4
Labrus mixtus	3	2.9	3	0.2	401.5	0.6	2.4	210-252	228	98.6-185.6	133.8
Pomatochistus minutus	7	6.8	47	3.7	3,821.7	5.7	63.8	73-1,612	140	2.9-95.3	81.3
Unidentified Gobiidae	1	1.0	1	0.1	47.0	0.1	0.1	139	-	47.0	-
Ammodytidae	23	22.3	666	51.8	6,384.1	9.6	1370.9	63-435	131	0.7-180.6	9.6
Scorpaena spp.	1	1.0	1	0.1	11.0	0.0*	0.1	89	-	11.0	-

Table 6.2 Continue	**F**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**	**Length range**	**Average length**	**Weight range**	**Average weight**
Pleuronectiformes											
Scophthamus spp.	2	1.9	5	0.4	712.5	1.1	2.8	160-228	192	76.4-228.8	142.5
Platichthys flexus	2	1.9	3	0.2	1,506.8	2.3	4.8	292-461	369	257.3-827.1	502.3
Hippoglossoides platessoides	7	6.8	12	0.9	456.0	0.7	11.0	74-298	145	2.6-226.3	38.0
Pleuronectes platessa	3	2.9	4	0.3	1,317.5	2.0	6.7	205-399	296	75.5-706.0	329.4
Limanda limanda	1	1.0	2	0.2	83.2	0.1	0.3	158-183	170	32.0-51.2	41.6
Glyptocephalus cynoglossus	2	1.9	3	0.2	21.2	0.0*	0.5	53-149	93	1.7-16.2	7.1
Microchirus variegatus	2	1.9	18	1.4	376.0	0.6	3.8	75-159	121	4.4-44.2	29.9
Arnoglossus laterna	1	1.0	1	0.1	25.6	0.0*	0.1	155	-	25.6	-
Arnoglossus thori	1	1.0	1	0.1	7.1	0.0*	0.1	106	-	7.1	-
Solea solea	2	1.9	36	2.8	4,862.3	7.3	19.6	170-294	238	41.8-250.3	135.1
Unidentified flatfish	5	4.9	8	0.6	314.4	0.5	5.3	121-197	155	17.7-76.0	39.3
Unidentified fish	14	13.6	14	1.1	-	-	-	-	-	-	-
Cephalopoda											
Loligo spp.	2	1.9	3	0.2	1,957.3	2.9	6.2	308-316	312	628.8-676.3	652.4
Eledone spp.	1	1.0	1	0.1	77.5	0.1	0.2	-	-	77.5	-
Unidentified cephalopod	1	1.0	1	0.1	-	-	-	-	-	-	-
Crustacean											
Nephrops norvegicus	5	4.9	6	0.5	357.5	0.5	4.9	50-221	105	27.3-68.7	59.6
Unidentified Crustacea	6	5.8	6	0.5	-	-	-	-	-	-	-
Molusca (no Cephalopoda)											
Bivalvia	3	2.9	3	0.2	-	-	-	-	-	-	-
Gastropoda	1	1.0	2	0.2	-	-	-	-	-	-	-
TOTAL	**103**		**1,285**		**66,761.8**						

Table 6.3 Prey species identified from grey seal scats collected on the west coast of Ireland (N=132). Each prey is represented as percentage frequency of occurrence (%F), percentage importance by number (%N), percentage importance by weight (%W), and index of relative importance (IRI). Length of prey is total length (mm) for fish and dorsal mantle length (mm) for squid; weight is given in grams.

Prey species	F	F%	N	N%	W	W%	IRI	Length range	Average length	Weight range	Average weight
Chondrichthyes											
Raja spp	2	1.5	2	0.2	NA	NA	NA	NA	NA	NA	NA
Osteichthyes											
Anguilliformes											
Anguilla anguilla	1	0.8	1	0.1	49.8	0.1	0.1	345	-	49.8	-
Conger conger	1	0.8	1	0.1	6,454.6	6.6	5.1	1,380	-	6,454.5	-
Clupeifomres											
Clupea harengus	2	1.5	2	0.2	142.2	0.1	0.5	165-252	209	25.0-117.2	71.11
Beloniformes											
Belone belone	4	3.0	15	1.6	1,646.2	1.7	9.9	465	-	109.8	-
Petromyzontiformes											
Petromyzon marinus	3	2.3	3	0.3	3,750.0	3.8	9.4	600	-	1,250.0	-
Salmoniformes											
Salmo spp.	31	23.5	46	4.9	23,388.4	23.8	674.7	180-553	345	70.0-1,870.0	508.44
Gadiformes											
Micromesistius poutassou	19	14.4	29	3.1	10,548.9	10.8	199.2	89-274	179	28.9-1,241.2	363.8
Merlangius merlangus	22	16.7	28	3.0	1,999.2	2.0	83.7	116-250	192	14.8-144.1	71.4
Melanogrammus aeglefinus	2	1.5	2	0.2	257.9	0.3	0.7	254-257	255	111.9-143.0	129.0
Pollachius spp	14	10.6	20	2.1	5,023.1	5.2	76.9	141-388	289	17.6-542.5	254.2
T. esmarkii	3	2.3	3	0.3	44.7	0.1	0.8	109-139	128	8.9-21.9	14.9
T. luscus	19	14.4	26	2.8	2,308.1	2.4	73.8	96-264	188	12.1-233.7	88.8
T. minutus	26	19.7	34	3.6	1,895.3	1.9	109.4	80-278	166	7.0-265.3	55.8
T.luscus/T.minutus	22	16.7	59	6.3	2,797.4	2.9	152.2	66-281	157	3.8-286.7	47.4
Trisopterus spp.	42	31.8	75	8.0	1,627.1	1.7	306.9	31-227	125	0.2-109.0	21.7
Unidentified Gadidae	56	42.4	63	6.7	4,607.6	4.7	483.8	72-212	152	6.3-170.3	73.1
Gaidropsaurus vulgaris	3	2.3	3	0.3	3,118.0	3.2	7.9	421-664	583	350.3-1,383.8	1,039.3
Ciliata mustela	1	0.8	1	0.1	264.4	0.3	0.3	382	-	264.4	-
Molva molva	1	0.8	1	0.1	547.2	0.6	0.5	491	-	547.2	-
Merluccius merluccius	5	3.8	5	0.5	1,365.1	1.4	7.3	181-309	253	246.1-193.2	273.0
Perciformes											
Callionymus maculatus	3	2.3	4	0.4	177.0	0.2	1.4	176	-	44.2	-
C. lyra	19	14.4	32	3.4	1,592.4	1.6	72.4	112-264	182	11.4-135.0	47.8
Callionymus spp.	25	19.0	25	2.7	929.6	1.0	68.4	89-271	167	6.4-113.6	37.2
Trachurus trachurus	3	2.3	3	0.3	488.9	0.5	1.9	264	-	163.0	-
Scomber scombrus	1	0.8	1	0.1	1,906.5	1.9	1.6	599	-	1,906.5	-
Caragoboides geomys	3	2.3	3	0.3	27.0	0.0*	0.8	69-104	90	2.7-13.2	9.0

Table 6.3. cont.	**F**	**F%**	**N**	**N%**	**W**	**W%**	**IRI**	**Length range**	**Av.length**	**Weight range**	**Av.weight**
Ammodytidae	50	37.9	292	31.1	4,355.0	4.4	1,346.0	47-256	148	1.0-331.1	14.9
Triglidae	2	1.5	2	0.2	NA	NA	NA	NA	NA	NA	NA
Zoarces viviparous	4	3.0	10	1.1	2,550.0	2.6	11.1	260	-	255.0	-
Perca fluviatilis	1	0.8	1	0.1	23.6	0.0*	0.1	131	-	23.6	-
Labrus bergylta	1	0.8	1	0.1	157.5	0.2	0.2	216	-	157.5	-
L. mixtus	2	1.5	2	0.2	331.9	0.3	0.8	226-259	243	126.9-205.5	166.0
Labrus spp.	8	6.1	16	1.7	1,617.0	1.7	20.3	168-272	207	46.2-242.3	101.06
Pleuronectiformes											
Arnoglossus spp.	1	0.8	1	0.1	18.0	0.0*	0.1	134	-	18.0	-
Buglossidium luteum	3	2.3	3	0.3	157.7	0.2	1.1	53	-	172.0	-
Limanda limanda	2	1.5	2	0.2	1,000.0	1.0	1.9	400	-	500.0	-
Hippoglossus hippglossus	3	2.3	4	0.4	608.1	0.6	2.4	145-191	176	76.5-189.9	152.0
Hippoglosoides platessoides	2	1.5	2	0.2	193.1	0.2	0.6	222-246	234	79.8-113.3	96.6
Microstomus kitt	8	6.1	9	1.0	1,950.2	2.0	17.9	211-337	253	121.5-439.7	216.7
Pleuronectes platessa	1	0.8	1	0.1	1,897.8	1.9	1.5	557	-	1897.8	-
Solea solea	2	1.5	3	0.3	1,845.5	1.9	3.5	311-388	351	300.2-624.3	461.4
Glyptocephalus cyanoglossus	2	1.5	2	0.2	30.8	0.0*	0.4	143-151	147	14.1-16.8	15.4
Unidentified flatfish	13	9.9	14	1.4	2976.3	3.0	44.5	95-246	226	9.1-254.2	212.6
Unidentified fish	53	40.2	75	8.0	NA	NA	NA	NA	NA	NA	NA
Cephalopoda											
Loligo spp.	5	3.8	6	0.6	22.5	0.0*	2.5	15-152	95	0.1-22.2	3.7
Eledone spp.	5	3.8	5	0.5	1,454.4	1.5	7.6	NA	NA	0.5-727.7	290.9
TOTAL	**132**		**939**		**98,145.9**						

Fish length varied depending on both the predator and prey (Fig. 6.6, 6.7, 6.8, 6.9). Harbour seals preyed on small fish (less than 70mm), while the other three predators fed on a wider range of prey (Fig 6.6). However, the prey found in the diet of harbour porpoises was the smallest recorded (55% of all prey was below 10cm), followed by grey seal prey (92% of ranged between 3cm and 27cm length). Bottlenose dolphins consumed larger prey with a peak (32%) of fish prey larger than 35cm (Fig 6.6).

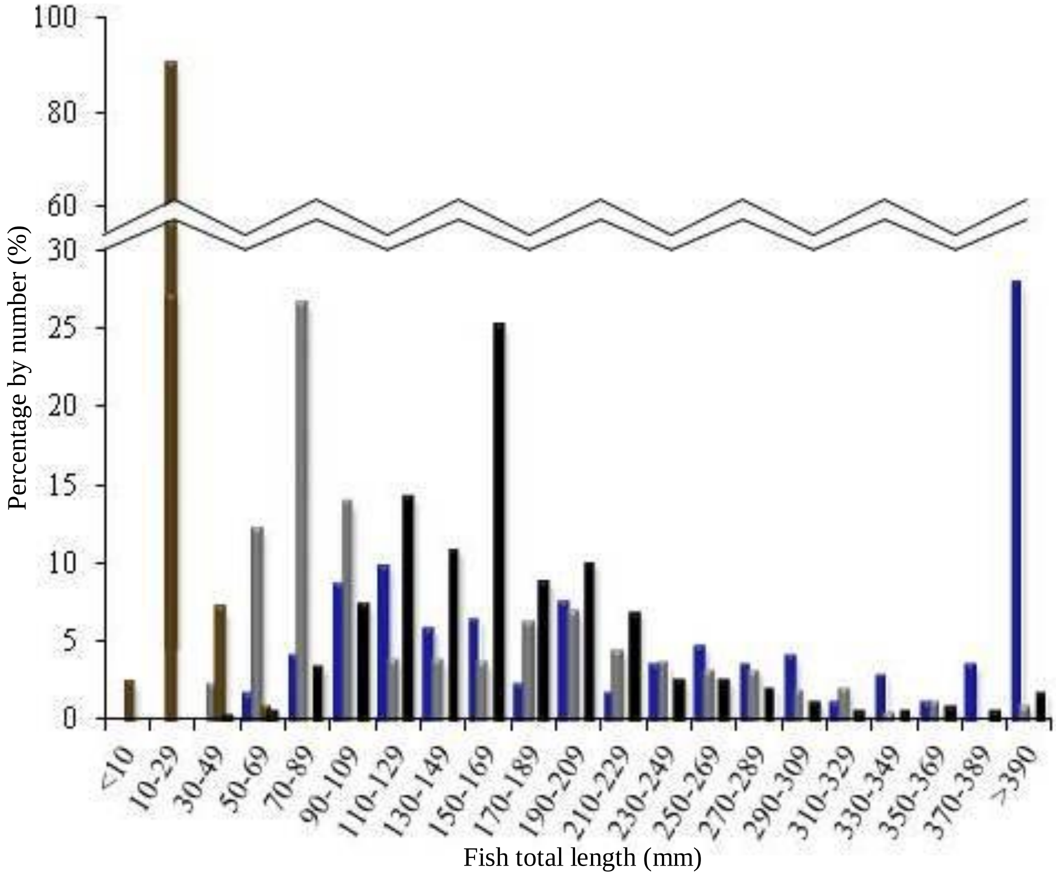


Figure 6.6 Size of fish prey found in grey seal (black), harbour seal (brown), harbour porpoise (grey) and bottlenose dolphin (blue) diet.

Trisopterus spp. were eaten by all predators and were predominately juvenile/early life stages (85% of these species were below 130mm in length), and 98% were below 250mm. *Trisopterus* spp. was consumed primarily by harbour porpoises (66%N), followed by grey seals (19%N) and harbour seals (13%N), Fig. 6.7. Whiting/blue whiting smaller than 150mm comprised 69% of all prey items within this group, while 11% were larger than 170mm (MLS for blue whiting in North West of Iberian Peninsula), and only 6.5% were over 270mm (MLS for haddock) (Fig 6.8). Within the Gadiformes, the haddock/pollack/saithe group occurred within the diet of all four

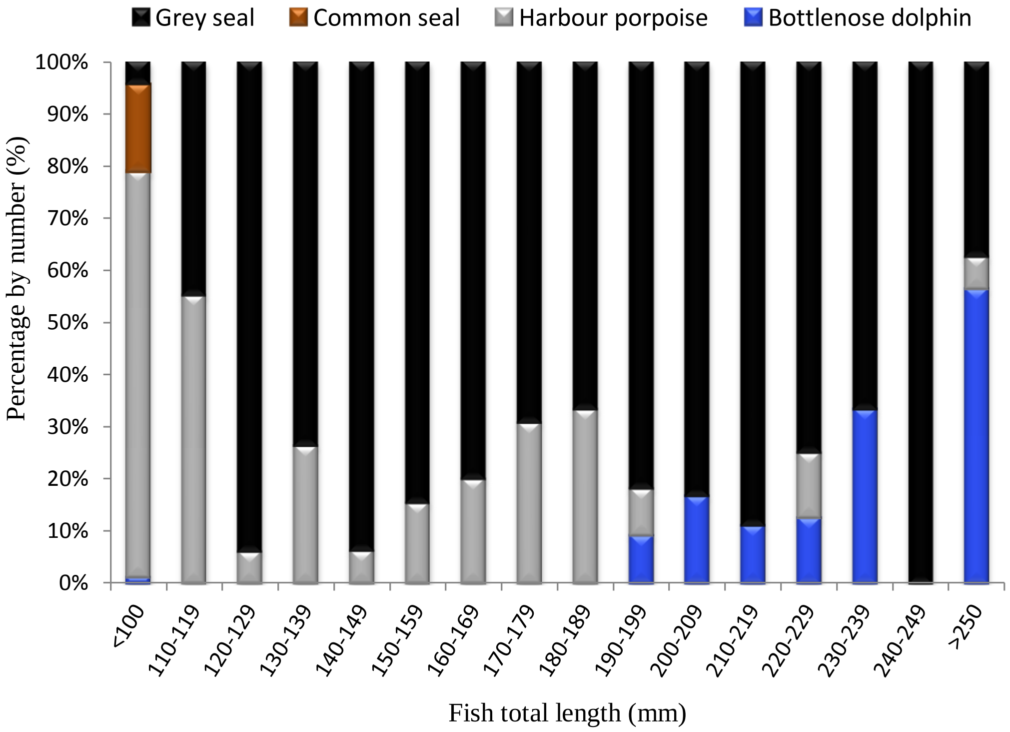


Fig 6.7. Length frequency distribution of *Trisopterus* spp. found within the diet of the four coastal marine mammals in Irish waters.

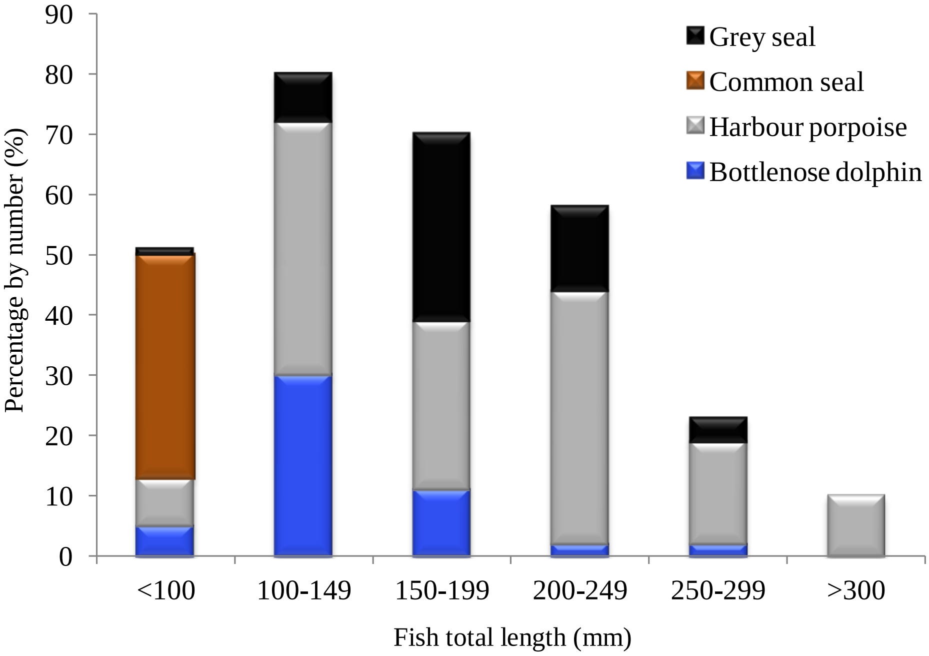


Fig. 6.8. Length frequency distribution of whiting/blue whiting group found within the diet of the four coastal marine mammals in Irish waters.

predators and the length of 64% of this group was below the MLS (300mm for haddock and pollack) (Fig. 6.9).

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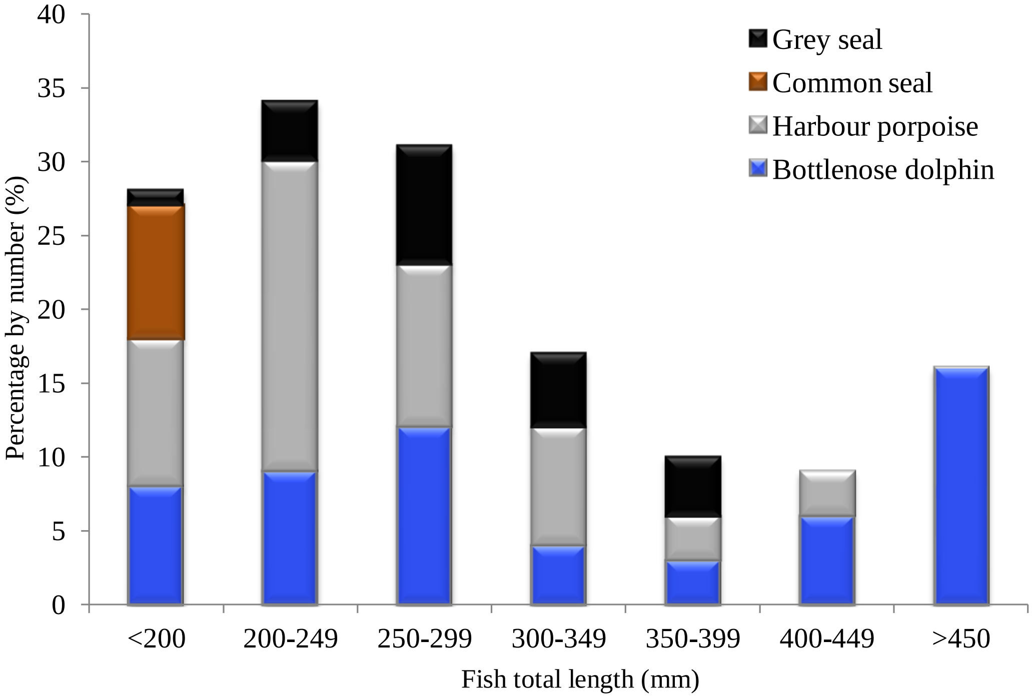

Fig. 6.9. Length distribution of haddock/pollack/saithe group found within the diet of the four coastal marine mammals in Irish waters.

6.4.3. Annual food consumption and statistical analysis

The estimated weights of the bottlenose dolphin (Chapter 5) and harbour porpoise in this study ranged from 257 to 632 kg and from 9 to 64 kg, respectively (Appendix VI). It was not possible to the estimate the length of the seals as the scats were collected when seals were not on the haul outs; however, an average weight of 97.5kg and 194kg was assumed for harbour and grey seals, respectively (Burns, 2002; Bonner, 1981; Chapter 7).

The results of the annual food consumption for bottlenose dolphin, harbour porpoise, harbour seal and grey seal coastal populations are presented in Table 6.4. A total of

25,946 tonnes of prey was estimated to be consumed by these coastal marine mammals around Ireland using the general equation given by Col et al. (2012).

		Bottlenose dolphin	Harbour porpoise	Harbour seal	Grey seal
C (tonnes)		2,051.9	10,852.3	3,387.6	5,793.9
Population estimation*	Irish Sea	235 (0.75)	15,230 (0.35)		
	Other coasts	313 (0.81)	10,716 (0.37)		
	Total	538	25,946	4,153	5,343 (5,509-7,083)

Table 6.4. Annual food consumption calculated using the Col et al. 2012 equation for the average weight estimated for the bottlenose dolphin (381.8kg, SD=92.4), harbour porpoise (32.3kg; SD=13.3), harbour seal (97.5kg) and grey seal (195kg). Coefficient of variation for cetaceans are in brackets; grey seal population range in brackets

The annual food consumption estimations using equation 1.12 for the main prey groups is shown in Table 6.5. Equal weighting and weighting related to the body weight of the marine mammal estimations are included in the Appendix.VII

	Bottlenose dolphin	Harbour porpoise	Harbour seal	Grey seal
Whiting/blue whiting	46.2	4,241.0	250.0	751.8
Pollack/saithe/haddock	226.0	3,213.5	409.7	316.4
Trisopterus spp.	28.2	962.0	285.4	519.6
Other Gadoids	57.4	15,484.3	842.0	511.6
Atlantic hake	146.3	100.0	14.4	39.5
Pelagic fish	42.4	17,661.3	404.6	250.7
Demersal species	427.4	77.5	1,578.1	3,325.5
Cephalopods	25.2	0	103.5	79.0
Total	**999.1**	**41,739.5**	**3,887.6**	**5,793.9**

Table 6.5. Annual food consumption (tonnes) of the grouped prey of bottlenose dolphin, harbour porpoise, harbour seal and grey seal.

As it can be seen from Table 6.5, the total annual food consumption for all coastal species is higher for the two cetacean species in comparison to results presented in Table 6.4 of the estimated biomass consumed using equation 1.12. The main prey (by weight) consumed fell within the category demersal fish species, which were mainly predated on by the pinniped species. Whiting/blue whiting was the next important prey group by weight being consumed mostly by grey seals and harbour porpoise

To examine differences in feeding preferences between species, redundancy analysis was carried out and the results are summarized in Table 6.6. In this analysis, the four marine mammals were treated as response variables and prey items as the explanatory variables. Significant effects were found in different group-prey items, although association trends were weak and only 28% of the explanatory variables (prey items) explained the associations. A positive relationship was found between grey seals and salmonids (SAL), and a negative relationship between salmonids and harbour porpoise (Figure 6.8). Bottlenose dolphin was found to be associated with large demersal prey (BEN_l), Atlantic hake (HKE) and cephalopods (CEP) in the biplot; however, large demersal prey did not show a significant result (Figure 6.8, Table 6.6). On the other hand, harbour seals were weakly associated with sandeels (SAN) and dragonets (DRA), although the statistical significance was very low for sandeels (Figure 6.8, Table 6.6).

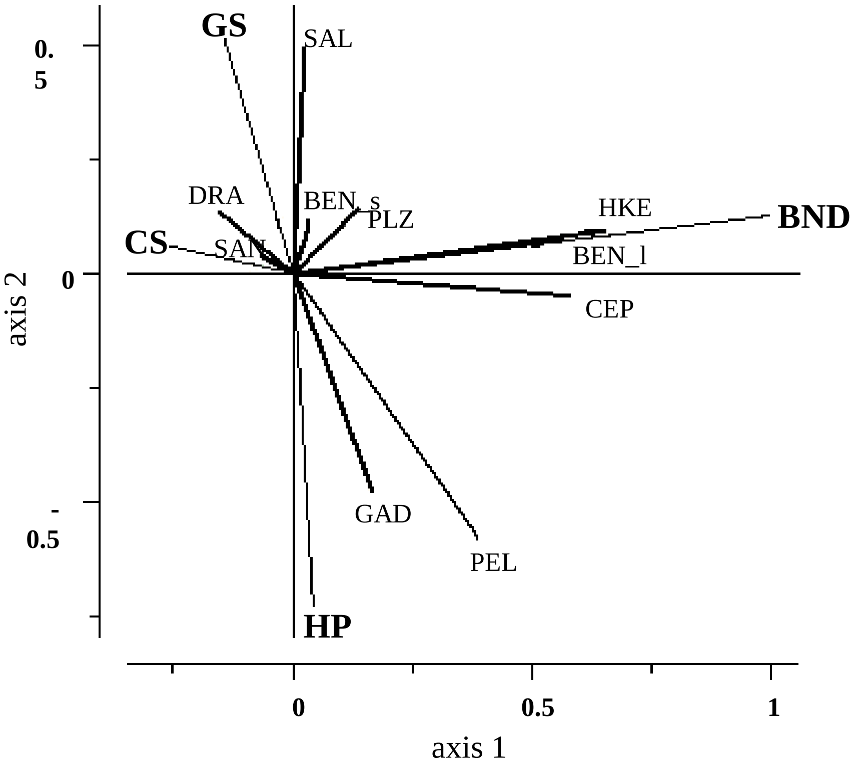

Fig 6.8 Redundancy analysis vector biplot for diet; prey codes are explained in table 5.6; CS: harbour seal; GS: grey seal, BND: bottlenose dolphin, HP: harbour porpoise. Response variables are represented by thick lines and explanatory variables by fine lines.

λ1	**λ2**	**Sum**	**Explanatory variables** **Categories**	**Codes**	**F**	***p***
12.4	9.6	0.28	Salmonids	SAL	13.409	0.000
			Gadoids	GAD	8.225	0.005
			Atlantic hake	HKE	15.614	0.000
			Pelagic fish	PEL	16.295	0.000
			Dragonets	DRA	6.300	0.002
			Sandeels	SAN	2.589	0.04
			Large demersal fish	BEN_l	8.016	0.012
			Small demersal fish	BEN_s	2.876	0.045
			Flatfish	PLZ	1.109	0.308
			Cephalopods	CEP	13.848	0.000

Table 6.6. Numerical output of the RDA (description of response and explanatory variables are in Table 5.6); analysis is based on prey numbers. The table lists the eigenvalues for the first two axes (*λ1, λ2*), the sum of all canonical values (*Sum*), results of F test (*F*) and associated p-value (*p*)

Results from the discriminant analysis, using the same variables as in the RDA (Table 6.6), showed that 96% of the data could be explained by the first two axis; and the statistical tests indicated that the data separated by groups and samples were classified correctly for most of the predators (Table 6.7). Harbour seals were poorly discriminated (26.5%), whereas in contrast, grey seals were very well defined (89.9%). The tolerance interval graph (Figure 6.9) shows that both seal species were feeding on similar prey,

Statistics	Value	F	p-value
Wilks' lambda	0.547	11.815	0.000
Barlett-Pillai	0.517	11.039	0.000
Hotelling-Lawley	0.712	12.417	0.000

Percentage of correctly classified samples	
Harbour seal	26.5%
Grey seal	89.9%
Bottlenose dolphin	55.6%
Harbour porpoise	48.3%

Table 6.7. Numerical output of the discriminant analysis test.

and that both seal species represented an overlapping diet with harbour porpoise. In contrast, bottlenose dolphins appeared to have a different diet, with no overlap with the other species (Figure 6.9).

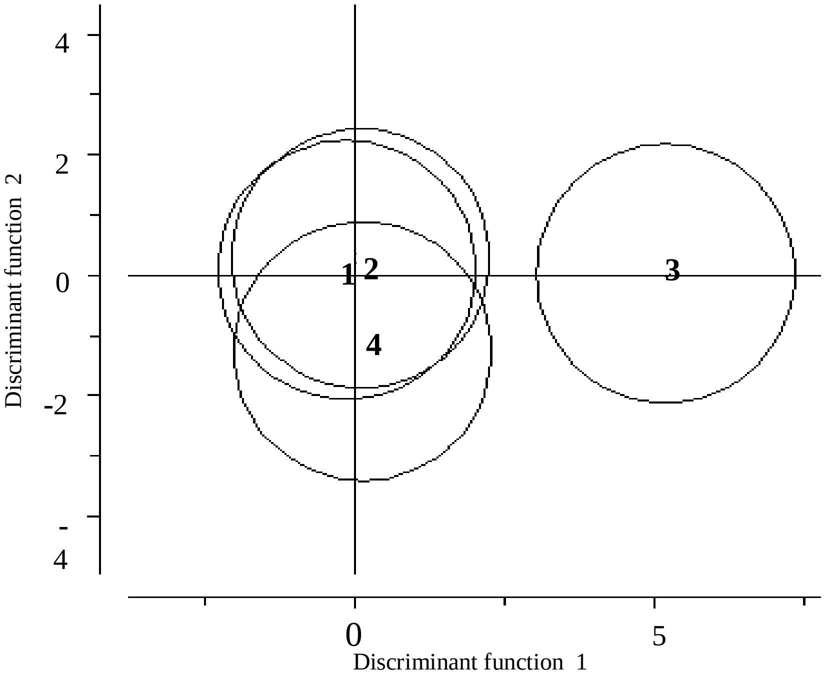

Fig 6.9 Discriminant analysis plot of the 95% tolerance intervals (were 95% of the data are found). The numbers refer to the different predators: harbour seal (1), grey seal (2), bottlenose dolphin (3), and harbour porpoise (4).

6.5. DISCUSSION

There are relatively few published studies comparing the diet of different marine mammal species (Dinis et al., 2008; Garcia-Godos et al., 2004; Hassani et al., 1997; Hauksson and Bogason, 1997; Querouil et al., 2013; Spitz et al., 2006b; Thompson et al., 1996; Villegas-Amtmann et al., 2013), but studies combining diet information from both seals and dolphins have not been found in the literature. A number of studies have looked at overlap between cetaceans and other predators such as sharks; for example, Heithaus (2001) reviewed the potential overlap between different species of sharks and dolphins around the world, and he found that diet overlap occurred between sharks and common dolphins. In contrast, Acevedo-Gutierrez (2002) found that sharks decreased their food intake when bottlenose dolphin group size increased on the Pacific coast of Costa Rica. A number of recent studies have used stable isotope analysis to examine niche width and trophic position within and between cetacean species (e.g., Das et al., 2003; Mendez-Fernandez et al., 2012, 2013; Ryan et al., 2013) and other top predators (Cherel et al., 2010; McClellan et al., 2010; Pusineri et al., 2008; Shiffman et al., 2012; Young et al., 2010).

Identification of prey in dolphin diet studies are usually carried out by analysing stomach contents recovered from carcasses. However, two different sources of samples can be obtained from seals – carcasses and scats. Carcasses are rarely found on beaches, and they are often in an advanced stage of decomposition, whereas the recovery of seals from fishing nets is a potential sample source. Some authors have indicated that a high proportion of by caught animals present empty stomachs (e.g., Pierce et al., 1989, 1991; Rae, 1968), therefore scats are a good source for dietary studies in seals. On the other hand, Ridoux et al. (2007) found that prey in stomachs from by caught seals differed substantially from prey found in scats in the same area; those differences might be due to the fact that animals collected in the nets were younger and scats might be more representative of more diverse age-classes; indeed, by caught seals are usually reported to be juveniles (e.g., Rae, 1962; Kiely et al., 2000), and a recent study on the west coast of Ireland has suggested that adults might avoid fishing areas at least where mobile gears are used (Cronin et al., 2012).

Biases on the use of this type of samples for foraging ecology of marine mammals have been already described (Chapter 2; Pierce et al., 2004; Tollit et al., 2010). Remains obtained from scats are usually highly eroded and the application of digestion coefficient factors for otoliths (Grellier and Hammond, 2006; Tollit et al., 1997) are usually applied to reduce the probability of under-estimating the prey biomass consumed by seals. In this study, 20% of grey seal prey was identified using structures other than otoliths and no digestive coefficient factors were available in the literature for these bones. Therefore, the size and weight of prey identified through bones will likely be underestimated. On the other hand, the average weight of grey seal was used by taking the average weight for males and females, as reported in the literature (Bonner, 1981). This value will be biased by the considerably heavier male weight, therefore food consumption estimates may be overestimated, unless the sex ratio is skewed in favour of females.

The diet of all species showed a high diversity of prey species, suggesting that all might be generalist predators, feeding on locally available prey. However, more than 50% of the diet comprised gadoid species, such as haddock, pollack, whiting, and *Trisopterus* spp. The latter group comprises three species (Norway pout -*Trisopterus esmarki* (Nilsson, 1855)-, poor cod -*T.minutus* (Linnaeus, 1758)-, bib -*T.luscus* (Linnaeus, 1758)) whose distributions are restricted to European and North African waters (www.fishbase.org). On the other side of the Atlantic, these predators feed on Perciformes (Barros and Wells, 1998; Bowen and Harrison, 1994; Payne and Selzer, 1989) or clupeoids (Palka et al., 1996), which might also suggest an opportunistic behaviour preying on the more available species.

The relatively high importance of the occurrence of *Trisopterus* spp. species in all coastal predators is of note, and different to studies in other areas in the European Atlantic waters (e.g., Brown et al., 2001; Olsen and Bjørge, 1995; Ridoux et al., 2007; Santos and Pierce, 2012; Santos et al., 2001c, 2004; Spitz et al., 2006b). In Ireland, it seems that the occurrence of this prey-group might be important for a wide variety of dolphin species (Chapter 2 -striped dolphin (*Stenella coeruleoalba*, Meyen 1833), Chapter 3 -Atlantic white-sided dolphin (*Lagenorhynchus acutus*, Gray 1828), Brophy et al., 2009 -common dolphin (*Delphinus delphis*, Linnaeus 1758)), as well as in other European waters (Canning et al. 2008; De Pierrepont et al., 2005; Meynier, et al. 2008;

2004; Santos et al., 2004; Silva, 1999; Spitz et al., 2006b). However, the biomass contribution in the diet in all studies suggests that they were feeding on small fish, as the percentage by number was relatively high and the percentage by reconstructed biomass was relatively low. This is borne out by the reconstructed length frequency distribution of these species, with 98% below 250mm length.

Alongside the importance of gadoids in the diet of all predators, each species appears to have some prey preferences, as was reported in other areas of European waters. In the North Sea, sandeels were found to be important for both grey and harbour seals, as well as for harbour porpoises (Brown et al., 2001; Prime and Hammond, 1990; Santos et al., 2004; Thompson et al., 1996). Sandeels aggregate in large concentrations in the North Sea and sandeels are very important for both top predators and fisheries (ICES, 2012). In the Celtic Sea and on the west coast of Ireland, large sandeel concentrations are unusual (David Reid, *pers. comm.*). This type of fish behaviour might limit predation opportunity.

Dragonets (*Callionymus* spp., Linnaeus 1758) were found to be an important prey item in the diet of grey seals in Irish waters; however dragonets present very fragile otoliths and their occurrence might be underestimated. Gosch et al. (2014) and Luck (2013) indicated that the occurrence of dragonets in the diet increased when specific bones were included in diet reconstruction. Luck (2013) found that the occurrence of dragonets using only otoliths was 6%, however when bones were included this increased to 13%. In other areas, the occurrence of *Callyonimus* spp. in the diet was lower or non-existent (Hammond et al., 1994a, 1994b; Prime and Hammond, 1990; Thompson et al., 1996). This is either as a result of differing local abundances and species distribution, or an over-reliance on otoliths to reconstruct diet, resulting in an underestimation of this prey. Harbour seals have been reported to feed on gobies and small flatfish in the Moray Firth, Scotland (Thompson et al., 1996), North Sea (Hall et al., 1998; Mees and Reijnders, 1994), and the Shetland Islands (Brown et al., 2001). A high proportion of these prey items were also found in harbour seals in this study. In contrast, flatfish were found in both seal species but they were usually smaller in length in the diet of harbour seals. The fact that they are feeding on different prey sizes might indicate that despite the dietary overlap between these two species, some resource partitioning might occur, with harbour seals feeding in more inshore waters.

Salmonids (Atlantic salmon -*Salmo salar*, Linnaeus 1758- and sea trout -*Salmo trutta*, Linnaeus 1758) have been reported in the diet of seals and seabirds in the NE Atlantic (e.g., Brown, 2008; Butler et al., 2006 and refs therein; Butler et al., 2011; Cronin et al., 2010; Gosch et al., 2014), and in particular in grey seals. The prey remains recovered from harbour seal scats were more damaged than those ones recovered from grey seals. Furthermore, only a few bones were recovered from harbour seal scats and they were mainly identified as salmonid bones; it was not possible to differentiate to species level. It is likely that salmonids are underrepresented in the diet of harbour seals. Harbour seals may be feeding on salmonids more regularly that it has been found in the diet due to the fragility of the bones/otolith.

Spawning grounds of Atlantic herring and sprat are concentrated in the coastal areas of the Celtic Sea during Autumn and Winter, and they migrate offshore and more northwards following the slope to their feeding grounds (ICES, 1994; MI, 2013; O'Donnell et al. 2005c). This availability of high energy prey might attract predators into the area, as it was reported in the North Sea (e.g., Furness and Tasker, 2000; Jansen et al., 2013; Thompson et al., 1991). While Rogan and Berrow (1996) reported that herring was found in the diet of a small number of harbour porpoises (n = 26), to date, only fin and humpback whales (Ryan et al., 2013) and common dolphins (Davey, 2012) have been reported to be feeding on Atlantic herring and sprat in Irish waters, and minke whales in Scottish waters (Pierce et al., 2004). In this study, this group was also found to be relatively important for harbour porpoises. In dietary studies of harbour porpoise elsewhere in the Atlantic European waters, the occurrence of this prey has been reported to be low, usually below 3% (Jansen et al., 2013; Santos et al., 2004; Spitz et al., 2006b); again, this difference may reflect local prey abundance and/or local selection by these animals.

Aggressive and fatal interactions between bottlenose dolphin and harbour porpoises have been detected along the south coast of Co. Cork (Hernandez-Milian et al., 2012; Ryan, 2008). A number of hypothesis have been put forward to explain this antagonistic behaviour, including “practice” infanticide in bottlenose dolphins (Patterson et al., 1998) and diet overlap (Ross and Wilson, 1996; Spitz et al., 2006b) or a combination of both (Barnett et al., 2009). Despite the small sample size for bottlenose dolphins, both species appear to be feeding on different prey species and different sized prey in this area. Recently, in the South East of the North Sea, grey seals have been reported to attack harbour porpoises and eat some of them, particularly the blubber (Bouveroux et al., 2014; Haelters et al., 2012). Bouveroux et al. (2014) suggested that the increase of grey seal populations and the decline of their main prey (sandeels) might explain these attacks and, potentially, the use of porpoises as part of their diet. In Ireland, sandeels are not an important part of the diet of grey seals in contrast to the North Sea, where it is their main prey, but they have some prey species in common with porpoises (gadoids) and they might be competing for the same resources. To date, no signs grey seals attacks on harbour porpoises have been detected, but grey seal populations have increased over the last 10 years and this interaction may occur in the future.

Although all species were considered coastal species for the purpose of analysis, they also occur on the continental shelf (in the Celtic Sea) and can be distributed out to the continental slope (especially in the west). This is reflected by the fact that some pelagic/offshore prey (e.g., silvery pout -*Gadiculus argenteus thori*, Guichenot 1850, garfish -*Belone belone*, Linnaeus 1761) occurred in the diet. Some dietary partitioning is also thought to exist in bottlenose dolphins (Chapter 5), and potentially three different feeding habits might occur in this area (proper coastal feeding, continental slope feeding and offshore feeding).

Samples from cetaceans were collected over a long time period (more than ten years), while scats were collected over two years for both grey and harbour seals. These differences in sample size and the timing of sample collection should be taken into consideration when interpreting the results, and only exploration tools such as redundancy analysis and discriminate analysis were used to investigate the potential overlap among the species. This overlap is also considered in Chapter 7. Studies of the diet of bottlenose dolphin are usually carried out with small sample sizes (Blanco et al., 2001; Santos et al., 2001c; Santos et al., 2007), because despite their coastal behaviour they rarely strand, carcasses are usually found in an advanced state of decomposition, and the loss of the carcass with the next tide before examination is common. Stable isotope analysis is an alternative technique to improve the knowledge of their dietary patterns. In Irish waters, Rogan et al. (2011) reported that the two main coastal populations of bottlenose dolphin (Mayo-Connemara, Shannon-Cork) (n = 36) were mainly feeding in inshore waters, which is in accordance with the diet contents analysis presented in Chapter 5. These results indicate that dietary information obtained using stomach contents are showing a potential realistic view of the bottlenose dolphin preferences, despite the distribution of the samples (see Table 5.1 in Chapter 5). Diet of harbour porpoises in Irish waters reflects two different components, one pelagic with clupeids as the main prey species, and another demersal with three gadoid species (whiting, haddock and *Trisopterus* spp.) as the main prey species. A former study of stable isotopes in harbour porpoises in the southern North Sea (Das et al., 2003) showed that this cetacean species presented a preference for planktivourous prey such as clupeids, Atlantic mackerel and horse mackerel. In contrast, Santos et al. (2004) found that in harbour porpoises in Scotland switch this preference to gadoid species (mainly whiting) and sandeels, whereas planktivorous prey comprised only 4% of the biomass of prey ingested. Important nursery grounds of these planktivorous fish species occur in coastal areas of Ireland while sandeels were more dispersed (Anon. 2009). In the middle and northern North Sea waters sandeel grounds are very important whereas Atlantic mackerel and horse mackerel grounds are less important, however in the southern area of the North Sea the picture is more similar to Irish waters with lower occurrence of sandeels and more planktivorous fish (Ellis et al., 2012). This difference in prey availability among these three areas may explain the dietary partitioning between harbour porpoise populations, probably related to the gene flow segregation suggested by Fontaine et al. (2007) in European waters.

Seal diet information was obtained within a very short period of time, and the diet of these two predators (grey and harbour seals) can change over longer periods. In general, these predators are considered generalist but with few species accounting for most of the diet (e.g., Hammond et al., 1994a, 1994b; Gosch et al., 2014); inter- and intra-annual variability in the diet of these seal species was suggested to be related to prey availability (e.g., Hammond et al., 1994a, 1994b; Santos and Pierce, 2003; Gosch et al., 2014). Although the seal diet information obtained in this study may reflect the preferences of the species in the area, longer study on dietary patterns of these species, compared with the other two predators (bottlenose dolphin and harbour porpoise) will help to understand the interactions among these four marine mammal species.

Marine mammal annual food consumption has been estimated in different marine ecosystems (e.g., Antonelis and Perez, 1984; Col et al., 2012; Trites et al., 1997), but this study represents the first approach to estimate annual food consumption of coastal marine mammal predators in Ireland. In general, annual consumption of species in different areas use general equations which are not prey specific and prey-specific requirements are not considered (Col et al., 2012; Kenney et al., 1997; Sigurjónsson and Víkingsson, 1997; Trites et al., 1997). In this study, the dietary information is provided to give a more realistic and meaningful analysis of the prey requirements (with grouped prey) of the main marine mammal predators. Biases due to sample size should be considered in these results, especially, as previously discussed, for grey seal annual food consumption. In both cetacean species, the energy food intake was estimated using the estimated weight of dolphins stranded in Ireland, harbour seal energy food intake was estimated using the average adult weight given by Burns (2002), and grey seal energy food intake was estimated using the average weight of adult males and females given by Bonner (1981). With cetaceans, both juveniles and adults were considered and the annual food consumption reflects this. However, for seals, the annual food consumption was estimated using adult average weight and results are therefore overestimated. Grey seal annual food consumption was estimated to be similar to the total annual food consumption of the other three species together; but the grey seal weight is likely overestimated due to the extreme sexual dimorphism seen in this species and subsequently the annual food consumption is probably overestimated. If age structured abundance estimates were available, it would be possible to examine this in more detail, by using the weights in proportion to the ratio of juveniles, adult males and adult females. Also, larger differences of the annual food consumption between both equations were found; the use of residency ratio in Col et al. (2012), where the seasonal abundance of the marine mammal species is considered, is probably an important approach to use in annual food consumption estimations. For example, bottlenose dolphin populations tend to increase during late spring and summer months while in winter dolphin groups are more dispersed and population abundance probably lower. The annual food consumption used in this study was estimated using population abundances obtained during the summer months for cetacean species (Hammond et al., 2013) and moulting seasons for seals (Cronin et al., 2004; O'Cadhla et al., 2007), and the residency ratio for North East US was used. The development of residency ratios for the species inhabiting Irish waters and the inter-annual abundance of these predators will help to improve our knowledge of the interactions between these predators and fisheries.

Chapter 7

MODELING THE ECOSYSTEM ROLE OF TOP PREDATORS (CETACEANS AND SEALS) IN THE IRISH SEA

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MODELING THE ECOSYSTEM ROLE OF TOP PREDATORS (CETACEANS AND SEALS) IN THE IRISH SEA

7.1 ABSTRACT

The Irish Sea is a relatively enclosed sea area between the United Kingdom and the Republic of Ireland. Important commercial fisheries, some of which are exploited unsustainably, are operating within the area. There are also a number of key protected apex predators (cetaceans, seals and seabirds) inhabiting or using the area temporally. Understanding the interactions between fisheries and ecosystem functioning, in particular for these apex predators, is therefore important for the Irish Sea.

The use of mass-balance models for developing an Ecosystem Approach to Fisheries Management (EAFM) has been widely adopted, and Ecopath models are often used in this role due to their relatively low data requirements and its well developed user framework. An Irish Sea model, representing the Irish Sea ecosystem in 1973 was constructed by Lees and Mackinson (2007); however some discrepancies within the data in the model were found, in particular for the apex predators that are the focus of the present study. Specifically, two species of toothed whales (bottlenose dolphin and harbor porpoise), one baleen whale (minke whale) and two seal species (grey and common seal) were considered as top predators and updates were carried out on this basis. Although both scenarios showed that the Irish Sea could be considered as an immature ecosystem, the present study showed an increase in the number of trophic levels as well as a decrease in the net system production suggesting that a trend to maturation might be occurring. Niche overlap was found between both seal species and bottlenose dolphin; minke whales and seabirds also showed niche overlap.

7.2 INTRODUCTION

7.2.1 The Ecosystem Approach to Fisheries management (EAFM)

The Ecosystem Approach to Fisheries management (EAFM) is a widely used term and has been reportedly implemented in many different aquatic ecosystems to help manage fisheries in a sustainable manner; however the definition and the main goals of the concept have been interpreted differently depending on the interested sector. For instance, FAO (2003) defined EAFM as an approach that "*strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries*". More recently, different authors (Moroshita, 2006; Rice, 2008b) emphasised specific aspects to be considered in an ecosystem approach to fisheries, such as direct and direct impacts of the fishery (e.g., by-catch, mortality pressure on fisheries stocks), environmental characteristics that might affect the stocks, protection of vulnerable ecosystems and the involvement of different human sectors (social, economic and institutional). The main goal of this EAFM strategy is to obtain the most realistic information about the ecosystems and the use of their natural resources in a sustainable manner, and implementing specific routes to obtain better solutions when ongoing activities in the ecosystem was unsustainable (Rice, 2008b). Multi-species mass-balance models such as ECOPATH, endorse the construction of hypothetical scenarios using biological and social components (e.g., fisheries) using models constructed with current data; and enable us to examine possible future scenarios if, for example, a stock (natural resource) is harvested unsustainably.

7.2.2. Ecosystem Modelling

Multispecies models have become a useful tool for developing an EAFM and the study of the dynamics of each component of an ecosystem (Ulanowicz, 1993); and several such models have been developed in a range of different ecosystems (e.g., Christensen, 1995; Gascuel et al., 2011; Mackinson and Daskalov, 2007; Pauly et al., 2000). These models can be used to address ecological questions such as the relative importance of the direct/indirect interactions and these effects upon other species, such as the depletion of a forage fish species; the importance of changes in species abundance within the dynamics of the ecosystem; or how the life-history traits (e.g., sex segregation) of different species can affect the wider structure of the ecosystem (Sutherland et al., 2013). Plagányi (2007) describes a range of modelling approaches and the requirements that are necessary for them. Some approaches require a substantial amount of data and knowledge of the habitat, and often this is not available. Christensen and Pauly (1992) developed a mass-balance model (ECOPATH) based on principals outlined in Polovina (1984), and improved it (Pauly et al., 2000) using approaches developed by Ulanowicz (1993) to allow simulations within the Ecopath framework – Ecopath with Ecosim (EwE) (Pauly et al., 2000). These authors represented marine food webs using a system of boxes (compartments) and arrows (energy fluxes), providing an easy view of the ecosystem structure and functioning. A key advantage of the EwE approach is that, in well studied ecosystems, the data are generally available to parameterise the model and the mechanics of setting up and running the models are well developed and relatively simple to use. Since the 1980s at least 21 different modelling techniques for single- and multi-species have been developed for the study of food webs and the interactions occurring within them (Plagányi, 2007; Polovina, 1984; Ulanowicz, 1986). Most importantly in the context of this study, the EwE approach has already been attempted in the Irish Sea by Lees and Mackinson (2007).

The modelling approaches for marine ecosystems can be addressed using single-species or multi-species models; however, changes in the energy flow between compartments and the complex interactions within a whole ecosystem requires a multi-species perspective (Hollowed et al., 2000; Plagányi, 2007).

Consideration of top predators, fisheries and any biological changes within the ecosystem becomes important when a model has to be chosen. The direct and indirect effects of fisheries can be difficult to evaluate (e.g., removal of both targeted and non-targeted species, possible changes in the trophic structure of the ecosystem and effects on the benthic ecosystem). The role of apex predators (e.g., elimination of some predators), or the modification of the abiotic characteristics of the ecosystem can also be difficult to assess (Trites et al., 2006); however, these multi-species interactions are important to help us to understand the functioning of the ecosystem. Plagányi (2007) indicated that there were four types of models suitable to answer all these questions, suggesting that the i) GADGET (Globally applicable Area Disaggregated General Ecosystem Toolbox) model was the most sensible and statistically rigorous approach, however the model needs many computers running at the same time to obtain the model and does not cover the full trophic spectrum. However, the limitations on physical resources (multiple computers running simultaneously are needed) and their constraints to represent a small part of the ecosystem make it unsuitable for all ecosystems. The ii) InVitro model investigates the effects of human activity within an ecosystem combining physical (currents, waves, bathymetry, etc) and biological data (Gray et al., 2006), however the model only allows the inclusion of a small number of functional groups (10-20). She indicated that the multi-species models which adress broader questions are: iii) the ATLANTIS model which was developed by Fulton et al. (2004) to study the whole ecosystem including the biophysical information of the ecosystem and economical and social data; however, because of data demands it will not be applicable to many study areas (Plagányi, 2007). Finally iv) EwE (Ecopath with Ecosim) which can be run using diet data, biomass of the species or taxa groups (functional groups, FG), and fishery landings, discards and costs (Pauly et al. 2000). It was decided to use this multi-species model due to the low data requirements, the user-friendly interface and because it is probably the most widely used model. Since EwE was first developed, more than 300 different applications have been built and many more are being developed, applying their results to the ecosystem approach to fisheries management.

The main aims of this chapter were to:

i) Build the multi-species model for the Irish Sea using fishery information from 2004. Previously, Lees and Makinson (2007) used fishery information for 1973 while information on non-assessed species where obtained from the beam trawl survey carried out in 2004.

ii) Update the diet information for the area, in particular for the marine mammal species.

iii) Use the ecological indicators provided by the model, and present the ecosystem properties.

7.2.3 The Irish Sea Ecosystem

Ireland is situated in the North East Atlantic, and the waters around Ireland are included within the Celtic Seas Ecoregion (www.ices.dk). This region roughly extends from 5ºW to the West coast of Britain and from 60º to 48º N. It comprises many different habitats and topographical structures that make the area relatively complex with heterogeneous ecosystems. It is influenced by the North Atlantic Drift (Gulf Stream) which makes the continental shelf (Celtic Sea and Porcupine Bank), the Irish Sea, and the Porcupine-Rockall margin (Fig. 7.1a) some of the most productive sea areas in Europe (OSPAR, 2000). All these characteristics make Irish waters an important area for apex predators, such as cetaceans, seals, sharks, sea turtles, and seabirds, as well as fish that are targeted by commercial fisheries (e.g. Atlantic mackerel -*Scomber scombrus*, Linnaues 1758-, Atlantic herring -*Clupea harengus*, Linnaeus 1758-, Atlantic cod -*Gadus morhua*, Linnaeus 1758-, whiting -*Merlangius merlangus*, Linnaeus 1758-, haddock -*Melanogrammus aeglefinus*, Linnaeus 1758-, sole and tuna species) (ICES, 2003a; OSPAR, 2000).

The Irish Sea is a semi-enclosed sea between the Republic of Ireland and Great Britain delimited by the Islay Front to the North and the Celtic Sea Front in the south (Fig. 7.1b). The maximum depth recorded in the Irish Sea is registered in the Beaufort Dyke (315m) in the North West of the Irish Sea; however, the general depth of the sea ranges from 20m to 100m (Vincent et al., 2004). The main water currents flow northwards (Fig 7.1c) from the Celtic Sea through St. George's Channel, giving the Irish Sea a relatively high salinity in comparison to the Celtic Sea; the current turns east with an anti clockwise movement, when it goes close to Isle of Man, and moves northerly again within Liverpool Bay (Huntley, 1980). Sedimentology patterns in the Irish Sea shows a primarily sandy seabed with intermittent gravel areas in the middle of the Irish Sea running from south to north (Fig 7.1d); two main mud grounds are also present, a large one in the northwest and a smaller one in the northeast (Fig 7.1d). The Irish Sea sea surface temperature (SST) ranges from 6°C to 17.8°C, with an average of 11.9°C (Lees and Mackinson, 2007; the Irish Meteorological Service, www.met.ie).

Marine mammals comprise one of the main groups of predators in the ocean, and their role within the trophic food webs and pelagic ecosystems may have an important link to top-down and bottom-up effects (e.g., Estes, 1996; Merrick, 1997). A total of 23 species of cetaceans have been recorded within Irish waters, 16 of these have been recorded breeding or migrating through Irish waters on a regular basis (Berrow, 2001; Berrow, 2002; Berrow and Rogan, 1997; Evans, 1980; O'Cadhla et al. 2004), while 21 species have been recorded stranded (Berrow and Rogan, 1997). The occurrence of a number of different small dolphin species in the pelagic ecosystems and their interaction with fisheries (Berrow 2000, 2001, 2002; Gordon et al., 2000; Rogan and Berrow, 1996; Rogan and Mackey, 1997; Rogan et al. 2000) would suggest that these marine mammals are important within the Celtic Seas Ecoregion. In addition, two species of seals breed and live along Ireland's coasts: Grey seal (*Halichoerus grypus*, Fabricius 1791) and Common seal (*Phoca vitulina*, Linnaeus 1758) (Lyons, 2004; Cronin et al., 2007).

In addition to marine mammals, twenty four seabird species breed along the coast of Ireland and another eight regularly occur during the winter season, in particular along the South and West coast (Mitchell et al., 2004; Roycroft et al., 2007). As well as the mammals and birds, other important species include sharks such as basking sharks (*Cetorhinus maximus*, Gunnerus 1765) (Berrow and Heardman, 1994), porbeagle (*Lamna nasus*, Bonnaterre 1788), shortfin macko (*Isurus oxyrinchus*, Rafinesque 1810) and blue shark (*Prionace glauca*, Linnaeus 1758) (Clarke et al., 2008). Leatherback turtles (*Dermochelys coriacea*, Vandelli 1761) have been reported to be associated with jellyfish, and may occasionally occur in Irish Sea looking for jellyfish hotspots (Houghton et al., 2006); this group was considered as unusual species group and not used in the model.

Lees and Mackinson (2007) constructed the model grouping all marine mammals in three categories (Baleen whales, toothed whales and seals) and the model used data based on 1973 fish data. In this chapter, the model was built up using the marine mammal species present in the Irish Sea as individual functional groups (minke whale -*Balaenoptera acutorostrata*, Lacépède 1804-, bottlenose dolphin -*Tursiops truncatus*, Montagu 1821-, harbour porpoise -*Phocoena phocoena*, Linnaeus 1758-, common seal and grey seal). In addition, more recent fishery data were included in the model. The aim of this chapter was to build a more realistic model of the Irish Sea, examine possible temporal changes to the ecosystems, examine the linkages between top predators and determine the niche overlap between these species.

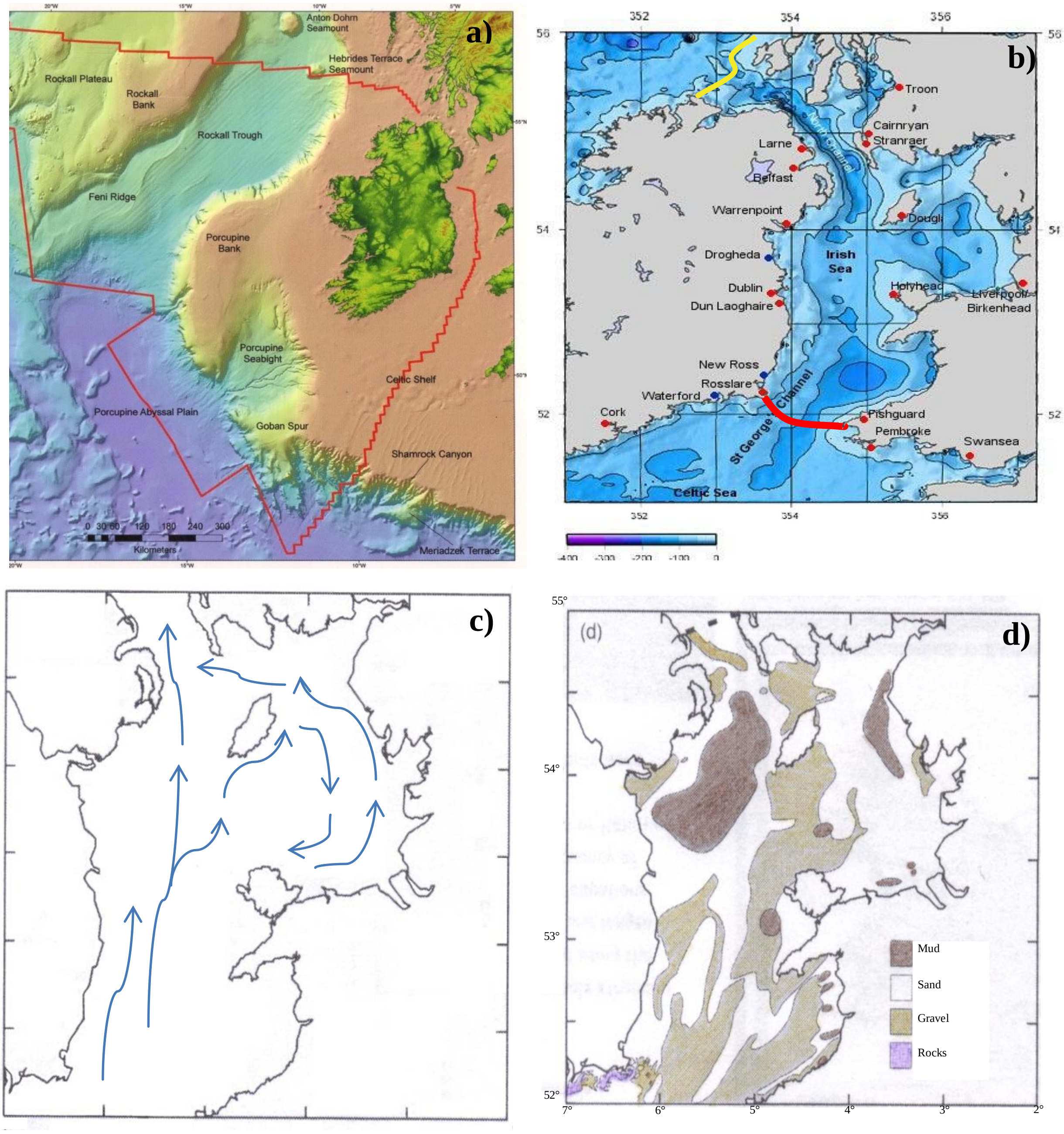


Figure. 7.1 Maps of the a) seas around Ireland (from Marine institute: www.marine.ie), b) the Irish Sea (area of study) and the main fronts, c) the sea surface water currents (adapted from Huntley 1980), and d) seabed surface sediment pattern (adapted from Parker and Humphreys, 2004)

7.3 MATERIAL AND METHODS

7.3.1 Area of study

As mentioned earlier, the Irish Sea is a semi-enclosed sea of 58,000 km^2 (Vincent et al., 2004) between the Republic of Ireland and Great Britain that reaches from St. George's Channel and the Celtic Sea front in the South (52.2N/-6.4W-51.9N/-5.3W) to the Malin Shelf and the Islay Front in the North (54.7N/-5.6W-54.6N/-4.9W) (Fig. 7.1b). It is surrounded by large cities on both sides of the Irish Sea, influencing the contaminant loading in the Irish Sea, with some species of marine mammal showing elevated levels of both persistent organochlorine and metals (e.g. Murphy et al., 2010; Pierce et al., 2008) as well as other biological components of the ecosystem (e.g. Glynn et al., 2004). In addition, radiocaesium discharge from the Sellafield reprocessing plant has been shown to accumulate in this area (e.g. Berrow et al., 1998). A number of large salmonid rivers enter the sea, especially in Wales and Ireland, giving also a localised freshwater influence. There are a large number of diverse fisheries operating in this area. The most commercially valuable is the "Dublin bay prawn" (*Nephrops norwegicus*, Linnaeus 1758), with other species landed including European plaice (*Pleuronectes platessa*, Linnaeus 1758), haddock, whiting and Atlantic herring.

7.3.2 The Ecopath approach and its requirements

Ecopath software was developed to integrate different ecological data from a multi-species system and to study ecosystem functioning of the whole ecosystem using a mass-balance approach (Ulanowicz, 1993). Data requirements of Ecopath are relatively simple and the model is based around two main or "master" equations. The first equation describes the production for each functional group; functional groups are described as groups that are taxonomically different (different species or taxa) or a group of species with similar ecological characteristics (size, habitat and/or feeding preferences):

Production = Predation + Fishery + Biomass accumulation + Net migration + Other mortality

Or

$$P_i = B_i * M2_i + Y_i + BA_i + E_i + B_i * MO_i \qquad \text{eq. 7.1}$$

Where P_i is the production estimated for group i, B_i is the biomass for group i, $M2$ is the predation for the group i, Y_i is the total fishery catch for the group i, BA_i is the bioaccumulation rate for group i, E_i is the net migration (emigration – immigration) rate for the group i, MO_i is the other mortality rate for the group i.

The $M2$ is defined by equation 7.2, where Q_j is the total consumption rate for the group "j", and DC_{ji} corresponds to the fraction of prey "i" which contributes to the predator (j)'s diet.

$$M2_i = \sum_{j=1}^{n} Q_j * DC_{ji} \qquad \text{eq. 7.2}$$

BA_i is a production parameter that can be calculated as the difference in the biomass of the functional group at the beginning and at the end of a year, and a default value of 0 is usually given for all living groups assuming that no biomass accumulation occurs. A positive value will mean an increase in biomass during the modelled period, while a negative value will mean a decrease in biomass.

The MOi is the mortality not included elsewhere, such as mortality due to old age or diseases, and this is internally computed:

$$MO_i = P_i * (1 - EE_i) \qquad \text{eq. 7.3}$$

Where EE_i is the “ecotrophic efficiency” of the group i, described as the proportion that is utilized in the system.

The second main equation defines the consumption of each functional group.

$$\text{Consumption} = \text{Production} + \text{Unassimilated food} + \text{Respiration} \qquad \text{eq. 7.4}$$

The data are included in the Ecopath model as the rates of production/biomass (P/B_i) and consumption/biomass (Q/B_i) (see 7.3.3.2 section).

7.3.3 Basic input parameters and data sources

The biodiversity of the Irish Sea ranges from plankton to marine mammals (Atalah et al., 2013; Connor et al., 2004; Hammond et al., 2013; Roche et al., 2007; Wall et al., 2013); however, such a wide range of species is difficult to handle individually, especially as some species are relatively rare, and so species were often grouped into “functional groups” (FG) based on habitat, taxonomic similarities, size and/or feeding preferences. Most of the functional groups were based on pooled species as described by Lees and Mackinson (2007). One of the main aims of this study was to develop a more detailed understanding of the role of top predators in the system, and how system changes might affect these species. In this context, the top predator functional groups used by Lees and Mackinson (2007) were subdivided to species level as new diet information for Irish mammals was available (Chapter 6). However, in order to compensate for the number of functional groups, sea bass (*Dicentrarchus labrax*, Linnaeus 1758), gurnard and mullet functional groups were removed from the original model. This decision was made based on the dietary patterns of the top predators occurring in the Irish Sea. Some commercial species were included as individual functional groups because detailed information was available in the literature from stock assessments and surveys etc. It was also possible to divide three commercial fish groups (cod -*Gadus morhua*, Linnaeus 1758-, haddock and European plaice) into juveniles and adults based on the ICES Stock assessments. A total of 52 functional groups were included within this model (Table 7.1). Ecopath VI software (www.ecopath.org) was used to construct the mass-balance model for the Irish Sea. Lees and Mackinson (2007) built up the model using the fishery information available for 1973; however the exploitation and population dynamics in the area have changed in recent years (ICES, 2008b; MI, 2013). Landings of some of the species have increased (e.g. whiting, and *Nephrops*), and some have decreased (e.g. Cephalopods, and common sole -*Solea solea*, Linnaeus 1758), and others species follow different peaks from 1973 to 2011 (e.g. haddock, cod) (ICES, 2008b; MI, 2013). Therefore, the average data from 1973 to 2011 was used to build up the new model (e.g. Díaz López et al., 2008; Frisk et al,. 2011; Okey and Pugliese, 2001; Wabnitz et al., 2010). A time series of cetacean relative abundance using platforms of opportunity has been reported by the Irish Whale Dolphin Group up to 2006; in 2005, the SCANS II survey (Hammond et al., 2013) was carried

Table 7.1. Functional groups used in the Ecopath model. Species classified as toothed cetaceans (*) and seals (†) in Lees and Makinson (2007)

Marine mammals and Seabirds

FG 1	Bottlenose Dolphin*
FG 2	Harbour Porpoise*
FG 3	Minke Whale
FG 4	Common Seal†
FG 5	Grey Seal†
FG 6	Seabirds

Fish groups

FG 7	Basking Shark
FG 8	Adult Cod 2+
FG 9	Juvenile Cod 1+
FG 10	Adult Haddock 2+
FG 11	Juvenile Haddock 1+
FG 12	Adult Plaice 2+
FG 13	Juvenile Plaice 1+
FG 14	Whiting
FG 15	Sole
FG 16	Salmonids
FG 17	Sandeels
FG 18	Small flatfish
FG 19	Medium Flatfish
FG 20	Large Flatfish
FG 21	Dragonets
FG 22	Other Large Demersal
FG 23	Mackerel
FG 24	Monkfish
FG 25	Large Gadoids
FG 26	Other Small Demersal
FG 27	Other Small Gadoids
FG 28	Small Pelagic Planktivorous
FG 29	Small Sharks
FG 30	Large Sharks
FG 31	Skates and Rays

Invertebrate groups

FG 32	Epifaunal Macrobenthos
FG 33	Epifaunal Mesobenthos
FG 34	Infauna (Polychaeta)
FG 35	Infaunal Macrobenthos
FG 36	Infaunal Mesobenthos
FG 37	Lobster and Large Crabs
FG 38	*Nephrops*
FG 39	Cephalopods
FG 40	Prawns and Shrimp
FG 41	Sesile Epifauna
FG 42	Meiofauna
FG 43	Gelatinous Zooplankton
FG 44	Carnivorous Zooplankton
FG 45	Omnivorous Zooplankton
FG 46	Herbivorous Zooplankton

Primary producers

FG 47	Seaweed
FG 48	Microflora
FG 49	Phytoplankton

Detritus groups

FG 50	Particulate Organic Matter
FG 51	Dissolved Organic Matter
FG 52	Discards

out to obtain summer abundance estimations of cetacean populations inhabiting the continental shelf of European waters. As in previous chapters, SCANS II survey data was used for the estimation of cetacean biomass in the Irish Sea. For common and grey seal population abundance, Cronin et al. (2003) and O'Cadhla et al. (2007) were used, respectively.

Ecopath parameters (Biomass, Production/Biomass -P/B- ratio, Consumption/Biomass -Q/B- ratio, Ecotrophic efficiency, Production/Consumption -P/Q-, Trophic level) for each functional groups are compiled in Appendix IX and Table 7.5.

Diet information for each functional group is given in Appendix X and Table 7.6.

The main data support for the current model was the previous model for the Irish Sea developed by Lees and Mackinson (2007). Parameter values were generally taken from that model except in those cases where there was new or contradictory data available. In such cases the changes have been documented.

7.3.3.1 Marine Mammals and Seabirds

In the Lees and Mackinson (2007) model, harbour porpoise and short-beaked common dolphin (*Delphinus delphis*, Linnaeus 1758) species were considered the most commonly occurring species in the Irish Sea. The short-beaked common dolphin is widely distributed in European waters including the Irish Sea waters (Hammond et al., 2013); however, sighting records reported by Irish Whale and Dolphin Group (www.iwdg.ie) indicated that this species is rarely seen in the area, while it is common along the southern and south-western areas of Ireland. Short-beaked common dolphin diet is largely composed of small schooling fish such as clupeids and horse mackerel (*Trachurus trachurus,* Rafinesque 1810) (Jefferson et al., 1993; Meynier et al., 2008; Santos et al., 2004; Silva, 1999); although this type of prey also occurs in the Irish Sea, given the low frequency of sightings of this species, it was decided to exclude them from the model. On the other hand, bottlenose dolphin and harbour porpoises occur regularly and could be considered the two "resident" toothed whales in the Irish Sea

(Pesante et al. 2008; Hammond et al., 2013). Other odontocete species have been reported within the study area, such as Risso’s dolphin (*Grampus griseus,* Cuvier 1812) and northern bottlenose whales (*Hyperoodon ampullatus*, Forster 1770) but they were considered to use the area for travelling through (Pesante et al., 2008; Hammond et la., 2013; MacLeod et al., 2004; Rogan and Hernandez, 2011).

Baleen whales are more unusual within the Irish Sea, and only minke whales are regularly sighted in the area (Pesante et al, 2008; Hammond et al., 2013) and therefore included in the model.

Biomass of marine mammals was estimated using the equation in Lees and Mackinson (2007):

$$\text{Biomass (t * Km}^{-2}\text{)} = \text{Abundance * average body weight (t) / Area of Irish Sea (Km}^{2}\text{)} \qquad \text{eq 7.5}$$

FG 1 Bottlenose dolphin

Hammond et al. (2013) estimated that the bottlenose dolphin abundance using aerial survey line transect methodology for the Irish Sea was 235 (CV=0.75) dolphins. Pesante et al. (2008) estimated the bottlenose dolphin population in Cardigan Bay (Wales) as ranging from 109 (CV=41.7) to 206 (CV=35.2) using a mark-recapture technique. For the purpose of this analysis, it was assumed that the SCANS abundance estimate better reflects the whole area and therefore this was used to estimate the biomass of this dolphin species in the model. The average adult body weight of bottlenose dolphins range between 220kg and 500 kg (www.cms.int); however, the average weight estimated for the bottlenose dolphin stranded along the Irish coast was 381.8kg using the equation given by Kastelein et al. (2002) (Chapter 5), and this value was used to estimate the biomass of the species. Biomass of the bottlenose dolphin in the area was estimated to be 0.0016 t Km^{-2} using equation 7.4.

Production/biomass and consumption/biomass rates were obtained from the 1980’s model built by Trites et al. (1999) for toothed whales: these were 0.02 and 13.11 respectively (Table 7.5 and Appendix IX)

Bottlenose dolphin diet data were obtained from the analysis carried out in the Chapter 5; the Ecopath model was run for the Irish Sea, therefore some changes in prey items, depending on the abundance and diversity of species in the area of study were made. For example, European hake (*Merluccius merluccius*, Linnaeus 1758) is not a common species in the Irish Sea and the proportion of this prey item was integrated into large gadoid functional group (Table 7.6, Appendix X)

FG 2 Harbour porpoise

The harbour porpoise population in the Irish Sea was estimated to be 11,118 (CV=0.36) (Hammond et al., 2013). This is a much higher value than the one used by Lees and Mackinson (2007). The average body size was estimated to be 55 kg using the equations given by Bjørge and Tolley (2009) (Chapter 6); therefore, the biomass estimation for harbour porpoises for the Irish Sea using eq. 7.5 was 0.0105429t/km^2.

Production/biomass and consumption/biomass rate were obtained from the 1980's model built by Trites et al. (1999) for toothed whales: 0.02 and 13.11 respectively (Table 7.5 and Appendix IX).

Harbour porpoise diet was obtained from the data used in Chapter 6, but in this model, diet was reconstructed using only porpoises stranded on the Irish Sea coastline (Table 7.6, Appendix X).

FG 3 Minke Whale

Abundance estimation of minke whales within the Irish Sea during the summer survey in 2005 was estimated to be 789 (CV=0.91) (Hammond et al., 2013). As with harbour porpoises, this is a much higher but more robust estimate than that used in Lees and Mackinson (2007). Trites and Pauly (1998) estimated the average mass of minke whales was 7,011 kg for males and 6,121 kg for females; we do not know how many whales from this population were female or male, therefore the value used was the average weight of both sexes (6,566 kg). The Irish Sea biomass of minke whales was estimated to be 0.089t/km^2 using the eq. 7.5.

Production/biomass and consumption/biomass rate were obtained from the 1980's model built by Trites et al. (1999) for baleen whales: 0.02 and 11.38 respectively (Table 7.5 and Appendix IX).

There is no specific information about minke whale dietary preferences in Irish waters. The diet data reported by Pierce et al. (2004) for Scottish waters was used with some modifications, as the animals studied in Scottish waters were primarily from the North Sea and West of Scotland. Based on information about the prey available in the Irish Sea, the prey species and their biomass percentage considered were: 61.71% sandeels, 32.36% Clupeids, 5.83% Atlantic Mackerel, 0.1% *Trisopterus* spp. (Table 7.6, Appendix X).

FG 4 Common seal

There are a number of haul out and breeding sites for harbour seals in the Irish Sea. Most of these sites are small, often comprising uninhabited and remote islands (e.g. Lambey, Saltees (e.g., Lidgard et al., 1999). On the Irish coastline, the largest breeding site for this species is in Strangford Lough, in Northern Ireland. Cronin et al. (2003) gave a maximum value of 73 common seals in Carlingford Lough; however, Wilson et al., (2008) reported higher values (178-187 seals in July and 350-376 seals in August-September). Therefore, the average abundance given by Wilson et al. (2008) is 273 seals. On the other hand, a population of 1,200 seals along all coasts of Northern Ireland were reported using aerial surveys (Duck, 2010; SMRU, 2004) before the Phocine Distemper Virus (PDV) outburst; leading to a 66% increase in mortality likely reducing the Northern Ireland population from 1,200 seals to 400 (SMRU, 2004). A decline of the common seal population along UK coasts has also been reported (Duck, 2010; SCOS, 2007; SMRU, 2004). A smaller number of seals are known to occur along the coastlines of Wales. Therefore, a conservative value of 500 seals was considered for the whole area. This is a smaller value than that given by Lees and Mackinson (2007).

Burns (2002) gave an average weight of 97.5 kg for common seals. Biomass estimation of common seals within the Irish Sea was calculated to be 0.0004589t/km^2 using equation 7.5.

The values of 0.06 for production/biomass and 15.93 for consumption/biomass rate were obtained from the 1980's model built by Trites et al. (1999) for seals (Table 7.5 and Appendix IX).

Diet information for common seal was obtained from Kavanagh et al. (2010), and the prey items were reviewed for this study (Chapter 6). Similar to bottlenose dolphins, some prey was adjusted based on knowledge of prey availability in the Irish Sea, as the majority of scat samples of common seal were from west coast of Ireland (Table 7.6, Appendix X).

FG 5 Grey seal

Kiely et al. (2000) reported an abundance of 6,000 grey seals in the Irish Seas, with a maximum number of 488 harbour seals in 1998 in Irish coasts; however, Ó Cadhla and Strong (2007) estimated the grey seal population in the Irish Sea as 712 seals, and SCOS (2007) estimated the grey seal population of Wales and South-West England as 1750 seals. A conservative value of 2,000 seals was considered in the study. Average adult body weight for grey seals has been estimated to be 233 and 155 kg for males and females, respectively (Bonner, 1981); and the average of 194kg was used for the biomass estimation. Biomass of grey seals in the Irish Sea using equation 7.5 was 0.004014655t/km^2.

The values of 0.06 for production/biomass and 15.93 for consumption/biomass rate were obtained from the 1980's model built by Trites et al. (1999) for seals (Table 7.5 and Appendix IX).

Previous work carried out by McKibben (2000) on the diet of seals in the Saltee islands was examined. This work was based on a small sample size, and suggested that grey seals were foraging on Gadoids and flatfish. For the purposes of this study, grey seal diet information obtained from the MSc projects of Martha Gosch and Alice Doyle (Chapter 6; Doyle, 2011; Gosch, 2010; Gosch et al., 2014), mostly derived from scats collected from the Blasket Islands (South West of Ireland) was adjusted for the Irish Sea, informed by the information provided in McKibbon (2000). (Table 7.6, Appendix X).

FG 6 Seabirds

Lees and Mackinson (2007) indicated that the most abundant seabird species were northern fulmar (*Fulmarus glancialis*, Linnaeus 1758), manx shearwater (*Puffinus puffinus*, Brünnich 1764), northern gannet (*Sula bassana*, Linnaeus 1758), European shag (*Phalacrocorax aristotelis*, Linnaeus 1761), black scoter (*Melanitta nigra*, Linnaeus 1758), common gull (*Larus canus*, Linnaeus 1758), lesser black-backed gull (*L. fuscus*, Linnaeus 1758), herring gull (*L. argentatus argentatus*, Pontoppidan 1763), great black-beaked gull (*L. marinus*, Linnaeus 1758), black-legged kittiwake (*Rissa tridactyla*, Linnaeus 1758), common guillemot (*Uria aalge*, Pontoppidan 1763), razorbill (*Alca torda*, Linnaeus 1758), Atlantic puffin (*Fratercula arctica*, Linnaeus 1758), storm petrel (*Hydrobates pelagicus*, Linnaeus 1758), Sternidae. However, ICES (2002) indicates that great cormorant (*Phalacrocorax carbo*, Linnaeus 1758), black-headed gull (*L. ridibundus*, Linnaeus 1766), black guillemot (*Cepphus grylle*, Linnaeus 1758) are also very common in the Irish Sea. Estimated abundance of all species was compiled in Appendix IX. The total estimated biomass of seabirds for the Irish Sea using equation 7.5 was 0.0033t/km^2.

Consumption/biomass rate was obtained from the Lees and Mackinson (2007) model (82.664). Production/biomass rate was not available in the literature for the area; therefore a value of 0.013 for production/consumption rate was used (Lees and Mackinson, 2007) (Table 7.5).

Diet information of the different seabird species was obtained from the literature and are summarised in Table 7.6, Appendix VIII, and Appendix X.

7.3.3.2 Fish groups

In contrast to the Lees and Mackinson (2007) model, bass, gurnards and mullet functional groups were discarded in this model. As mentioned in section 7.3.3 Atlantic cod, haddock and European plaice were split into two groups: adult and juveniles (Lees and Mackison, 2007), based this division on stock assessments. Lees and Mackinson (2007) used seatrout (*Salmo trutta*, Linnaeus 1758) as a functional group, and Atlantic salmon (*Salmo salar*, Linnaeus 1758) was excluded; in Ireland both these species occur on the east coast of Ireland (FRS, 2004) and top predators also feed on this prey species (Chapter 6; Gosch et al., 2014). In this study this FG was extended to include both salmonid species.

Biomass estimates for the different groups were obtained from the literature – detailed below.

Production rate (Z) was estimated as the sum of fishing mortality (F) and natural mortality (M), and it was entered as P/B y^{-1} ratio.

$$Z = F + M \qquad \text{eq. 7.6}$$

The fishing mortality rate was obtained from ICES (2004). If there were no catch data available from an unexploited species, only natural mortality was used as the Z value following the approach taken by Lees and Mackinson (2007). Natural mortality can be estimated using the formula given by Pauly (1980), which combined two von Bertalanffy Growth Function (VBGF) parameters and the local environmental temperature:

$$M = K_{0.65} * L_{\infty}^{-0.279} * T_c^{0.463} \qquad \text{eq. 7.7}$$

Where M is the natural mortality per year, K is the growth parameter of the VBGF, $L\infty$ is the asymptotic length in centimetres, and T_c is the mean habitat temperature (13°C). VBGF parameters where obtained from the literature usually from studies carried out in the Irish Sea, but when these data were not available the values from adjacent areas were used (English Channel, West Scotland, North Sea). When no values were available through this approach, a value of 0.2 was assumed as natural mortality (Lees and Makinson, 2007).

The Palomares and Pauly (1998) equation was used to estimate the consumption (Q/B y^{-1}) ratio:

$$\text{Log}\,(Q/B) = 5.847 + 0.280 * \text{Log}\,Z - 0.152 * \text{Log}\,W_{\infty} - 1.360 * T' + 0.062 * A + 0.510 * h + 0.390 * d \qquad \text{eq. 7.8}$$

Where W_{∞} is the asymptotic weight (g) given in VBGF model, T' is an expression of the temperature of the environment:

$$T' = 1000 / (°C + 273.15) \qquad \text{eq. 7.9}$$

A is the aspect ratio of the caudal fin of fishes that use it as the main structure of propulsion (height^2/surface area) and it is correlated with its level of activity (Pauly, 1989) (Fig 7.2); and h and d are “dummy” variables expressing food type (where 1 is for herbivores and 0 for detritivores for the value h, and 1 is for detritivores and 0 for herbivores and carnivores for the value d).

If Z was not available, the following equation was used:

$$\text{Log}\,(Q/B) = 7.964 - 0.204 * \text{Log}\,W_{\infty} - 1.965 * T' + 0.083 * A + 0.532 * h + 0.398 * d \qquad \text{eq. 7.10}$$

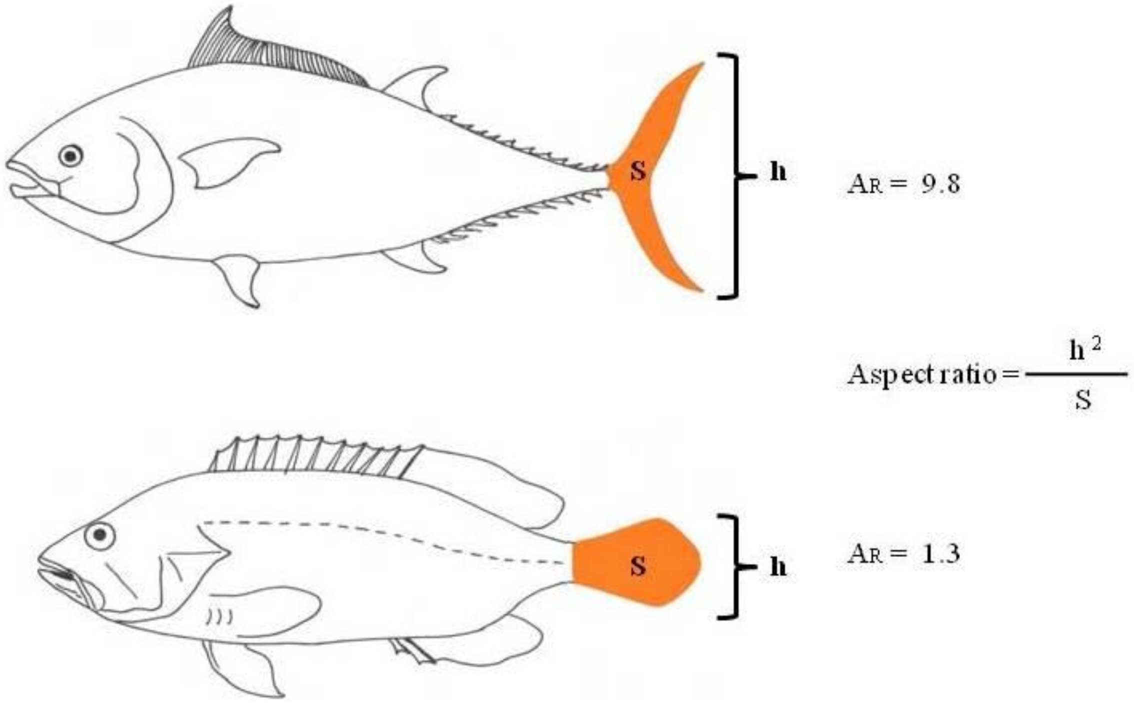


Figure 7.2. Method to estimate the aspect ratio of the caudal fin of a pelagic fish (top) and demersal fish (bottom).

Three commercial fish species (cod, haddock and plaice) were introduced as multi-stanza groups, as they are also divided ontogenetically within the ICES catches; two multi-stanza categories were used: adults (2+) and juveniles (1+). The data on biomass, P/B and Q/B for the adults were estimated following the information available and equations 7.5, 7.6 and 7.8; however, juvenile values were calculated using the assumptions from the VBGF model. Following Lees and Mackinson (2007) methodology, biomass estimation of the non-leading stanzas ('juveniles') was calculated using equations 7.11 and 7.12, where B is the whole population biomass, B_l is the biomass of the leading stanza, B_{ls} is the relative biomass of the leading stanza, B_s is the biomass for the non-leading stanza and b_s is the relative biomass of the non-leading stanza.

$$B = B_l / b_{ls} \qquad \text{eq. 7.11}$$

$$B_s = b_s * B \qquad \text{eq. 7.12}$$

The assumption given by Lees and Mackinson (2007) for the *Q/B* ratio for the non-leading stanza groups was also applied; these authors assumed that the feeding rate of juveniles varied as two thirds of the body weight.

FG 7 Basking shark

Biomass of basking sharks for the Irish Sea was estimated using equation 7.5. A total of 243 sharks were reported by Vincent et al. (2004) within the Irish Sea. Considering the average body mass estimation using the ICES (2008a) equation and using the mean length (4.06 meters) of the species provided by Sims (2000), biomass of basking sharks in the Irish Sea was 0.001564t/km^2 (Table 7.7).

As in Lees and Mackinson (2007) the *Q/B* ratio of 3.7 for basking sharks in the North Sea given by Pauly (1989) was used. *P/B* ratio of 0.07 was calculated as in Lees and Mackinson (2007), obtained from Stanford and Pitcher (2000) and based on natural mortality from Pauly (1980) (Table 7.5, Appendix IX).

Sims and Merrett (1997) reported that basking sharks feed mainly on Calanoid copepods (included as carnivorous, herbivorous and omnivorous zooplankton); however, Lees and Mackinson (2007) gave a value of 0.25 for each group of zooplankton (including gelatinous zooplankton). In this model the same approach given by Lees and Mackinson (2007) was applied (Table 7.6, Appendix X).

FG 8 Adult cod FG 9 Juvenile cod

Atlantic cod was divided in two groups as in Lees and Mackinson (2007); adult cod (age 2+) and juvenile cod (age 1+). Cod stocks within the Irish Sea have experienced considerable reduction in the last few decades (Kelly et al., 2006; ICES, 2004); Lees and Mackinson (2007) used the 1973 value, which is the maximum cod stock value recorded in the area. In this study, an average value of 10,528.92 tonnes was used (ICES 2004). Using equation 7.5, biomass of cod was estimated to be 0.181533t/km^2. Juvenile biomass (0.069587 t/km^2) was estimated multiplying the average of total recruitments by the average weight by at age 1 given by ICES (2004) (Table 7.7).

The *P/B* ratio (equation 7.6) was estimated as 1.2587 using the average fishing mortality (*F*) and natural mortality (*M*) obtained from ICES (2004). Values for Cod 4+ were applied for adult cod, as Blanchard et al. (2002) consider cod to be mature at this age. The *Q/B* ratio for adults was estimated to be 3.6728 using equation 7.8. *P/B* and *Q/B* ratio for juveniles were assumed to be double that of the adult cod as in Lees and Mackinson (2007) (Table 7.5, Appendix IX).

Cod diet was obtained using the information provided in Magnussen (2011), Mehl (1991), and Rowlands et al. (2008). Adult cod were reported to be feeding on demersal fish and cephalopods as well as benthic invertebrates; juvenile cod mainly feeds on zooplankton (Table 7.6, Appendix X).

FG 10 Adult haddock and FG 11 juvenile haddock

Following Lees and Mackinson (2007) haddock was also split into two stanza groups: adult haddock (2+) and juvenile haddock (age 1+) as reported in ICES (2004). Haddock stock abundance has been undergoing an increase in the Irish Sea, and as with cod, an average value of 2,956 tonnes was used (ICES, 2004). Adult haddock biomass was estimated to be 0.050966t/km^2. Juvenile biomass (0.040935t/km^2) was estimated multiplying the average of total recruitments by the average weight by at age 1+ given by ICES (2004) (Table 7.5).

The *P/B* ratio (equation 7.6) for adult haddock was estimated to be 1.224 using the average fishing mortality (*F*) and natural mortality (*M*) obtained from ICES (2008b). The *Q/B* ratio was estimated to be 4.8521 using equation 7.8. *P/B* and *Q/B* ratios for juvenile haddock were again estimated to be double those of the adult fish (Lees and Mackinson, 2007) (Table 7.5).

Haddock diet was obtained using the information given by Albert (1995), Metheven (1999), and Rowlands et al. (2008). Adult haddock were reported to be feeding on benthic invertebrates and zooplankton, but also on demersal fish; juvenile haddock mainly feeds on zooplankton (Table 7.6, Appendix X).

FG 12 Adult European plaice FG 13 Juvenile European plaice

European plaice was also divided into two groups as in Lees and Mackinson (2007) and reported in ICES (2004); however, Lees and Mackinson (2007) considered 2+ fish as adult, in this analysis 3+ was used based on Freyhof (2011). Unlike Atlantic cod and haddock, plaice has undergone fluctuations in abundance since 1968. As was done for some other species, it was considered appropriate to take an average value, rather than arbitrarily select a year, therefore average values (ICES, 2004) were used in order to be conservative (Díaz López et al., 2008; Frisk et al., 2011; Okey and Pugliese, 2001; Wabnitz et al., 2010), and biomass estimation was calculated as 0.152325t/km^2. Juvenile biomass (0.028741t/km^2) was estimated multiplying the average of recruits and the weight at age 1 (Table 7.5).

The *P/B* ratio (equation 7.6) was estimated to be 0.611 using the average fishing mortality (*F*) and natural mortality (*M*) obtained from ICES (2008b). The *Q/B* ratio was estimated to be 4.438 using equation 7.8. The ratios for juveniles were assumed to be double that of adults (Lees and Mackinson, 2007) (Table 7.5).

European plaice diet comprises mainly on benthic invertebrates (Raedemaecker, 2012; Raedemaecker et al., 2011; Rijnsdorp and Vingerhoed, 2001), although some demersal prey and zooplankton crustaceans have also been recorded (Table 7.6, Appendix X).

FG 14 Whiting

Biomass of whiting was estimated using the spawning stock biomass (SSB) provided by ICES (ICES, 2008b). In their model, Lees and Mackinson (2007) used the SSB given at age 6+, however whiting maturation has been reported to occur when fish are about 2 years of age (Gerritsen et al., 2003); values for age 4 were considered more appropriate and, therefore, biomass of whiting for the area used was estimated to be 0.842t/km^2 (Lees and Mackinson, 2007) (Table 7.5).

The *P/B* ratio (equation 7.6) was estimated to be 0.842, using the fishing mortality used by Lees and Mackinson (2007) and assuming a natural mortality of 0.2. The *Q/B* ratio was estimated to be 5.941 using equation 7.8 (Table 7.5).

Adult whiting are reported to feed on small demersal and pelagic prey, prawns and zooplankton; however, juvenile whiting feed also on benthic invertebrates (Hamerlynck and Hostens, 1993; Hislop et al., 1991; Rowlands et al., 2008) (Table 7.6, Appendix X).

FG 15 Sole

Biomass of sole was estimated using the SSB given by ICES (ICES, 2008b). Mollet et al. (2013) indicated that sole maturation occurs at age 3+, therefore values for 4+ were used for biomass and *P/B* estimations; again average data (ICES, 2008b) was used for those estimations. Biomass of sole for the Irish Sea was estimated to be 0.068402t/km^2 using equation 7.5 (Table 7.5).

P/B ratio estimation (equation 7.6) was 0.5094, using fishing mortality average (ICES, 2008b) and a natural mortality of 0.1 (ICES, 2008b) *Q/B* was 4.572 using equation 7.8 (Table 7.5).

Sole diet is comprised mainly of polychaeta and other benthic invertebrates, although a small amount of fish prey has also been reported (Rinjnsdorp and Vingerhoed, 2001) (Table 7.6, Appendix X).

FG 16 Salmonids

Biomass of salmonids was obtained from FRS (2004) and the Environmental Agency (2003). The total estimated biomass for trout in the 2002 season for the UK coasts was 42,282 and for Atlantic salmon 15,518 fish; the only estimated value available for salmonids on the Irish coasts were 1,421 fish for 2006. Lees and Mackinson (2007) double the total number of fish based on UK data; the same approximation was taken due to low data found for Irish coasts and knowing that numbers might be higher. Therefore, biomass of sea trout was estimated to be 84,564 and Atlantic salmon 31,036; biomass for the sum of both species in the Irish Sea was taken to be 0.0191t/km^2 (Table 7.7).

Exploitation rate of these species was reported to be 15% (Lees and Mackinson, 2007), and natural mortality (Palomares and Pauly, 1998) was reported to be 0.36 for seatrout and 0.38 for Atlantic salmon; therefore *P/B* ratio (equation 7.6) was estimated to be 0.51 for sea trout and 0.53 for Atlantic salmon; *Q/B* ratio was found to be 5.2 for seatrout and 6.67 for Atlantic salmon using equation 7.8. Values for salmon were used in the model as their economic value is high (Table 7.5).

Diet of salmonids while they are at sea, comprises small fish and zooplankton (Haugland et al., 2006; Rikardensen et al., 2006) (Table 7.6, Appendix X).

FG 17 Sandeels

Sandeel species are more dispersed in the Irish Sea than in the North Sea and biomass estimation is therefore more difficult to obtain, there is no commercial fishery and no survey indices. Five species inhabit the area: lesser sandeel (*Ammodytes marinus*, Raitt 1934), small sandeel (*A.tobianus*, Linnaeus 1758), smooth sandeel (*Gymnammodytes semisquamatus*, Jourdain 1879), greater sandeel (*Hyperoplus immaculatus*, Corbin 1950), and great sandeel (*H.lanceolatus*, Le Sauvage 1824); however, the most common ones are small sandeel and great sandeel (Lees and Mackinson, 2007). Biomass for these species was not available in the literature and the data provided by Lees and Mackinson (2007) were used. Sandeel Irish Sea biomass was estimated to be 2.014t/km^2 (Table 7.5).

P/B ratio (equation 7.6) was estimated using only the natural mortality (equation 7.7, 1.287), as there is not fishing mortality. The consumption ratio (equation 7.8) was estimated to be 7.8975 (Table 7.5).

Sandeel diet was obtained from Lees and Mackinson (2007) and comprises mainly planktivorous prey (Table 7.6, Appendix X).

FG 18 Small flatfish

Three species were included within this functional group: Thickback sole (*Microchirus variegatus*, Donovan 1808), Mediterranean scaldfish (*Arnoglossus laterna*, Walbaum 1792), and solenette (*Buglossidium luteum*, Risso 1810). Data reported by Lees and Mackinson (2007) was used; therefore biomass in the area was 0.097t/km^2 (Table 7.5).

No fishing mortality estimates were available for these species; however ICES (2008b) indicated that an average of 0.2 can be applied for commercial species. Natural mortalities for the three species were estimated using equation 7.7, but the highest value (1.3555 for *A.laterna*) obtained was much lower than the value given by Lees and Mackinson (2007). These authors indicated that the relative catch of these small fish was made up 48% for thickback sole, 44% for solenette, and 8% for scaldfish; however, recent beam trawl surveys found that these species were represented 13%, 44% and 21% respectively, and 22% other small flatfish (ICES, 2012). Due to this inconsistency, it was decided to use the *A.laterna* value, following Lees and Mackinson (2007), for *P/B* and *Q/B* ratios. *Q/B* was estimated to be 11.104 (Table 7.5).

Small flatfish diet was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X)

FG 19 Medium flatfish

Lees and Mackinson (2007) indicated that the main medium sized flatfish found during the CEFAS groundfish survey in the Irish Sea was common dab (*Limanda limanda*, Linnaeus 1758) which made up to 73% of the total fish of this group, and the ICES working group on beam trawl survey (ICES, 2012) also found dab to be the most common species within the medium flatfish group. However, other species such as European flounder (*Platichthys flesus*, Linnaeus 1758), witch flounder (*Glyptocephalus cyanoglossus*, Linnaeus 1758), lemon sole (*Microstomus kitt*, Walbaum 1792) and megrim (*Lepidorhombus whiffiagonis*, Walbaum 1792) are considered medium flatfish too. Irish Sea medium flatfish biomass value (8.919t/km^2) was taken from Lees and Mackinson (2007) (Table 7.5).

Fishing mortality was also obtained from Lees and Mackinson (2007), and natural mortality was estimated to be 0.9932 (equation 7.7); therefore, *P/B* ratio was estimated to be 1.0072 following equation 7.6. *Q/B* ratio was estimated to be 6.56 using equation 7.8 (Table 7.5).

Raedemaecker et al. (2011) reported that common dab feed mainly on zooplankton and benthic invertebrates (Table 7.6, Appendix X)

FG 20 Large flatfish

Four large flatfish species occur in the Irish Sea: Turbot (*Scophthalmus maximus*, Linnaeus 1758), Brill (*S. rhombus*, Linnaeus 1758), American plaice (*Hippoglossoides platessoides*, Fabricius 1780), and Atlantic halibut (*Hipoglossus hippoglossus*, Linnaeus 1758). Lees and Mackinson (2007) and ICES (2012) reported that most of large flatfish comprised turbot and brill; therefore, the biomass of 0.0794t/km^2, given by Lees and Mackinson (2007), was used in the model (Table 7.5).

For the estimation of *P/B* ratio (0.6435) equation 7.6 was used, where fishing mortality was 0.064 (Lees and Makinson, 2007) and natural mortality was estimated using equation 7.7 (0.5795). *Q/B* ratio estimation using equation 7.8 was estimated to be 4.3168 (Table 7.5).

Fish was found to be the main prey for *Scophthalmus* spp., although cephalopods and benthic invertebrates are also taken (Lees and Mackinson, 2007; Vinagre et al., 2011; Table 7.6, Appendix X).

FG 21 Dragonets

As in the Lees and Mackinson (2007) model, this functional group was also included because of its importance in predator diets, especially for seals. Three species are included within this functional group: common dragonet (*Callionymus lyra*, Linnaeus 1758), spotted dragonet (*C.maculatus*, Rafinesque 1810), and reticulated dragonet (*C. reticulatus*, Valenciennes 1837); while Lees and Mackinson (2007) indicated that the main dragonets in the Irish Sea were common dragonet (77%) and spotted dragonets (23%), www.fishbase.org indicates that the main dragonet species in the area were spotted and reticulated dragonet, followed by common dragonet. Biomass of dragonets (0.171t/km^2) for the Irish Sea was obtained from Lees and Mackinson (2007) model (Table 7.5).

P/B ratio was estimated to be 1.0004 using equation 7.6, were only natural mortality was used as there are no fishing mortality data. *Q/B* ratio was estimated to be 8.3811 (Table 7.5).

Benthic crustaceans and polychaetes has been recorded to be the main prey of common dragonet (Griffin et al., 2012), while spotted dragonet feed also on zooplankton and other benthic epifauna (Gibson and Ezzi, 1979); the diet information from both common and spotted dragonet was pooled as both species are present in the same abundance in the Irish Sea (Table 7.6, Appendix X).

FG 22 Other large demersal species

Two species were considered within this group: Conger (*Conger conger*, Linnaeus 1758) and Ling (*Molva molva*, Linnaeus 1758), following Lees and Mackinson (2007). Biomass for the area used in their model was also used here (0.199t/km^2) (Table 7.5).

P/B ratio was estimated to be 0.5932 using equation 7.6, where fishing mortality was assumed to be 0.2 (ICES, 2008b) and natural mortality was calculated using equation 7.7 (0.3932). *Q/B* ratio was estimated to be 4.1326 using equation 7.8 (Table 7.5).

Small and medium Gadoids and pelagic fish were the most abundant prey items found in the diet of Ling ("year of the stomach" database, http://www.ices.dk/marine-data/data-portals/Pages/Fish-stomach.aspx); conger diet comprised different types of fish (Gadoids, pelagic and demersal fish) and also cephalopods and zooplankton (Xavier et al., 2010) (Table 7.6, Appendix X).

FG 23 Mackerel

Atlantic mackerel biomass in the Irish Sea (1.623 t/km^2) was obtained from Lees and Mackinson (2007) (Table 7.5).

The estimation of *P/B* ratio (1.0814) was calculated using equation 7.6, where fishing mortality was 0.26 (ICES, 2006) and natural mortality (0.8214) was estimated using equation 7.7. *Q/B* ratio was estimated to be 7.0076 using equation 7.8 (Table 7.5).

Small fish, including Gadiformes, and zooplankton were found to be the main prey items in the diet of Atlantic mackerel (Bigelow and Schroeder, 1953; Langøy et al., 2012) (Table 7.6, Appendix X).

FG 24 Monkfish

Biomass data for the Irish Sea (0.652t/km^2) was obtained from Lees and Mackinson (2007). These authors indicated that 92% of monkfish were identified as anglerfish (*Lophius piscatorius*, Linnaeus 1758), while 8% were identified as white anglerfish (*L. budegassa*, Spinola 1807) (Table 7.5).

Lees and Mackinson (2007) calculated a fishing mortality of 0.026 for this functional group; however, this was considered to be a very low value for a commercially valuable species, that has also low fecundity, is slow growing and late maturing, so a more general value of 0.2 (ICES, 2008b) was used in this model. Natural mortality was estimated to be 0.2008 using equation 7.7. Therefore, a *P/B* ratio of 0.4008 was estimated. *Q/B* ratio was estimated to be 2.0814 using equation 7.8 (Table 7.5).

The diet of monkfish given by Lees and Mackinson (2007) was used in this model (Table 7.6, Appendix X).

FG 25 Large Gadoids

Pollack (*Pollachius pollachius*, Linnaeus 1758) was the main species included within this functional group by Lees and Mackinson, (2007); however, the other main *Pollachius* species (saithe; *Pollachius virens*, Linnaeus 1758) was also found to be important in the diet of some predators (e.g. seals, bottlenose dolphin and harbour porpoise -Chapters 5 and 6). No biomass data are available for saithe in the area of study, and so the biomass of the large gadoids group (pollack and saithe combined) estimated for the Irish Sea (0.194 t/km^2) was obtained from Lees and Mackinson (2007), even though it may be underestimated (Table 7.5).

The *P/B* ratio was estimated to be 0.6969 using equation 7.6, where fishing mortality was 0.375 (Homrum et al., 2013) and natural mortality was estimated to be 0.3219 using equation 7.7. The estimation of *Q/B* ratio (3.6678) was calculated using equation 7.8 (Table 7.5).

The diet information of this functional group was obtained from Lees and Mackinson (2007). In that model, the total diet proportion was over 1, and the small planktivorous fish proportion was reduced as both pollack and saithe are demersal predators (Table 7.6, Appendix X).

FG 26 Other small demersal species

Lees and Mackinson (2007) indicated that the composition of this group is made up by the lesser weaver (*Echiichthys vipera*, Cuvier 1829), greater weaver (*Trachinus draco*, Linnaeus 1758), argentine (*Argentina* spp., Linnaeus 1758), and triggerfish (Balistidae). However, there are other species included within the Order Perciformes, such as the members of the Gobidae and Labridae family, that inhabit the Irish Sea and they are found within the diet of different predators. Biomass given by Lees and Mackinson (2007) was 0.316t/km^2; these authors used the ground fish survey to come up with this estimate, which does not include inshore species (such as gobids and labrids). The coastline along UK and Ireland supports a large biomass of small fish that in surveys are inaccessible and not usually considered. However, Lees and Mackinson (2007) increased the biomass of this group to 0.544 after balancing the model. A value of 0.6 t/km^2 was considered for the original model constructed in this study (Table 7.5).

P/B ratio (1.57) and *Q/B* ratio (5.421) used in the model were obtained from Lees and Mackinson (2007) (Table 7.5).

Diet information was also obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 27 Other small Gadoids

All *Trisopterus* spp. (Norway pout –*Trisopterus esmarkii*, Nilsson 1855; poor cod –*T. minutus*, Linnaeus 1758-; pouting –*T. luscus*, Linnaeus 1758), and blue whiting (*Micromesistius poutassou*, Risso 1827) were included in this group in Lees and Mackinson, (2007). Biomass estimation for the Irish Sea of 0.974 t/km^2 was given by Lees and Mackinson (2007) (Table 7.5).

P/B ratio was estimated for all species (1.0457 for Norway pout, 1.0089 for poor cod, 1.0549 for pouting, and 0.7275 for blue whiting) using equation 7.6, where fishing mortality was assumed to be 0.2 (ICES, 2008b) for the whole group and natural mortality was estimated using equation 7.8. The most common species reported by Lees and Mackinson (2007) was poor cod; therefore its *P/*B ratio was used for the model. *Q/B* ratio estimated (7.21) was also calculated for the poor cod using equation 7.8 (Table 7.5).

Small gadoid diet was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 28 Small planktivorous fish

Species included within this functional group in Lees and Mackinson (2007) were Atlantic herring (*Clupea harengus*, Linnaeus 1758), European pilchard (*Sardina pilchardus*, Walbaum 1792), allis shad (*Alosa alosa*, Linnaeus 1758), European sprat (*Sprattus sprattus*, Linnaeus 1758), European anchovy (*Engraulis encrasicolus*, Linnaeus 1758), and Atlantic horse mackerel (*Trachurus trachurus*, Linnaeus 1758). Small planktivorous biomass for the Irish Sea (3.643t/km^2) was obtained from Lees and Mackinson (2007) (Table 7.5).

Using equation 7.6, with a fishery mortality of 0.477 (Lees and Mackinson, 2007); a natural mortality estimation of 0.25 as given in ICES (2005), who indicated that the main small pelagic species in the Irish Sea was herring. The *P/B* ratio was estimated to be 0.727. *Q/B* ratio (6.516) was obtained from Lees and Mackinson (2007) (Table 7.5).

The diet information was also obtained from Lees and Mackinson (2007); however, the total biomass proportion was 0.995 and the 0.005 missing was added to Cephalopod prey (Table 7.6, Appendix X).

FG 29 Small sharks

The functional group information was obtained from Lees and Mackinson (2007). These authors considered that the main species was small-spotted dogfish (*Scyliorhinus canicula*, Linnaeus 1758), with a biomass of 1.874 t/km^2 for the Irish Sea Table 7.5.

A *P/B* ratio of 0.972 was calculated, where fishing and natural mortality were estimated to be 0.012 and 0.96 respectively. *Q/B* ratio was reported to be 9.72 (Lees and Mackinson, 2007) (Table 7.5).

Diet information used was obtained in Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 30 Large sharks

The functional group information of large sharks was obtained from Lees and Mackinson (2007). These authors indicated that the main species were picked dogfish (*Squalus acanthias*, Linnaeus 1758), tope shark (*Galeorhinus galeus*, Linnaeus 1758), and porbeagle, and they gave a biomass of 0.115 t/km^2 for the Irish Sea (Table 7.7).

P/B ratio was estimated to be 0.318, where only natural mortality was used (Lees and Mackinson, 2007). Due to lack of information on consumption estimates of this functional group, a *P/Q* value of 0.1 was given as Lees and Mackinson (2007) reported (Table 7.5).

Diet information used was taken from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 31 Skates and rays

This functional group information was obtained from Lees and Mackinson (2007). The main species considered by these authors were common or blue skate (*Dipturus batis*, Linnaeus 1758), cuckoo ray (*Leucoraja naevus*, Müller and Henle 1841), blonde ray (*Raja brachura*, Lafont 1871), thornback ray (*Raja clavata*, Linnaeus 1758), small-eyed ray (*Raja microocellata*, Montagu 1818), and spotted ray (*Raja montagui*, Fowler 1910); they gave a biomass of 0.714 t/km^2 for the Irish Sea (Table 7.5).

A *P/B* ratio of 1.6 was obtained from Lees and Mackinson (2007). There was no consumption estimates for this functional group, however Stanford and Pitcher (2000) gave a value of 0.1 for *P/Q* ratio (Table 7.5).

Diet information used was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

7.3.3.3 Invertebrate groups

A biomass estimation of invertebrate groups for the Irish Sea is not available in the literature and information given by Lees and Mackinson (2007) was used. These authors used information collected with a 4 m beam trawl during the CEFAS survey in 2003.

Also, *P/B* ratios were obtained from the Lees and Mackinson (2007) model, where the authors obtained the values using Brey's (2002) multi-parameter model, as fishery mortality and *Z* are not usually available for invertebrate species. Consumption estimates are not available in the literature for several invertebrate functional groups; however Christensen (1995b) used a value of 0.15 for *P/Q* allowing the program to estimate the appropriate *Q/B* for them. The functional groups used were epifaunal macrobenthos, epifaunal mesobenthos, polychaeta, infaunal macrobenthos, infaunal mesobenthos, lobsters and large crabs, *Nephrops*, prawns and shrimps, and finally, sessile epifauna.

FG 32 Epifaunal macrobenthos

The epifaunal macrobenthos species considered by Lees and Mackinson (2007) for the Irish Sea, included common starfish (*Asterias rubens*, Linnaeus 1758), sand star (*Astropecten irregularis*, Pennant 1777), and common sunstar (*Crossaster papposus*, Linnaeus 1776). However, other species should be included such as Echinoids and Ophiurids. Biomass estimation for the Irish Sea was reported to be 9.810t/km^2 (Lees and Mackinson, 2007), and this value was used due to the lack of information about Echinoid biomass.

P/B ratio was reported to be 0.561; consumption estimates for this group was not available and a value of 0.15 for *Q/B* was given by Christensen (1995b) for the North Sea model, therefore *Q/B* ratio was estimated by the model (Table 7.5).

Lees and Mackinson (2007) diet information was included in this model; however, the total proportion of diet they reported was 0.992 and for this reason 0.008 was added to Particulate Organic Matter (POM) in this analysis (Table 7.6, Appendix X).

FG 33 Epifaunal mesobenthos

Hermit crabs and *Liocarcinus* spp. were reported to be the most important species within this group in the Lees and Mackinson (2007) model. These authors reported a biomass estimation of 0.6918t/km^2 for the Irish Sea.

A *P/B* ratio of 1.062 was given by Lees and Mackinson (2007); however, there were no consumption estimates for this group and a *P/Q* value of 0.15 (Christensen, 1995b) was given to allow the program to estimate the *Q/B* value (Table 7.5).

Diet information for the model was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 34 Infauna (Polychaeta)

Biomass estimation given by Lees and Mackinson (2007) for this functional group was 0.00063t/km^2.

P/B ratio given by Lees and Mackinson (2007) was 1.683; for this group, and a value of 0.15 (Christensen, 1995b) for the *P/Q* ratio was used allowing the program to estimate the *Q/B* (Table 7.5).

Polychaete diet was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 35 Infaunal macrobenthos

Lees and Mackinson (2007) found that two thirds of the composition of this group was made up by the sand slug (*Philine aperta*, Linnaeus 1767). They estimated a biomass of 0.111t/km^2 for the Irish Sea.

A value of 0.695 for the *P/B* was used (Lees and Mackinson, 2007). A 0.15 value (Christensen, 1995b) for the *P/Q* ratio was used allowing the model to estimate the *Q/B* (Table 7.5).

The total diet proportion given by Lees and Mackinson (2007) was 1.2872, so 0.2872 had to be removed. Phytoplankton and seaweed were removed as they are unlikely prey for this group of species; also, infaunal macrobenthos and mesobenthos were decreased to 0.1240 and 0.1258 respectively in order to adjust the values (Table 7.6, Appendix X).

FG 36 Infaunal mesobenthos

More than 90% of this functional group comprised the cut trough shell (*Spisula subtruncata*, da Costa 1778), and Lees and Mackinson (2007) estimated that biomass in the Irish Sea was 0.0605t/km^2.

P/B ratio reported by Lees and Mackinson (2007) was 1.552; as in the previous invertebrate groups, a *P/Q* value of 0.15 (Christensen, 1995b) was given, in order to obtain the estimated *Q/B* value by the model (Table 7.5).

Lees and Mackinson (2007) model reported that the diet is composed mainly of infauna organisms and plankton. However, the total proportion given by the authors was 1.225; therefore, sessile epifauna and meiofauna were reduced to 0.01 and 0.015 respectively, as they are found in lower proportions within the diet of this group. (Table 7.6, Appendix X).

FG 37 Lobsters and large crabs

Biomass estimation for this functional group in the Irish Sea was estimated to be 0.0943t/km^2 (Lees and Mackinson, 2007).

Lees and Mackinson (2007) estimated that the *P/B* ratio was 0.783; for the estimations of *Q/B* ratio, a *P/Q* value of 0.15 (Christensen, 1995b) also was given (Table 7.5).

Standford and Pitcher (2000) reported that the diet of this group of species was mainly composed by detritus (62%), benthos (20%) and prawns (15%), with some cannibalism (3%) (Table 7.6, Appendix X).

FG 38 *Nephrops*

Lees and Mackinson (2007) indicated that Norway lobster biomass in the western Irish Sea given by ICES ranged from 35,000 to 102,000 tonnes depending on the assessment method; the biomass value given by these authors was used in the model (0.203t/km^2) (Table 7.5).

P/B ratio was estimated using equation 7.6, where fishing mortality was estimated to be 0.48 (ICES, 2003b) and natural mortality was estimated to be 0.3 (ICES, 2008b). *Q/B* ratio was estimated by the model, using a *P/Q* ratio of 0.15 (Christensen, 1995b) (Table 7.5).

Diet information was obtained from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 39 Cephalopods

Lees and Mackinson (2007) reported that the main species of cephalopods in the Irish Sea were long-finned squid (*Loligo forbesii*, Streenstrup 1857) and common cuttlefish (*Sepia officinalis*, Linnaeus 1758); however, octopuses species are also common in the area (Sacau et al., 2005), and Sacau et al. (2005) indicated that the most common cephalopod species in the Irish Sea were long-finned squid (*Loligo forbesii*, Steenstrup 1857) and the European common squid (*L.vulgaris*, Lamarck 1798). The biomass was therefore increased in comparison to the value given by Lees and Mackinson (2007) (from 0.167 to 0.25t/km^2 (Table 7.5).

P/B ratio was estimated to be 2.47 using equation 7.6, where fishing mortality was 0.75 and natural mortality 1.72 (Strandford and Pitcher, 2004). Araujo et al. (2005) gave a value of 15 for *Q/B* ratio (Table 7.5).

The diet information used for the model was obtained from Lees and Mackinson (2007) model (Table 7.6, Appendix X).

FG 40 Prawns and Shrimp

This group was considered to be mainly composed of pink shrimp (*Pandalus montagui*, Leach 1814) making up 86% of the total, and brown shrimp (*Crangon crangon*, Linnaeus 1758) with 9% (Lees and Mackinson, 2007). The biomass value (0.0335 t/km^2) given by Lees and Mackinson (2007) was used in the model.

The *P/B* ratio of 0.959 given by Lees and Mackinson (2007) model was also used; for the estimation of *Q/B* ratio, a *P/Q* value of 0.15 (Christensen, 1995b) was given allowing the program to estimate the *Q/B* ratio (Table 7.5).

Diet from Lees and Mackinson (2007) was used; however, the total biomass proportion given by these authors was 0.99; the missing value 0.01 was added to the different phytoplankton (Table 7.6, Appendix X).

FG 41 Sessile epifauna

Hornwrack (*Flustra foliacea*, Linnaeus 1758) and dead man's fingers (*Alcyonium digitatum*, Linnaeus 1758) were the most important species considered within this group (Lees and Mackinson, 2007). Biomass given by Lees and Mackinson (2007) was 13.944t/km^2

These authors gave a value of 0.066 for the *P/B* ratio; for the estimation of the *Q/B* ratio, the *P/Q* value of 0.15 (Christensen, 1995b) was given in order to allow the program to calculate the *Q/B* ratio (Table 7.5).

Diet was obtained from Lees and Mackinson (2007); however, the total biomass proportion given by these authors was 0.875; the value 0.125 missing was added to the different zooplankton groups (Table 7.6, Appendix X).

FG 42 Meiofauna

The value of Meiofauna biomass (0.11t/km^2) was also obtained from Lees and Mackinson (2007), who assumed a comparable value to that reported for the North Sea (Heip et al., 1990) (Table 7.5).

Heip et al. (1990) indicated that the *P/B* ratio in the North Sea varied from 10.1 to 35.3, and Heip (1984) reported a lower value of 8.0; an average value of 17.8 was used for the model; for the *Q/B* ratio estimation, the *P/Q* value of 0.15 (Christensen, 1995b) was given in order to allow the program to calculate the *Q/B* ratio (Table 7.5).

Diet information was taken from Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 43 Gelatinous zooplankton

Irish Sea biomass (1.1t/km^2) estimation was obtained from Stanford and Pitcher (2000) estimations. Lees and Mackinson (2007) did not consider the Chaetognatha reported by Stanford and Pitcher (2000) within this group; however, because of the morphology ("jelly" species) and behaviour similar to other gelatinous zooplankton they were considered here.

A *P/B* ratio of 7 and a *Q/B* ratio of 23.33 were obtained from the Irish Sea model carried out by Lees and Mackinson (2007), based on the information from the British Columbia (Larson, 1987) and English Channel models (Stanford and Pitcher, 2000) (Table 7.5).

Diet information was also obtained from the Irish Sea model of Lees and Mackinson (2007) (Table 7.6, Appendix X).

FG 44 Carnivorous zooplankton

All information for the model was obtained from Lees and Mackinson (2007), where the biomass of this functional group was 0.006t/km^2, the *P/B* ratio was 18, and *Q/B* ratio was 60 (Table 7.5).

Within the Lees and Mackinson (2007) model, diet proportion was 0.965; therefore the 0.035 value missing was added to particulate organic matter (POM) and dissolved organic matter (DOM) (Table 7.6, Appendix X).

FG 45 Omnivorous zooplankton

The biomass information (0.137t/km^2) for the model was obtained from Lees and Mackinson (2007), as well as the *P/B* ratio (18) and the *Q/B* ratio (60) (Table 7.5).

Also, Lees and Mackinson (2007) model diet proportion was lower than 1 (0.834); therefore the 0.166 value missing was added to phytoplankton (Table 7.6, Appendix X).

FG 46 Herbivorous zooplankton

Information for this part of the model was also taken from Lees and Mackinson (2007); biomass for the Irish Sea was 0.076t/km^2, the *P/B* ratio was 18, and the *Q/B* ratio was 60 (Lees and Mackinson, 2007) (Table 7.5).

Again, Lees and Mackinson (2007) model diet proportion was lower than one (0.965); therefore the 0.035 value missing was added to phytoplankton (Table 7.6, Appendix X).

7.3.3.4 Primary producers and bacteria

FG 47 Seaweed

Data from Lees and Mackinson (2007) model was used, where both the biomass (75t/km^2) and the *P/B* ratio (60) were obtained from Stanford and Pitcher (2000) (Table 7.5).

FG 48 Microflora

Data from Lees and Mackinson (2007) model were used, where biomass (3.92t/km^2) was obtained from Stanford and Pitcher (2000) and the *P/B* ratio (587) from Billen et al. (1990) (Table 7.5).

FG 49 Phytoplankton

Data from Lees and Mackinson (2007) model were used, where the biomass was estimated to be 9.667 t/km^2, and *P/B* ratio (152.5) was obtained from Stanford and Pitcher (2000) (Table 7.5).

7.3.3.5 Detritus groups

FG 50 Particulate Organic Matter (POM)

As in the Lees and Mackinson (2007) model, POM was obtained from the North Sea Ecopath model (Christensen, 1995b), where the biomass was given as 50t/km^2 (Table 7.5).

FG 51 Dissolved Organic Matter (DOM)

Also, as in the Lees and Mackinson (2007) model, DOM was obtained from the North Sea Ecopath model (Christensen, 1995b), where biomass was also given as 50t/km^2 (Table 7.5).

FG 52 Discards

The total biomass of discards for the Irish Sea given by Lees and Mackinson (2007) using ICES Stock Assessments was 0.309t/km^2 for 1973; however, Viana (2012) gave a value of 0.290t/km^2 using the Marine Institute discard data from 1994 to 2009. Viana (2012) was considered a more realistic estimate for the Irish Sea discard information (Table 7.5).

7.3.4 Fisheries and Fishery Parameters

The Irish Sea is a very productive region, where many commercial species have been found spawning, such as Atlantic herring, Atlantic cod, haddock, whiting, European plaice, common sole and *Nephrops*; and some of these species (e.g., herring, Atlantic mackerel) inhabit the coastal areas during their nursery period (MI, 2013). On the other hand, invertebrate stocks such as cockles, shrimps and crabs (Anon., 2009) are also important locally. Due to the importance of fisheries in the area, the International Council for the Exploration of the Sea (ICES) has classified the whole Irish Sea as sub-division VIIa for fisheries management purposes.

Fisheries catches can be split into two components: landings and discards. The second component comprises commercially landed species for which the vessel has no quota or market as well all as those species caught that do not have a commercial value and are returned to sea. The exploitation of the stocks in the Irish Sea are usually carried out by mixed demersal fisheries (Davie and Lordan, 2009), with a relatively important fish bycatch (MI, 2013); demersal fisheries (otter and beam trawls), for example, were found to catch a large number of both commercial and non-commercial species (Borges et al., 2005; Davie and Lordan, 2009; ICES, 2008b; MI, 2013; Viana, 2012).

ICES assessment reports provide landings data for the commercially valuable species (ICES, 2004; ICES, 2008b); however, as Lees and Mackinson (2007) reported, landings data are not available by gear. These authors grouped all gear types fishing in the Irish Sea into nine groups (Table 7.2), and they estimated the total landings by gear type for the area using the UK landings, assuming that the UK landings by gear were representative of all the other countries fishing in the Irish Sea. The same approach was used for the ICES landings data for 2004 (ICES 2008b) (Table 7.3). In Lees and Mackinson (2007), Sea trout and Atlantic salmon data was obtained from the Scottish Salmon and Sea trout catches report published by Fisheries Research Services (FRS, 2004) and the Environment Agency (Environment Agency, 2003) of UK for 2003 and 2002 respectively. Lees and Mackinson (2007) did not have landings data on monkfish, large sharks and infauna macrobenthos, but ICES Fishstat+ landings database provide that data for 2004.

Lees and Mackinson (2007) used the discard information from the UK fleets, considering that discards reported by the UK was 58% of the total discards for the area and it was increased by 42% assuming discards from the rest of the countries. This information was used as a baseline of discards and including small shark discard data provided by Borges et al. (2005). For the main apex predators, the information given by Lees and Mackinson (2007) for toothed whales by caught in trawlers was assumed to be for harbour porpoise, but was transferred to “Other net” category. By-catch of these predators by other nets (such as gill nets, and trammel nets) were also included in the model; Tregenza et al. (1997) indicate that 6.2% of harbour porpoise population are likely to be by caught in the South East of the Celtic Sea, and that value was also assumed for the study area. Reeves et al. (2013) indicated that minke whale by-catch occurs at a rate of less than one per year in the North East Atlantic, and a value of one animal was considered for the area of study. Following ICES (2013) 34 grey seals and nine common seals were considered by caught for the area (Table 7.4).

Table 7.2. Gear fishery type groups for UK landings (from Lees and Mackinson, 2007)

Nets...

Gear Types	Type of Fleets	Gear Types	Type of Fleets
Beam otter trawl	Beam trawls	*Nephrops* otter trawl	*Nephrops* trawls
Heavy otter trawl	Otter trawls	Twin *Nephrops* otter	*Nephrops* trawls
Light otter trawl	Otter trawls	Triple *Nephrops* trawl	*Nephrops* trawls
Bottom pair trawl	Otter trawls	Shank net	Other nets
Twin otter trawl	Otter trawls	Hand pushed net	Other nets
Triple otter trawl	Otter trawls	Ring net	Other nets
Unspecified otter trawl	Otter trawls	Drift net	Other nets
Prawn otter trawl	Otter trawls	Danish gill net	Other nets
Midwater demersal trawl	Midwater trawls	Tangle gill net	Other nets
Midwater trawl	Midwater trawls	Trammel gill net	Other nets
Midwater pair trawl	Midwater trawls	Hoop net	Other nets
Danish anchor seine	Seine nets	Stake net	Other nets
Scottish fly seine	Seine nets	Fyke net	Other nets
Beach seine	Seine nets		
Pair fly seine	Seine nets		
Purse seine	Seine nets		

Other gears...

Gear Types	Type of Fleets	Gear Types	Type of Fleets
Top opening pots	Lines and Pots	Surface picking	Pickers and gatherers
Side opening pots	Lines and Pots	Submerged picking	Pickers and gatherers
Parlour pots	Lines and Pots	Hand dredge	Dredges
Other or mixed pots	Lines and Pots	Power dredge	Dredges
Cuttle trap	Lines and Pots	Suction dredge	Dredges
Unspecified trap	Lines and Pots	Unspecified dredge	Dredges
Lon lines	Lines and Pots		
Hand lines (inc. gurdy)	Lines and Pots		
Rod and line	Lines and Pots		

Table 7.3 Total landings by gear type (t/km^2). From Lees and Mackinson (2007)

Functional Groups	Beam trawl	Otter trawl	Midwater trawl	*Nephrops* trawl	Seine net	Other net	Lines and Pots	Pickers and gatherers	Dredges	Total
Bottlenose Dolphin	0	0	0	0	0	0	0	0	0	**0**
Harbour Porpoise	0	0	0	0	0	0	0	0	0	**0**
Minke Whale	0	0	0	0	0	0	0	0	0	**0**
Common Seal	0	0	0	0	0	0	0	0	0	**0**
Grey Seal	0	0	0	0	0	0	0	0	0	**0**
Seabirds	0	0	0	0	0	0	0	0	0	**0**
Basking Shark	0	0	0	0	0	0	0	0	0	**0**
Adult Cod 2+	0.00018025	0.01952650	0	0	0.00060082	0.00002003	0	0	0	**0.020328**
Juvenile Cod 1+	0	0	0	0	0	0	0	0	0	**0**
Adult Haddock 2+	0.00006432	0.01302421	0	0	0.00003216	0	0	0	0	**0.013121**
Juvenile Haddock 1+	0	0	0	0	0	0	0	0	0	**0**
Adult Plaice 2+	0.00058296	0.01603152	0	0	0.00291482	0.00002242	0	0	0	**0.019552**
Juvenile Plaice 1+	0	0	0	0	0	0	0	0	0	**0**
Whiting	0.00000316	0.00351092	0	0	0.00000316	0	0	0	0	**0.003517**
Sole	0.00701478	0.00508571	0	0	0	0	0	0	0.00017537	**0.012276**
Salmonids	0	0	0	0	0	0	0	0.18043616	0	**0.180436**
Sandeels	0	0	0	0	0	0.00001724	0	0	0	**0.000017**
Small flatfish	0.00000010	0.00000081	0	0	0.00000002	0.00000080	0	0	0	**0.000002**
Medium Flatfish	0.00037157	0.00293345	0	0.0000000	0.00005867	0.00291390	0	0	0	**0.006278**
Large Flatfish	0.00026940	0.00282866	0	0	0.00013470	0	0	0	0	**0.003233**
Dragonets	0	0	0	0	0	0	0	0	0	**0**
Other Large Demersal	0.00004419	0.01405273	0	0	0	0	0.00026515	0	0	**0.014362**
Mackerel	0	0.00000745	0	0	0.00162475	0	0.00000745	0	0	**0.001640**
Monkfish	0.00111798	0	0	0.00214279	0.00154033	0.00566442	0	0	0	**0.010466**
Large Gadoids	0.00003199	0.01017263	0	0	0	0	0.00019194	0	0	**0.010397**

Table 7.3 *Conti*

Functional Groups	**Beam trawl**	**Otter trawl**	**Midwater Trawl**	***Nephrops* Trawl**	**Seine net**	**Other net**	**Lines and Pots**	**Pickers and gatherers**	**Dredges**	**Total**
Other Small Demersal	0	0.00735172	0	0	0	0	0	0	0	**0.007352**
Other Small Gadoids	0.00001962	0.00015452	0	0	0	0	0	0	0	**0.000174**
Small Pelagic Planktivorous	0	0.0086622	0.11715217	0	0	0.03313395	0	0	0	**0.158948**
Small Sharks	0.00034921	0.00377148	0	0	0	0	0	0	0	**0.004121**
Large Sharks	0	0	0.01625862	0	0	0.01089328	0	0	0	**0.027152**
Skates and Rays	0.00064550	0.04078371	0	0	0.00046945	0.00111495	0.00017605	0	0	**0.043190**
Epifaunal Macrobenthos	0.00061552	0.00789918	0	0	0	0	0.00174398	0	0.29750167	**0.307760**
Epifaunal Mesobenthos	0	0	0	0	0	0	0	0	0	**0**
Infauna (Polychaeta)	0	0	0	0	0	0	0	0	0	**0**
Infaunal macrobenthos	0	0	0	0	0	0	0	0.07855172	0	**0.078552**
Infaunal Mesobenthos	0	0	0	0	0	0	0	0	0	**0**
Lobster and Large Crabs	0	0	0	0	0	0	0.0415207	0	0	**0.041521**
Nephrops	0	0.00252810	0	0.133058103	0	0	0	0	0	**0.135586**
Cephalopods	0	0.00134483	0	0	0	0	0	0	0	**0.001345**
Prawns and Shrimp	0.00027488	0	0	0	0	0.00025961	0	0	0	**0.000535**
Sesile Epifauna	0	0	0	0	0	0	0	0	0	**0**
Seaweed	0	0	0	0	0	0	0	0	0	**0**
Total	**0.011585**	**0.159670**	**0.133412**	**0.135201**	**0.007379**	**0.054041**	**0.043906**	**0.258988**	**0.297677**	**1.101857**

Table 7.4 Total discards by gear type (t/km^2). From Lees and Mackinson (2007) and modified based on Borges et al. (2005), ICES (2008b) and Viana (2012)

Functional Groups	**Beam trawl**	**Otter trawl**	**Midwater trawl**	***Nephrops* trawl**	**Seine net**	**Other net**	**Lines and Pots**	**Pickers and gatherers**	**Dredges**	**Total**
Bottlenose Dolphin	0	0	0	0	0	0	0	0	0	**0**
Harbour Porpoise	0	0	0	0	0	0.000031	0	0	0	**0.000031**
Minke Whale	0	0	0	0	0	0.000086	0	0	0	**0.000086**
Common Seal	0	0	0	0	0	0.000007	0	0	0	**0.000007**
Grey Seal	0	0	0	0	0	0.000022	0	0	0	**0.000022**
Seabirds	0	0	0	0	0	0	0	0	0	**0**
Basking Shark	0	0	0	0	0	0	0	0	0	**0**
Adult Cod 2+	0	0.000658	0.000010	0	0	0.000041	0	0	0	**0.000709**
Juvenile Cod 1+	0.000517	0	0.000100	0	0	0.000001	0	0	0	**0.000618**
Adult Haddock 2+	0	0.000211	0.000010	0	0	0.000001	0	0	0	**0.000222**
Juvenile Haddock 1+	0	0	0.000010	0	0	0.000001	0	0	0	**0.000011**
Adult Plaice 2+	0.013400	0	0	0.00000	0	0	0	0	0	**0.013400**
Juvenile Plaice 1+	0.000002	0	0	0	0	0	0	0	0.000001	**0.000003**
Whiting	0.001410	0.002640	0.000100	0	0	0.000001	0	0	0	**0.004151**
Sole	0	0.000016	0	0	0	0	0	0	0.000001	**0.000017**
Salmonids	0	0	0	0	0	0	0	0	0	**0**
Sandeels	0	0	0	0	0	0.000001	0	0	0	**0.000001**
Small flatfish	0	0.000003	0	0.000001	0	0	0	0	0.001000	**0.001004**
Medium Flatfish	0.008200	0.000542	0	0.000100	0.000038	0	0	0	0.000100	**0.008980**
Large Flatfish	0.000036	0	0	0	0	0	0	0	0.000010	**0.000046**
Dragonets	0.000038	0.000012	0.000020	0	0	0	0	0	0	**0.000070**
Other Large Demersal	0	0.000808	0.000010	0	0	0	0	0	0	**0.000818**
Mackerel	0	0.001140	0.000010	0	0	0	0	0	0	**0.001150**
Monkfish	0.000008	0.000172	0.000001	0	0	0	0	0	0.000010	**0.000191**
Large Gadoids	0.000896	0.003710	0.000001	0	0.000006	0	0	0	0	**0.004613**

Table 7.4 Total discards by gear type (t/km^2). *Continued*

Functional Groups	**Beam trawl**	**Otter trawl**	**Midwater trawl**	***Nephrops* trawl**	**Seine net**	**Other net**	**Lines and Pots**	**Pickers and gatherers**	**Dredges**	**Total**
Other Small Demersal	0.000018	0.000046	0	0	0	0.000002	0	0	0	**0.000066**
Other Small Gadoids	0.000010	0.000036	0	0	0.000274	0	0	0	0	**0.000320**
Small Pelagic Planktivorous	0	0.000004	0.000100	0	0	0	0	0	0	**0.000104**
Small Sharks	0.000004	0.089100	0	0	0	0	0	0	0	**0.089104**
Large Sharks	0	0.000039	0	0	0.000064	0	0	0	0	**0.000103**
Skates and Rays	0	0.009280	0	0	0.000020	0	0	0	0	**0.009300**
Epifaunal Macrobenthos	0.019200	0.001730	0	0.000001	0.000037	0	0	0	0.000100	**0.021068**
Epifaunal Mesobenthos	0.007980	0.001480	0	0.000100	0.000007	0	0	0	0.000001	**0.009568**
Infauna (Polychaeta)	0.000595	0.000428	0	0	0	0	0	0	0	**0.001023**
Infaunal Macrobenthos	0	0	0	0.000010	0	0	0	0	0.000010	**0.000020**
Infaunal Mesobenthos	0	0	0	0	0	0	0	0	0	**0**
Lobster and Large Crabs	0	0.000672	0	0	0	0	0	0	0.000010	**0.000682**
Nephrops	0	0.015400	0	0	0	0	0	0	0	**0.015400**
Cephalopods	0.000651	0.000429	0	0	0	0	0	0	0	**0.001080**
Prawns and Shrimp	0.000532	0.000387	0	0.000100	0	0	0	0	0	**0.001019**
Sesile Epifauna	0.002150	0.000421	0	0.000010	0.000014	0	0	0	0.000010	**0.002605**
Zooplankton	0	0	0	0	0	0	0	0	0	**0**
Seaweed	0.001080	0.003010	0	0	0.000009	0	0	0	0	**0.004099**
Discards	0	0	0	0	0	0	0	0	0	**0**
Total	**0.056727**	**0.132374**	**0.000372**	**0.000322**	**0.000469**	**0.000194**	**00**	**0**	**0.001253**	**0.191711**

7.3.5 Ecopath Output

In order to describe the ecosystem and the position of the different functional groups within that, Ecopath software provides a visual flow chart that aggregates the functional groups into trophic levels. Functional groups are represented by circles and their abundance in the ecosystem is related to its size; the inter-trophic relations among the functional groups are shown as lines. Trophic levels are generally described as a function of their feeding behaviour, where herbivorous groups are at lower levels, and top predators at higher levels.

In addition, a Lindeman-spine analysis was also carried out. This analysis summarizes complex food webs converting them into simple chains based on trophic transfer efficiencies and movements of energy between successive trophic levels (Ulanowicz, 1995, Christensen et al., 2008). The transfer efficiencies are defined as the ratio of the sum of the flow transferred from trophic level '*i*' to trophic level '*j*' and the sum of the exports from the trophic level '*i*', and the throughput of the trophic level '*i*' (Christensen et al., 2008).

Statistical analysis of the ecosystem is also available within Ecopath, using indicators of the size and maturation state of the ecosystem (Odum, 1969). Three indicators can be considered as the main ecological attributes describing the maturation of an ecosystem (Lees and Mackinson, 2007; Odum, 1969): net system production (difference between the total primary production and respiration), total primary production/total biomass ratio, total biomass/throughput ratio (which describes the size of the system in term of flow; Ulanowicz, 1986), and Finn's cycling index (an index that estimates the percentage of material that is recycling within the ecosystem and is expressed as a percentage, Finn 1976). Other indices can be used to indicate the complexity of food webs (Christensen et al., 2008); the system omnivorous index can be expressed as the variance of the trophic level of a consumer's prey group, where a value close to zero means a specialized consumer and a large value a generalist consumer feeding on different trophic levels; Finn's mean path is the average number of groups that flow in, or out of the system, and should increase with the development of the ecosystems.

The gross efficiency ratio (catch/ net primary production) provides information about the fisheries operating in the ecosystem. Trites et al. (1999) indicated that one would expect an increment in the gross efficiency at the same time that fisheries are targeting catches in lower trophic levels.

In the Chapter 6 the overlap in feeding behaviour among the marine mammals as top predators in Irish coastal waters was investigated. Within Ecopath it is also possible to further investigate niche overlap. Ecopath software (Christensen et al., 2008) estimates the niche overlap of the functional groups using a modification of the Pianka equation (Pianka, 1973):

$$O_{jk} = \sum_{i=1}^{n} (p_{ij} * p_{ik})/(\sum_{i=1}^{n} (p^2_{ji} + p^2_{ki})/2) \qquad \text{eq. 7.13}$$

Where O_{jk} is the index of the niche overlap for two functional groups j and k, and p_{ij} and p_{ik} are the resource proportions (i) by the functional groups (j and k).

7.4. RESULTS

7.4.1 Structure of the mass-balance approach

The original data model showed an unbalanced result, where ecotrophic efficiency for several groups showed a value over one; therefore, a balancing strategy was carried out modifying different values from the basic input framework. Firstly, the diet of the different functional groups (FG) was modified taking into account new information on the different prey species in the area. It was also modified considering the possibility of finding other types of prey that animals might be feeding on, but that might be difficult to investigate from stomach data due to fast degradation.

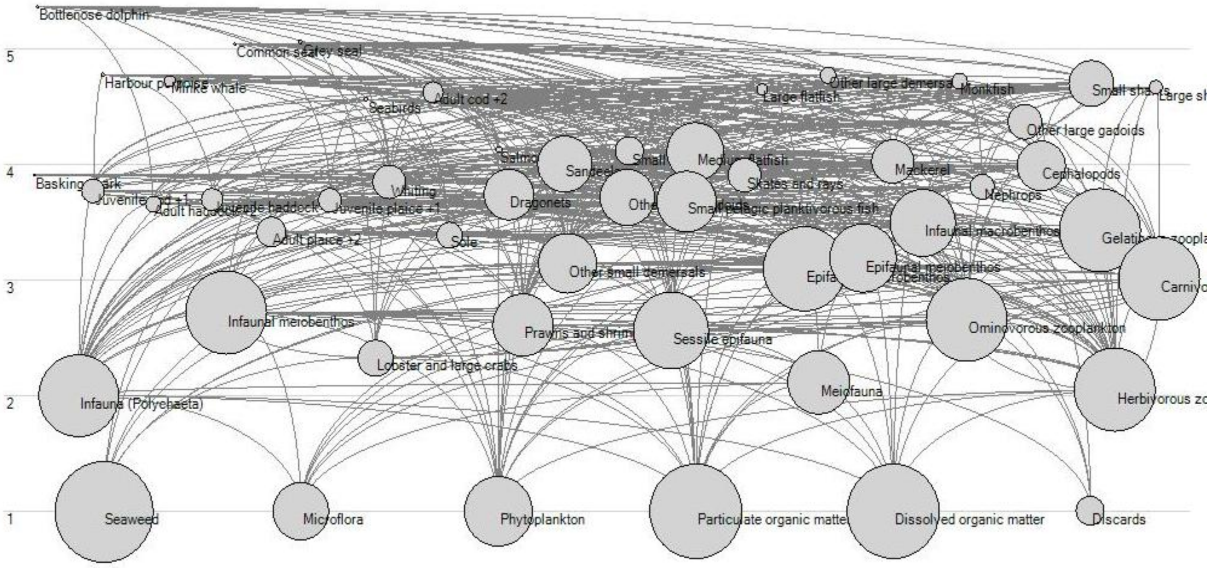
A second option for balancing the model is to change the biomass of some of the FG. The biomass of some FG could be seen as very low for the area in comparison to other better studied areas (e.g. sandeels, other small demersals, dragonets, and many invertebrate functional groups). Some of the decisions to increase or decrease the biomass of the FG were based on similar decisions made by Lees and Mackinson (2007) for their model. However, for sole, sandeels, dragonets, and small pelagic planktivorous fish groups, the improved knowledge of their diet (especially for the top predators) was also used to refine the approach. Both the large and small gadoids (e.g. saithe) functional groups were mainly composed of non–commercial species; and their biomass might be underestimated and they occur widely in top predator’s diet. However, the small gadoids FG biomass was still much lower than the final biomass value given by Lees and Mackinson (2007). Invertebrate functional groups biomass was largely increased in a similar fashion to that used by Lees and Mackinson (2007). Herbivorous zooplankton was increased to a similar degree to the Lees and Mackinson (2007) model, and the rest of zooplankton groups were also considered to occur at a similar level to the final values that Lees and Mackinson (2007) gave after balancing the model.

Thirdly, production (*P/B*) and consumption (*Q/B*) values were increased or decreased until the model was fully balanced. Three main components were considered for the desirable situation: firstly, the ecotrophic efficiency (*EE*) should be smaller than ‘1’, secondly, respiration as a flow between groups must always be positive, and thirdly, gross efficiency (*P/Q*) values should be between 0.05 to 0.3 except for those groups with fast growing species which can present higher values (e.g. nauplii and bacteria) (Christensen et al., 2005). Final results of the model are presented in Table 7.7.

7.4.2 Web structure

The Irish Sea ecosystem can be seen as having five main trophic levels, as illustrated in Fig. 7.3, where circles represent the functional groups used within the model and where the trophic interactions between the functional groups are represented by connection lines. This result shows that the new model contains a higher trophic level than that presented by Lees and Mackinson (2007). However, there was only a small variation in the overall biomass of the main trophic levels between the two models, with the new model being 28% higher. In the new model, the number of the main trophic levels increased from IV to V, probably because the diet of both species of seals and bottlenose dolphins was updated with more local information and they were classified within the V

Figure 7.3 Trophic flow for the Ecopath model of the Irish Sea after Lees and Mackinson (2007). Each circle represents each functional group and their size is related to the biomass of the functional group within the ecosystem.



trophic level (Table 7.5, Table 7.7, and Figure 3 and 4). Harbour porpoise, minke whales, seabirds, small and large sharks, adult cod, large gadoids, medium and large demersals were some of the species/functional groups classified in level IV. Sandeels, mackerel and cephalopods straddle levels III and IV, while other groups in level III include juvenile fish, dragonets, small pelagics and small demersals. Within the fish species, biomass appears to be largest for sandeels, dragonets, small pelagics, medium flatfish and cephalopods. Differences were found between the models in biomass in trophic levels III and IV, where biomass increased in comparison to that presented by Lees and Mackinson (2007) (Table 7.7), probably due to changes in the diet

composition used for some species such as invertebrates and sandeels (Table 7.6, Appendix X).

Table 7.7. Estimated biomass (t/km^2) for each trophic level for the model reported by Lees and Makinson (2007) (L&M) and the model built up this study. Detritus groups were removed.

Trophic level	L & M model	New model	Variation (%)
I	88.587	88.587	0
II	130.919	114.677	-12.4
III	24.234	97.365	301.8
IV	1.189	12.549	955.5
V	0.000	0.006	0.006
Total (no detritus)	244.9	313.184	27.9

7.4.3. Trophic Flows and Summary Statistics

Linderman-spine analysis also showed that the new model contained one additional trophic level (Fig. 7.4). However, the transfer efficiencies between trophic levels were relatively similar between both models, with a slightly reduced efficiency seen in the new model (Table 7.8). The highest transfer efficiencies were found in trophic level II in both the Lees and Mackinson (2007) and the new model (28% and 22% respectively), however the transfer efficiencies in the new model decreased with higher variability while increasing the trophic level (Table 7.8). In general, all trophic levels had higher trophic efficiencies of between 15-20% of the original Lees and Mackinson (2007) model.

Table 7.5 Basic input and estimated parameters for the final Irish Sea model.

Functional Groups	**Biomass (t/km^2)**	**Production/ Biomass (/year)**	**Consumption/ Biomass (/year)**	**Production/ Consumption**	**Ecotrophic Efficiency**	**Trophic Level**
Bottlenose Dolphin	0.001600	0.200	13.11	0.0153	0.0000	5.363
Harbour Porpoise	0.010529	0.200	13.11	0.0153	0.0297	4.772
Minke Whale	0.089320	0.200	11.38	0.0176	0.0965	4.727
Common Seal	0.000459	0.060	15.93	0.0038	0.5157	5.040
Grey Seal	0.004015	0.060	15.93	0.0038	0.1835	5.059
Seabirds	0.003329	1,075	82.664	0.0130	0.0000	4.560
Basking Shark	0.001564	0.070	3.700	0.0189	0.0009	3.908
Adult Cod 2+	0.181533	1.123	2.985	0.3762	0.5158	4.630
Juvenile Cod 1+	0.374016	2.336	6.325	0.3693	0.2555	3.767
Adult Haddock 2+	0.090000	1.536	4.852	0.3166	0.7807	3.662
Juvenile Haddock 1+	0.147113	2.448	12.389	0.1976	0.9508	3.698
Adult Plaice 2+	0.192300	0.955	4.438	0.2152	0.6524	3.417
Juvenile Plaice 1+	0.079998	1.222	9.387	0.1302	0.9493	3.685
Whiting	0.842000	0.445	5.941	0.0749	0.9891	3.844
Sole	0.125000	0.686	4.572	0.1500	0.7928	3.394
Salmonids	0.019100	0.530	6.670	0.0795	0.9060	4.134
Sandeels	3.092300	1.286	5.676	0.2266	0.9902	4.010
Small Flatfish	0.330100	1.356	3.588	0.3778	0.8039	4.113
Medium Flatfish	4.325000	1.007	2.689	0.3746	0.3919	4.105
Large Flatfish	0.074150	0.643	4.317	0.1491	0.2186	4.654
Dragonets	2.680000	1.000	6.113	0.1637	0.7327	3.746
Other Large Demersal	0.152000	0.989	4.137	0.2391	0.5547	4.777
Mackerel	1.623000	1.081	7.008	0.1543	0.5413	4.021
Monkfish	0.155000	0.450	2.081	0.2162	0.9509	4.726
Large Gadoids	0.505000	1.190	4.168	0.2855	0.9906	4.369
Other Small Demersal	4.745000	2.025	5.621	0.3603	0.3510	3.145
Other Small Gadoids	3.616000	1.399	4.825	0.2700	0.6455	3.722
Small Pelagic Planktivorous	4.000000	1.050	3.416	0.3074	0.9779	3.685
Small Sharks	1.874000	0.972	2.958	0.3286	0.9974	4.706
Large Sharks	0.115000	0.318	3.180	0.1000	0.0039	4.664
Skates and Rays	0.714000	1.600	16.000	0.1000	0.3752	3.901
Epifaunal Macrobenthos	20.000000	0.985	3.740	0.2634	0.9868	3.098
Epifaunal Mesobenthos	8.974000	1.776	7.080	0.2509	0.9918	3.186
Infauna (Polychaeta)	22.726000	1.958	11.220	0.1745	0.9724	2.000
Infaunal Macrobenthos	8.007000	1.157	4.675	0.2475	0.9497	3.495
Infaunal Mesobenthos	24.604300	1.638	10.437	0.1570	0.9927	2.715
Lobster and Large Crabs	0.098700	0.783	5.220	0.1500	0.9610	2.330
Nephrops	0.350000	0.480	8.310	0.0578	0.6367	3.808
Cephalopods	0.426500	2.890	15.000	0.1927	0.9677	3.988
Prawns and Shrimp	4.847000	1.499	6.393	0.2345	0.9932	2.612
Sesile Epifauna	13.944000	4.412	10.330	0.4271	0.9948	2.565
Meiofauna	2.456800	18.450	68.000	0.2713	0.5378	2.110
Gelatinous Zooplankton	19.000000	12.000	35.500	0.3380	0.9242	3.427
Carnivorous Zooplankton	23.000000	18.800	51.870	0.3625	0.9986	3.007
Omnivorous Zooplankton	23.000000	18.000	53.000	0.3396	0.9849	2.652
Herbivorous Zooplankton	23.000000	18.000	60.000	0.3000	0.8997	2.047
Seaweed	75.000000	60.000	0.000	-	0.0062	1.000
Microflora	3.920000	587.000	0.000	-	0.2471	1.000
Phytoplankton	9.667000	152.500	0.000	-	0.3137	1.000
Particulate Organic Matter	50.000000	-	-	-	0.4073	1.000
Dissolved Organic Matter	50.000000	-	-	-	0.1090	1.000
Discards	0.500000	-	-	-	0.5723	1.000

Table 7.6. Diet matrix included in the final model of the Irish Sea

Predator Prey	Bottlenose Dolphin	Harbour Porpoise	Minke Whale	Common Seal	Grey Seal	Seabirds	Basking Shark
Bottlenose Dolphin	0	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0	0
Juvenile Cod 1+	0	0.0059	0	0	0	0.0105	0
Adult Haddock 2+	0.0593	0	0	0	0	0	0
Juvenile Haddock 1+	0	0.0135	0	0	0	0	0
Adult Plaice 2+	0.0027	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0.0032	0	0.1000	0
Whiting	0.2000	0.2130	0	0.0350	0.0300	0.0240	0
Sole	0.0010	0	0	0.0200	0.0200	0	0
Salmonids	0.0101	0	0	0.0081	0.1000	0.1141	0
Sandeels	0	0.1000	0.0050	0.1038	0.0160	0.1286	0
Small Flatfish	0	0	0	0.9004	0.0150	0	0
Medium Flatfish	0.0060	0.0090	0	0.0463	0.0250	0.2281	0
Large Flatfish	0.0170	0.0280	0	0	0.0075	0.0200	0
Dragonets	0	0	0	0.0371	0.0060	0	0
Other Large Demersal	0.3609	0	0	0.2001	0.1800	0.0177	0
Mackerel	0.0126	0.0149	0.4000	0	0.0950	0.1801	0
Monkfish	0	0	0	0	0	0	0
Other Large Gadoids	0.1950	0.0671	0	0.0120	0.1000	0.0137	0
Other Small Demersal	0.0150	0.1470	0	0.0110	0.0300	0.1094	0
Other Small Gadoids	0.0607	0.1980	0	0.2561	0.1799	0.1111	0
Small Pelagic Planktivorous	0.0266	0.1691	0.3900	0.0740	0.0870	0.1000	0.0500
Small Sharks	0.1000	0	0	0.0050	0.0100	0	0
Large Sharks	0	0	0	0	0	0	0
Skates and Rays	0	0	0	0.0790	0.0300	0	0
Epifaunal Macrobenthos	0	0	0	0	0	0.0397	0
Epifaunal Mesobenthos	0	0	0	0	0	0.0281	0
Infauna (Polychaeta)	0	0	0	0	0	0	0
Infaunal Macrobenthos	0	0	0	0	0	0.0007	0
Infaunal Mesobenthos	0	0	0	0	0	0.0070	0
Lobster and Large Crabs	0	0	0	0	0.0150	0	0
Nephrops	0	0	0	0	0.0150	0	0
Cephalopods	0.0129	0.0343	0.0900	0.0191	0.0395	0.0003	0.0500
Prawns and Shrimp	0	0	0.1	0	0	0	0.1000
Sessile Epifauna	0	0	0	0	0	0	0
Meiofauna	0	0	0	0	0	0	0
Gelatinous Zooplankton	0	0	0	0	0	0	0.2400
Carnivorous Zooplankton	0	0	0.0090	0	0	0.0157	0.1900
Omnivorous Zooplankton	0	0	0.0030	0	0	0	0.1850
Herbivorous Zooplankton	0	0	0.0030	0	0	0	0.1850
Seaweed	0	0	0	0	0	0	0
Microflora	0	0	0	0	0	0	0
Phytoplankton	0	0	0	0	0	0	0
Particulate Organic Matter	0	0	0	0	0	0	0
Dissolved Organic Matter	0	0	0	0	0	0	0
Discards	0	0	0	0	0	0.0726	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator **Prey**	**Adult Cod 2+**	**Juvenile Cod 1+**	**Adult Haddock 2+**	**Juvenile Haddock 1+**	**Adult Plaice 2+**	**Juvenile Plaice 1+**	**Whiting**
Bottlenose Dolphin	0	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0	0
Juvenile Cod 1+	0.0075	0.0100	0	0.0100	0	0.0100	0
Adult Haddock 2+	0	0	0	0	0	0	0
Juvenile Haddock 1+	0.0050	0	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0	0	0
Whiting	0.0295	0	0	0	0	0	0
Sole	0	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0	0
Sandeels	0.0500	0	0.02071	0	0.0043	0	0
Small Flatfish	0	0	0	0	0	0	0
Medium Flatfish	0.0700	0	0	0	0	0	0
Other Large Flatfish	0	0	0	0	0	0	0
Dragonets	0.0026	0	0.0060	0	0.0043	0	0
Other Large Demersal	0	0	0	0	0	0	0
Mackerel	0.0500	0	0	0	0	0	0
Monkfish	0.025	0	0	0	0	0	0
Large Gadoids	0	0	0	0	0	0	0
Other Small Demersal	0.0760	0	0.0207	0	0.0043	0	0.0500
Other Small Gadoids	0.1786	0	0	0	0	0	0.0500
Small Pelagic Planktivorous	0.0855	0	0.0207	0	0	0	0.0600
Small Sharks	0	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0	0
Skates and Rays	0.0298	0	0	0	0	0	0
Epifaunal Macrobenthos	0.1090	0.0900	0.1509	0.1400	0.0845	0.0270	0.1570
Epifaunal Mesobenthos	0	0	0	0	0.0410	0	0.0617
Infauna (Polychaeta)	0.0035	0.0500	0.1301	0.1000	0.4256	0.1640	0.0870
Infaunal Macrobenthos	0.0010	0.0500	0.0227	0.1000	0.1581	0.1507	0.0420
Infaunal Mesobenthos	0	0	0	0	0.0500	0	0.0220
Lobster and Large Crabs	0.0155	0	0.0070	0	0	0	0
Nephrops	0.0250	0	0	0	0	0	0
Cephalopods	0.1551	0	0	0	0	0	0
Prawns and Shrimp	0.0520	0	0.0949	0	0	0	0.1853
Sesile Epifauna	0.0026	0.2000	0	0	0.0039	0	0
Meiofauna	0	0	0	0	0	0	0
Gellatinous Zooplankton	0	0	0	0	0	0	0
Carnivorous Zooplankton	0.0192	0.3950	0.1505	0.1800	0.0456	0.0929	0.0950
Omnivorous Zooplankton	0.0078	0.1000	0.2015	0.2950	0.0500	0.4923	0.0950
Herbivorous Zooplankton	0	0.1000	0.1745	0.1700	0.0285	0.0581	0.0950
Seaweed	0	0	0	0	0.0500	0	0
Microflora	0	0	0	0	0	0	0
Phytoplankton	0	0.0050	0	0.0050	0.0500	0.0050	0
Particulate Organic Matter	0	0	0	0	0	0	0
Dissolved Organic Matter	0	0	0	0	0	0	0
Discards	0	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator **Prey**	**Sole**	**Salmonids**	**Sandeels**	**Small flatfish**	**Medium Flatfish**	**Large Flatfish**
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0.0020	0.0100
Juvenile Cod 1+	0	0.0053	0	0	0	0.1000
Adult Haddock 2+	0	0	0	0	0.0020	0.0100
Juvenile Haddock 1+	0	0.0014	0.0200	0	0	0.0850
Adult Plaice 2+	0	0	0	0.0200	0	0.0050
Juvenile Plaice 1+	0	0.0010	0	0	0	0
Whiting	0	0.0014	0.0194	0	0.0020	0
Sole	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0
Sandeels	0.1000	0.1327	0.2001	0	0.0200	0.2800
Small Flatfish	0.0100	0.0500	0.0250	0.0250	0.0020	0
Medium Flatfish	0.0170	0.0526	0.0250	0.1070	0.0020	0.0050
Large Flatfish	0	0	0	0	0	0.0050
Dragonets	0	0	0	0	0.1350	0
Other Large Demersal	0	0.0210	0	0	0	0
Mackerel	0	0	0	0	0.0050	0
Monkfish	0	0	0	0	0.0050	0
Other Large Gadoids	0	0	0	0	0.0510	0
Other Small Demersal	0	0.0625	0.0342	0.0770	0.0610	0.0010
Other Small Gadoids	0	0.0930	0.0132	0	0.0646	0.1770
Small Pelagic Planktivorous	0	0.0500	0.0691	0	0.0380	0.0050
Small Sharks	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0
Epifaunal Macrobenthos	0.1080	0.1163	0.0544	0.1500	0.1540	0.1000
Epifaunal Mesobenthos	0	0	0.0320	0	0.0360	0.0250
Infauna (Polychaeta)	0.7536	0.0741	0.0284	0.1500	0.1140	0.0470
Infaunal Macrobenthos	0.0113	0	0.0675	0	0	0.0250
Infaunal Mesobenthos	0	0	0	0	0	0
Lobster and Large Crabs	0	0	0	0	0	0.0200
Nephrops	0	0	0	0.0050	0.0009	0
Cephalopods	0	0.0005	0	0.2000	0.0070	0.1000
Prawns and Shrimp	0	0.0892	0.0493	0	0.1070	0
Sesile Epifauna	0	0	0	0.1000	0.0004	0
Meiofauna	0	0	0	0	0	0
Gelatinous Zooplankton	0	0	0	0	0	0
Carnivorous Zooplankton	0	0.0930	0.0900	0.0530	0.0745	0
Omnivorous Zooplankton	0	0.0834	0.0900	0.0530	0.0745	0
Herbivorous Zooplankton	0	0.0018	0.0550	0.0600	0.0420	0
Seaweed	0	0.0070	0	0	0	0
Microflora	0	0	0	0	0	0
Phytoplankton	0	0.0059	0.1100	0	0	0
Particulate Organic Matter	0	0.0577	0.0170	0	0	0
Dissolved Organic Matter	0	0	0	0	0	0
Discards	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator **Prey**	**Dragonets**	**Other Large Demersal**	**Mackerel**	**Monkfish**	**Large Gadoids**	**Other Small Demersal**
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0.0998	0.0250	0
Juvenile Cod 1+	0	0.0362	0.0019	0	0.0250	0
Adult Haddock 2+	0	0	0	0.0998	0.0200	0
Juvenile Haddock 1+	0	0.1837	0.0006	0	0.0120	0
Adult Plaice 2+	0	0	0	0.0950	0.0200	0
Juvenile Plaice 1+	0	0	0.0001	0	0	0
Whiting	0	0.0432	0.0002	0.0100	0.0010	0
Sole	0	0	0	0.0500	0.0100	0
Salmonids	0	0	0	0	0	0
Sandeels	0	0	0.2028	0	0.0050	0
Small Flatfish	0	0	0	0.0858	0.0210	0
Medium Flatfish	0	0	0.0003	0.1370	0.0400	0
Large Flatfish	0	0	0	0	0	0
Dragonets	0	0	0.0010	0.09606	0.0010	0
Other Large Demersal	0	0.0505	0	0	0	0
Mackerel	0	0.1313	0.0009	0.1240	0.1200	0
Monkfish	0	0	0	0	0	0
Other Large Gadoids	0	0.1161	0	0.0100	0.0200	0
Other Small Demersal	0	0.0488	0.0012	0.0680	0.1000	0
Other Small Gadoids	0	0.2023	0.0401	0.0040	0.1320	0
Small Pelagic Planktivorous	0	0.0400	0.0707	0	0.0500	0
Small Sharks	0	0.0250	0	0	0	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0.0200	0	0	0	0
Epifaunal Macrobenthos	0.6420	0	0.0246	0.0130	0.0320	0.0770
Epifaunal Mesobenthos	0	0	0	0	0.0100	0.0130
Infauna (Polychaeta)	0.2860	0	0.0035	0.0100	0	0.0600
Infaunal Macrobenthos	0	0	0.0001	0	0	0.0600
Infaunal Mesobenthos	0	0	0	0	0	0.0600
Lobster and Large Crabs	0	0	0	0.0100	0	0
Nephrops	0	0	0	0.0090	0.0199	0
Cephalopods	0	0.0030	0.0077	0	0.0180	0
Prawns and Shrimp	0	0.0060	0.1420	0.0190	0.0760	0.0500
Sesile Epifauna	0	0	0.0021	0.0600	0	0.2000
Meiofauna	0	0	0	0	0	0
Gelatinous Zooplankton	0	0	0.0196	0	0	0
Carnivorous Zooplankton	0.0240	0.0320	0.1500	0	0.0800	0.0450
Omnivorous Zooplankton	0.0240	0.0310	0.1500	0	0.0800	0.0450
Herbivorous Zooplankton	0.0240	0.0310	0.1800	0	0.0800	0.0800
Seaweed	0	0	0.0003	0	0	0.2500
Microflora	0	0	0	0	0	0
Phytoplankton	0	0	0.0003	0	0	0.0600
Particulate Organic Matter	0	0	0	0	0	0
Dissolved Organic Matter	0	0	0	0	0	0
Discards	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator. / **Prey**	**Other Small Gadoids**	**Small Pelagic Planktivorous**	**Small Sharks**	**Large Sharks**	**Skates and Rays**	**Epifaunal Macrobenthos**
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0.0300	0	0
Juvenile Cod 1+	0	0	0	0	0	0
Adult Haddock 2+	0	0	0	0.0300	0	0
Juvenile Haddock 1+	0	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0	0
Whiting	0	0	0	0.0300	0.0080	0
Sole	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0
Sandeels	0	0	0	0	0.0040	0
Small Flatfish	0.0020	0	0	0.0040	0.0010	0
Medium Flatfish	0.1250	0	0	0.0040	0.0030	0
Large Flatfish	0	0	0	0	0	0
Dragonets	0.0150	0	0	0	0.0180	0
Other Large Demersal	0	0	0	0.0700	0	0
Mackerel	0	0	0	0.1000	0.0060	0
Monkfish	0	0	0	0	0	0
Other Large Gadoids	0	0	0	0.0300	0	0
Other Small Demersal	0.0230	0.0100	0	0.0500	0.0570	0
Other Small Gadoids	0.0800	0	0	0.1160	0.0070	0
Small Pelagic Planktivorous	0.0070	0.0900	0	0.0960	0.0080	0
Small Sharks	0	0	0.2800	0	0.0060	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0	0.0500	0.2000	0.0030	0
Epifaunal Macrobenthos	0.0980	0.0280	0.3350	0.0500	0.2510	0.1000
Epifaunal Mesobenthos	0.0870	0.0060	0.0150	0	0.0310	0.1000
Infauna (Polychaeta)	0.0230	0.0020	0.0350	0	0.0210	0.1000
Infaunal Macrobenthos	0	0	0.2000	0.0010	0.0580	0.1000
Infaunal Mesobenthos	0	0	0	0.0010	0	0.1000
Lobster and Large Crabs	0	0	0	0.1140	0	0
Nephrops	0	0	0	0	0.0010	0
Cephalopods	0.0020	0.0010	0.0850	0	0.0070	0
Prawns and Shrimp	0.1210	0.0060	0	0.0010	0.4530	0
Sesile Epifauna	0.0200	0	0	0	0.0500	0.0060
Meiofauna	0	0	0	0	0	0.0690
Gelatinous Zooplankton	0	0	0	0.0700	0	0.0090
Carnivorous Zooplankton	0.0530	0.2800	0	0.0010	0	0.0090
Omnivorous Zooplankton	0.0900	0.2800	0	0.0010	0	0.0080
Herbivorous Zooplankton	0.0900	0.2970	0	0.0010	0	0.0090
Seaweed	0	0	0	0	0	0.2500
Microflora	0	0	0	0	0	0.0040
Phytoplankton	0	0	0	0	0	0.0190
Particulate Organic Matter	0.0164	0	0	0	0.0070	0.0760
Dissolved Organic Matter	0	0	0	0	0	0.0360
Discards	0	0	0	0	0	0.0050
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator **Prey**	**Epifaunal Mesobenthos**	**Infauna Polychaeta**	**Infaunal macrobenthos**	**Infaunal Mesobenthos**	**Lobster and Large Crabs**	***Nephrops***
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0
Juvenile Cod 1+	0	0	0	0	0	0
Adult Haddock 2+	0	0	0	0	0	0
Juvenile Haddock 1+	0	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0	0
Whiting	0	0	0	0	0	0
Sole	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0
Sandeels	0	0	0	0	0	0
Small Flatfish	0	0	0	0	0	0
Medium Flatfish	0	0	0	0	0	0
Large Flatfish	0	0	0	0	0	0
Dragonets	0	0	0	0	0	0
Other Large Demersal	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0
Monkfish	0	0	0	0	0	0
Other Large Gadoids	0	0	0	0	0	0
Other Small Demersal	0	0	0	0	0	0.0070
Other Small Gadoids	0	0	0	0	0	0.0020
Small Pelagic Planktivorous	0	0	0	0	0	0
Small Sharks	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0
Epifaunal Macrobenthos	0	0	0.1320	0	0.0200	0.1250
Epifaunal Mesobenthos	0.2000	0	0.1320	0.0250	0.0200	0.1200
Infauna (Polychaeta)	0.2000	0	0.1330	0.0250	0	0.2500
Infaunal Macrobenthos	0	0	0.1240	0	0.0250	0.2500
Infaunal Mesobenthos	0.3200	0	0.1258	0.0250	0.0350	0.0800
Lobster and Large Crabs	0	0	0	0	0	0
Nephrops	0	0	0	0	0	0
Cephalopods	0	0	0	0	0.0550	0
Prawns and Shrimp	0	0	0	0	0	0
Sessile Epifauna	0	0	0	0.2100	0	0.1610
Meiofauna	0	0	0.0112	0.0150	0	0
Gelatinous Zooplankton	0	0	0.0400	0.0500	0	0
Carnivorous Zooplankton	0	0	0.0300	0.0200	0	0
Omnivorous Zooplankton	0	0	0.0300	0.0200	0	0
Herbivorous Zooplankton	0	0	0.0500	0.0500	0	0
Seaweed	0.0400	0	0	0	0.2000	0
Microflora	0	0.3300	0	0.2050	0	0
Phytoplankton	0	0	0.0740	0.1500	0	0
Particulate Organic Matter	0.1200	0.3400	0.0680	0.1000	0.6200	0
Dissolved Organic Matter	0.1200	0.3300	0.0500	0.1000	0	0
Discards	0	0	0	0.0050	0	0.0050
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator **Prey**	**Cephalopods**	**Prawns and Shrimp**	**Sesile Epifauna**	**Meiofauna**	**Gelatinous Zooplankton**
Bottlenose Dolphin	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0
Minke Whale	0	0	0	0	0
Common Seal	0	0	0	0	0
Grey Seal	0	0	0	0	0
Seabirds	0	0	0	0	0
Basking Shark	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0
Juvenile Cod 1+	0.0100	0	0	0	0
Adult Haddock 2+	0	0	0	0	0
Juvenile Haddock 1+	0.0100	0	0	0	0
Adult Plaice 2+	0	0	0	0	0
Juvenile Plaice 1+	0.0100	0	0	0	0
Whiting	0.0100	0	0	0	0
Sole	0.0050	0	0	0	0
Salmonids	0	0	0	0	0
Sandeels	0.0100	0	0	0	0
Small Flatfish	0.0100	0	0	0	0
Medium Flatfish	0.0100	0	0	0	0
Large Flatfish	0	0	0	0	0
Dragonets	0	0	0	0	0
Other Large Demersal	0	0	0	0	0
Mackerel	0	0	0	0	0
Monkfish	0	0	0	0	0
Other Large Gadoids	0	0	0	0	0
Other Small Demersal	0.2500	0	0	0	0
Other Small Gadoids	0.0500	0	0	0	0
Small Pelagic Planktivorous	0.0350	0	0	0	0
Small Sharks	0	0	0	0	0
Large Sharks	0	0	0	0	0
Skates and Rays	0	0	0	0	0
Epifaunal Macrobenthos	0.0200	0	0	0	0
Epifaunal Mesobenthos	0.0200	0	0	0	0
Infauna (Polychaeta)	0.0100	0	0	0.0100	0
Infaunal Macrobenthos	0.0200	0	0	0	0
Infaunal Mesobenthos	0.0200	0	0	0	0
Lobster and Large Crabs	0	0	0	0	0
Nephrops	0	0	0	0	0
Cephalopods	0	0	0	0	0
Prawns and Shrimp	0	0	0	0	0
Sesile Epifauna	0	0	0	0	0
Meiofauna	0	0	0	0.0900	0
Gelatinous Zooplankton	0.0500	0	0	0	0.2000
Carnivorous Zooplankton	0.1500	0.1300	0.1200	0	0.2000
Omnivorous Zooplankton	0.1500	0.1300	0.1200	0	0.2000
Herbivorous Zooplankton	0.1500	0.1300	0.1200	0	0.2000
Seaweed	0	0	0	0	0
Microflora	0	0	0.1510	0.7000	0.2000
Phytoplankton	0	0.0100	0.1430	0	0
Particulate Organic Matter	0	0.0800	0.2030	0.2000	0
Dissolved Organic Matter	0	0.5200	0.1430	0	0
Discards	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**

Table 7.6. *Conti*.

Predator / Prey	Carnivorous zooplankton	Omnivorous zooplankton	Herbivorous zooplankton
Bottlenose Dolphin	0	0	0
Harbour Porpoise	0	0	0
Minke Whale	0	0	0
Common Seal	0	0	0
Grey Seal	0	0	0
Seabirds	0	0	0
Basking Shark	0	0	0
Adult Cod 2+	0	0	0
Juvenile Cod 1+	0	0	0
Adult Haddock 2+	0	0	0
Juvenile Haddock 1+	0	0	0
Adult Plaice 2+	0	0	0
Juvenile Plaice 1+	0	0	0
Whiting	0	0	0
Sole	0	0	0
Salmonids	0	0	0
Sandeels	0	0	0
Small Flatfish	0	0	0
Medium Flatfish	0	0	0
Large Flatfish	0	0	0
Dragonets	0	0	0
Other Large Demersal	0	0	0
Mackerel	0	0	0
Monkfish	0	0	0
Other Large Gadoids	0	0	0
Other Small Demersal	0	0	0
Other Small Gadoids	0	0	0
Small Pelagic Planktivorous	0	0	0
Small Sharks	0	0	0
Large Sharks	0	0	0
Skates and Rays	0	0	0
Epifaunal Macrobenthos	0	0	0
Epifaunal Mesobenthos	0	0	0
Infauna (Polychaeta)	0	0	0
Infaunal Macrobenthos	0	0	0
Infaunal Mesobenthos	0	0	0
Lobster and Large Crabs	0	0	0
Nephrops	0	0	0
Cephalopods	0	0	0
Prawns and Shrimp	0	0	0
Sesile Epifauna	0	0	0
Meiofauna	0	0	0
Gelatinous Zooplankton	0.1500	0	0
Carnivorous Zooplankton	0.1500	0.1500	0.0100
Omnivorous Zooplankton	0.1500	0.1300	0.0100
Herbivorous Zooplankton	0.0900	0.1300	0.0100
Seaweed	0	0	0
Microflora	0.1500	0.0800	0
Phytoplankton	0.2100	0.1600	0.0350
Particulate Organic Matter	0.0475	0.1800	0.9000
Dissolved Organic Matter	0.0525	0.1700	0.0350
Discards	0	0	0
Sum	**1**	**1**	**1**

Comparing both models, indicators of the ecosystem showed that the Irish Sea ecosystem might be in a developing stage when comparing with other models built in adjacent areas (Lees and Mackinson, 2007), where the net system production and total primary production/respiration were large, and the total biomass/throughput ratios were small (Table 7.9). Differences in the first two ratios between the original and the new model were found to be small (3.6% and 15.9% respectively).

The system omnivory index showed a relatively high value, and increased by 45.2% from the original model, indicating that predators of the system maybe generalists. Finn’s path length showed a smaller value (1.7) in comparison to the Lees and Mackinson (2007) model (2.7), indicating a decrease in species diversity (Table 7.9).

The new model showed a gross efficiency much lower than the original model (0.00007 and 0.00024, respectively), which indicates that fishing efficiency is lower in the model constructed in 2004 than in the model built by Lees and Mackinson (2007), and this could be related to a decrease in the total catch over the last two decades (Anon., 2009) (Table 7.9).

Figure 7.4. Lindeman-spine flow chart for the Irish Sea from a) adapted from Lees and Mackinson (2007), and b) this study. Flows out of the top and the bottom represent exports and respiration, respectively. Flows to detritus are recycling through the detritus and primary production (D+P) box (trophic level I). Annual trophic transfer efficiencies (% of ingested food) are represented as percentages within the boxes.

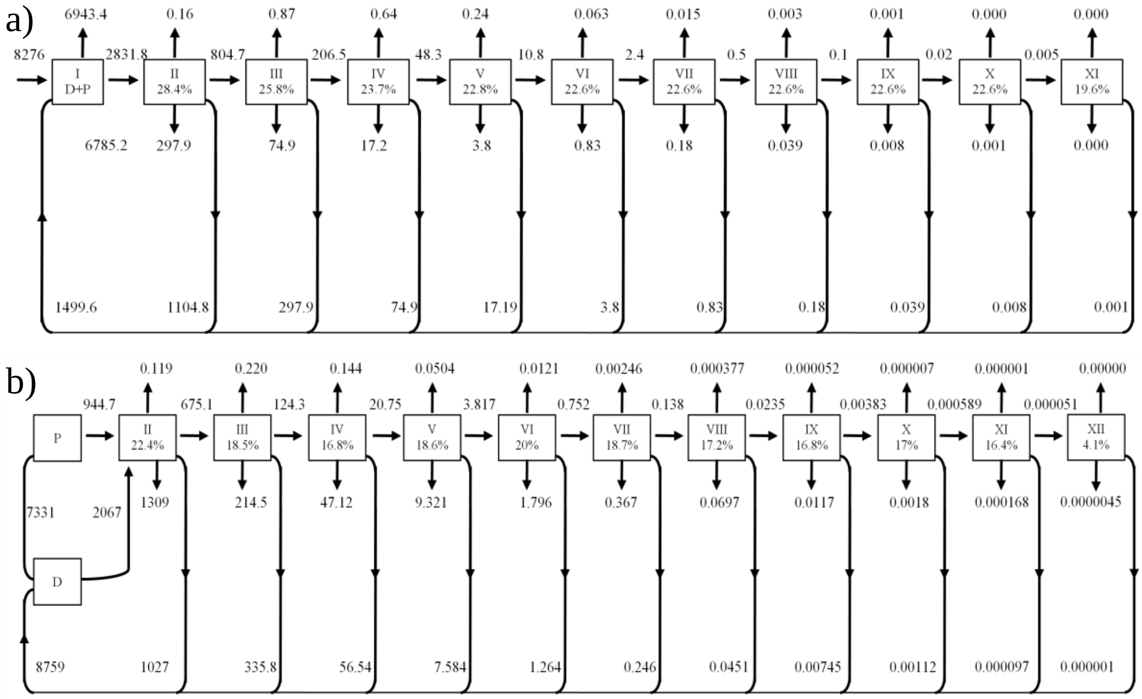


Table 7.8. Trophic transfer efficiencies (%) for each trophic level for the model reported by Lees and Makinson (2007) (L&M) and the model built up in this study. Variation between both models is given as a percentage

Trophic level	L & M model	New model	Variation (%)
II	28.4	22.4	21.1
III	25.8	18.5	28.3
IV	23.7	16.8	29.1
V	22.8	18.6	18.4
VI	22.6	20	11.5
VII	22.6	18.7	17.3
VIII	22.6	17.2	23.9
IX	22.6	16.8	25.7
X	22.6	17	24.8
XI	19.6	16.4	16.3
XII	-	4.1	-

Table 7.9. Summary of the estimated indices. A negative value in the variance indicates that there has been an increase in the index from the L&M study to this one.

Ecosystem theory indices	Units	L & M	This study	Variation (%)
Mean trophic transfer efficiency from detritus	%	24.8	19.0	23.4
Mean trophic transfer efficiencies from detritus and primary production	%	25.4	19.3	24.0
Sum of all consumption	t/km^2*year	3,905	4,631	18.6
Sum of all exports	t/km^2*year	6,945	6,694	3.6
Sum of all respiratory flows	t/km^2*year	1,330	1,582	-19.0
Sum of all flows into detritus	t/km^2*year	12,837	8,760	31.8
Total system throughput	t/km^2*year	25,017	21,666	13.4
Sum of all production	t/km^2*year	9,371	10,398	-11.0
Mean trophic level of the catch		3.61	3.75	-3.9
Gross efficiency	Catch/net p.p.	0.00024	0.00007	70.8
Calculated net primary production	t/km^2*year	8,275	8,275	0.0
Total primary production/total respiration		6.22	5.23	15.9
Net system production	t/km^2*year	6,945	6,694	3.6
Total primary/total respiration		33.71	24.66	26.9
Total biomass/total throughput		0.01	0.02	-50
Total biomass (excluding detritus)	t/km^2	245	336	-37.1
Total catches	t/km^2*year	2.00	0.6	70.0
Connectance index		0.223	0.244	-9.4
System Omnivory index		0.332	0.482	-45.2
Finn's cycling index	%	0.590	0.374	36.6
Finn's mean path length		2.68	1.70	36.6

7.4.4. Niche overlap for top predators

Results from the niche overlap analysis suggest that bottlenose dolphin feed on a similar proportion of specific prey items as both species of seal, showing a 60% and 69% overlap with common and grey seals, respectively Table 7.10), while only 21% of the prey biomass proportion occur with harbour porpoise. An overlap in diet between the seals species was suggested using alternative analyses (Chapter 6), and is consistent with the outcome from the Ecopath approach, with suggests an 80% similarity in diet between these species. In addition, some overlap was noted between harbour porpoises and both seal species (58% and 56% for common and grey seals respectively, Table 7.10). However, bottlenose dolphin showed a high overlap with seals in this analysis, while in Chapter 6 discriminate analysis (DA) showed that they feed on different prey.

Seabirds also appear to have a high degree of niche overlap, feeding on similar prey to harbour porpoises (61%), grey seals (55%) and minke whales (52%).

The output for minke whales suggest that they might be feeding on different resources than the other marine mammals, particularly with respect to common seals and to a lesser extent with harbour porpoise and grey seals (Table 7.10), although they appear to share food resources more with seabirds (52%).

Table 7.10. Trophic niche overlap (%) between the main top predators (cetaceans, seals and seabirds)

	Harbour porpoise	Minke whale	Harbour seal	Grey seal	Seabirds
Bottlenose dolphin	21.34	6.28	60.07	69.29	15.63
Harbour porpoise	-	31.32	57.55	55.99	60.76
Minke whale	-	-	13.17	34.49	51.62
Harbour seal	-	-	-	79.94	46.04
Grey seal	-	-	-	-	55.30

7.5 DISCUSSION

Multispecies models have become a useful tool for implementing an Ecosystem Approach to Fisheries Management (EAFM) and the study of the dynamics of each component (Ulanowicz, 1993); and many models have been built up in different ecosystems (e.g. Christensen, 1995; Gascuel et al., 2011; Mackinson and Daskalov, 2007; Pauly et al., 2000) to address ecological questions such as the relative importance of direct/indirect interactions and the effect on other species, the importance of changes in species populations within the dynamics of the ecosystems, or how a species trait can affect the structure of the ecosystem (Sutherland et al., 2013). The Ecopath approach was designed in a way that the data requirements of the model are usually available, and that the use of the modelling approach is relatively easy; it also has been identified as a useful tool for EAFM for the Irish sea (Lees and Mackinson, 2007).

Lees and Mackinson (2007) built an Ecopath model for the Irish Sea based on the fishery information obtained from ICES for 1973, but supplemented it with some information obtained from a CEFAS groundfish survey carried out in 2004; for instance, data for some of the piscivorous groups, such as sandeels and small Gadoids, and the invertebrate groups were obtained during that survey. This inconsistency may have affected the development of the model and conclusions from it. The present model was developed from that of Lees and Mackinson (2007) to focus in more detail on the top predators, and particularly cetaceans and seals, using previously unavailable data (Chapter 5 and 6; Kavanagh et al., 2010; Gosch et al., 2014; ICES, 2008b; ICES, 2012a, 2012b; Viana, 2012). In that context, the combining of the top predator species into four main FG (toothed whales, baleen whales, seals, and seabirds) by Lees and Mackinson (2007) makes it difficult to explore these groups in detail. Top predators have been suggested to be a useful indicator of ecosystem "health", as they can be seen as integrating the food web functioning through the lower trophic levels. They are also large (more than 100kg usually) and long-lived animals (Bowen et al., 2006), and are generally protected, and considered vulnerable. A model where each top predator corresponds to a different "compartment" in the ecosystem model would be more useful in this context, arguably, and more realistic.

Also, as Lees and Mackinson (2007) reported, some differences were found in the biomass estimates between the model and ICES data. These authors suggested that these discrepancies might be due to an underestimation of true catch (for a variety of causes including mis-reporting and discarding) and also as information was mainly obtained from areas that can be fished. Bowen et al. (2006) and Smout et al. (2014) suggested from diet studies of grey seals in Canada and the UK, respectively, that seals might be a better source of information on species presence and abundance estimations (of those species consumed) in the area than fisheries. For instance, in the North Sea, sandeels are largely concentrated in specific areas (Frank and Brickman, 2001; ICES 2010a; Lynam et al., 2013; Proctor et al., 1998) and the industrial fishery and predators (seals, cetaceans, birds and fish) are considered to fish/consume large amounts of this fish species (e.g. Furness and Tasker, 2000; Greenstreet et al., 2006 and ref. therein; Hammond et al., 1994a, 1994b; Pierce et al., 1991; Santos and Pierce, 2003). However, sandeel landings in the North Sea has been significantly reduced in the last two decades (ICES, 2010), leading to concerns about prey availability for some of the top predators. On the other hand, diet studies still reflect that sandeels are an important prey item in the diet of marine mammals and seabirds in the North Sea (e.g. Furness and Tasker, 2000; Santos et al., 2004; Smout et al., 2014). In the Irish Sea there is no commercial fishery targeting sandeels, and the biomass estimated by Lees and Mackinson (2007) was obtained based on the groundfish trawl survey carried out in 2004, which is unlikely to be a good sampler of sandeels due to the size of the fish and the mesh size of the net. In contrast, Lynam et al. (2013) reported that the larval biomass for this FG has increased during the period 1950-2005, suggesting that there should be an increase overall. However, there is no up to date adult biomass estimate for this functional group.

Other important species in the diet of many predators within Irish waters are the species of *Callionymus* spp. (dragonets). In Ireland, three different species occur: *C.lyra*, *C.maculatus*, and *C.reticulatus* (Whitehead et al., 1986); however, information on the trophic ecology of these species is scarce (Gibson and Ezzi, 1987; Whitehead et al., 1986). These species were found to be important in the diet of seals in Irish waters (e.g. Kavanagh et al., 2011; Gosch et al., 2014*;* Luck, 2013) as well as in other predators on a wider geographical scale (e.g. Hamerlynck and Hostens, 1993; Nedreaas, 1985; Trenkel et al., 2003).The biomass indicated by Lees and Mackinson (2007) was considered too low when balancing the model. In addition, the Marine Institute stock assessments (e.g., MI, 2009) reported that these species were quite abundant in the Irish Sea. Based on this information, the biomass of this FG was increased in the model.

Other species biomass values in the model were also increased from the original (Lees and Mackinson, 2007) values for similar reasons, in order to be able to balance the model. It can be argued, that population abundance of top predators might be easier to estimate than fish. In particular, seabirds and seals can be estimated from their nesting and haul-out places (e.g. Annex IX; Cronin et al., 2004; O'Cadhla et al., 2007). Recently, population estimations of cetaceans (Hammond et al., 2013) were also carried out, providing more realistic up-to-date information of these top predators’s abundance. The current model considered only two species of toothed whales and one species of baleen whales. Bottlenose dolphin and harbour porpoise are species that are considered largely resident in the area (Pesante et al., 2008; Hammond et al., 2013). Other toothed cetaceans, such as common dolphin and white-beaked dolphin (*Lagenorhynchus albirostris*, Gray 1846), were sighted in the Irish Sea during the SCANS survey (Hammond et al, 2013), and other cetaceans species such as Risso's dolphins and northern bottlenose whale (Rogan and Hernandez-Milian, 2011) are known to occur, but very occasionally. However, they might be considered as either occurring seasonally or as transient animals, as the SCANS survey was carried out during the summer and these species occur in larger numbers in adjacent areas to the Irish Sea.

Ecopath models are useful tools that generate interesting outputs describing the structure of the ecosystems, in particular the characteristics related to the interaction of the different trophic levels. Odum (1969) described different ecological attributes to indicate the developmental stage of ecosystems, and Ecopath provides some of these parameters to evaluate this issue. For instance, a large net system production (difference between the total primary production and respiration), a large total primary production/total biomass ratio, and a small total biomass/throughput ratio would all tend to indicate an immature or developing ecosystem. A value of 6,694 for the net system production and 0.02 for the total biomass/throughput ratio suggests that Irish Sea ecosystem is in early stages of development.

Other proxies of ecosystem maturation are the Connectance and the System Omnivory Indices (Odum, 1971). Odum (1971) suggested that the trophic structure of ecosystems changes from a simple linear-chain to a web during their development and maturation, and Christensen and Walters (2004) defined the connectance index as "*defined for a given food web as the ratio of the number of actual links to the number of possible links*" and the system omnivory index as "*a measure of how the feeding interactions are distributed between trophic levels*"; interestingly, the new model for the Irish Sea showed larger values than the model given by Lees and Mackinson (2007), indicating that the food web might be more complex that the original one, with more linkages among the FG, and the foraging behaviour of top predators might be more generalist as shown in the 2004 model.

The recycling and transfer of energy within the systems are important to understand the trophic complexity of the ecosystems. Ecopath also provides two measures for investigation of the ecosystem structure: Finn's cycling index (FCI) and Finn's Mean Path Length or Average Path Length (APL); FCI is a measure to assess the proportion of the flow that is recycling within ecosystems and gives an idea of ecosystem "health" and maturity (Allesina and Ulanowicz, 2004; Finn, 1976), while the APL is defined as "*the average number of transfers a unit of flux will experience from its entry into the system until it leaves the system*" (Baird and Ulanowicz, 1993).

Higher values of these indexes indicate that a large proportion of the internal production is retained within the system (Baird and Heymans, 1996); in other words, a decrease in the Finn's cycling index indicates that the ecosystem is potentially more degraded, while the lower average path length indicates that fishing pressure over the system might be a concern, as it might indirectly influencing the production of the system at the lower levels of the food web (Gislason, 2003).

Many marine ecosystems were estimated to have a gross fishing efficiency of 0.002 (Christensen et al., 2005). The value obtained for the model constructed in 2004 was much lower than the value obtained in Lees and Mackinson (2007) indicating that the fishery might be less efficient and was targeting fish at higher trophic levels than in 1973, which was reflected in the mean trophic level of the catch. Although depletion or a substantial decrease of some of the fish stocks in the Irish Sea (Anon., 2009; MI, 2013) has resulted in a significant decline of landings in this area (MI, 2013), this difference between the models could be related to the changes applied in the new model structure.

Although the gross efficiency and trophic level of the catch showed a potentially good scenario for the Irish Sea in 2004 in comparison to 1973, the decrease in Finn's index showed that the ecosystem was probably not in such a "healthy" situation (in 2004) and this may be due to the fishery pressure carried out during decades in the Irish Sea. However, it has also to be noted that changes to the model were carried out during this study, which might also influence the outputs. Simulations using the Ecosim framework will provide future scenarios testing different fishing policies.

One of the most interesting outputs of these models was related to trophic structure of the ecosystem food webs. Trophic level composition is a strategy to simplify the interactions between the different compartments within an ecosystem, and Ecopath models can aggregate different functional groups based on their foraging ecology ("who is eating who?") within the ecosystem (Christensen et al., 2008). Transfer efficiency between those compartments will then give us an insight into the amount of energy that is transferred from one trophic level to another and how much energy is recycled and going to detritus (Christensen et al., 2008; Lindeman, 1942). It has been widely accepted that a transfer efficiency between trophic levels should be expected to be around 10% (e.g. Christensen and Pauly, 1993; Pauly and Christensen, 1995). In both Lees and Mackinson (2007) and the new model, this was not the case. There was a difference in the general assumption of a transfer efficiency of 10% between trophic levels, as the Lees and Mackinson (2007) model showed a 25% transfer efficiency and the 2004 model showed 19%; the high efficiency at trophic level I might be explained by the inclusion of a microbial loop which might be expected to have a high efficiency (Lees and Mackinson, 2007; Table 7.10).

Another interesting result obtained from the Ecopath model was the degree of niche overlap identified between the top predators. The niche concept was defined by Hutchinson (1957) as an n-dimensional hypervolume of physical, chemical and biological characteristics that described a species or a group of species. Based on this principal and the Lotka-Volterra equations, Pianka (1973) developed the index which allows us to predict the foraging interactions between species, giving a value between 0 and 1 (0 suggesting that both groups did not share any prey, while 1 suggests that the overlap is complete). Using this as a basis, Christensen et al. (2000 and 2008) modified the equation to avoid unwanted results when prey was low. In Chapter 6, RDA and DA showed that both species of seals and harbour porpoises might be feeding on similar forage species, considering the frequency of occurrence, while bottlenose seemed to feed on different prey items. The Ecopath niche overlap results showed a similar result between grey seals and harbour porpoises, however it showed a somewhat different result when comparing bottlenose dolphin and both species of seals, with an apparently high degree of niche overlap. The diet analysis of bottlenose dolphin was based on a small sample size (10 dolphins), and the analysis carried out in Chapter 6 was based on number of occurrences and not percentage of biomass. As it has been reported in other areas of European waters (Hammond et al., 1994a, 1994b; Hall et al., 1998; Pierce et al., 1991; Ridoux et al., 2007; Santos and Pierce, 2003; Santos et al., 2001c, 2007; Spitz et al., 2006b) bottlenose dolphin and both species of seals seemed to prey upon the main gadoid fish groups occurring in the Irish Sea, however bottlenose dolphins were found to generally prey upon larger specimens than the seals. This difference might explain the discrepancies obtained from the analysis when using number of prey occurrence (Chapter 6) and biomass percentage (Ecopath niche overlap).

The associations between seabirds and minke whales (and other baleen species) are widely known (e.g. Anderwald et al., 2011; Evans, 1990; Gill et al., 2000; Haynes et al., 2011; Hoelzel et al., 1998; Robinson and Tetley, 2007). Those associations have been related to their common foraging behaviour upon schooling pelagic fish, such as sardine, Atlantic herring, horse mackerel, and sandeels (Anderwald and Evans, 2007; Pierce et al., 2004b; Robinson and Tetley, 2007). The Ecopath niche overlap results showed that seabirds and minke whales might be direct competitors, as it was suggested in other studies (e.g. Anderwald, et al., 2011; Gill et al., 2000; Robinson and Tetley, 2007) .

Although Ecopath can be useful to investigate the structure and function of ecosystems, it is basically a steady-state model where changes over time cannot be evaluated. The additional tool, Ecosim available within the Ecopath with Ecosim (EwE) software allows us to simulate different scenarios with changes in biomass of different functional groups as well as fleet activity. Therefore the next step in this research work should be to extend the scope to EwE to explore the impacts of changes in fishing pressure, and associated changes in fish stock abundance, on the likely prognosis for the top predator populations.

GENERAL DISCUSSION

CHAPTER 8

GENERAL DISCUSSION

8. General discussion

8.1. Studying the role of top predators

Understanding the role of apex predators, including marine mammals, in the marine ecosystem is complex. In some parts of the world, particularly the Pacific north west, there have been numerous examples of changes in the abundance of marine mammals. Species such as Steller's sea lion (*Eumetopias jubatus*, Schreber 1776), northern fur seal (*Callorhinus ursinus*, Linnaeus 1758), harbour seal (*Phoca vitulina*, Linaeus 1758) and sea otter (*Enhydra lutris*, Linnaeus 1758) have all shown precipitous declines in abundance (e.g., Estes et al., 1998, Springer et al., 2003). In this area, various hypothesis have been put forward to explain such declines, summarised by Horning and Mellish (2012), including the resource-driven junk food hypothesis and the consumer driven sequential megafaunal collapse hypothesis. The junk food hypothesis relates to changes in the abundance, distribution, composition and nutritional quality of prey species, which may be natural (such as changes in oceanographic conditions) or anthropogenic (e.g., through large scale industrial fishing). These bottom-up effects are thought to decrease the fitness of individuals in a population, through negative impacts on the energy budgets. In contrast, the sequential megafaunal collapse hypothesis, albeit controversial, has been suggested to have resulted from a shift in the diet of transient killer whales (*Orcinus orca*, Linnaeus 1758) as a result of the removal of their preferred prey, the great whales, through commercial whaling (Springer et al., 2003). The exploitation by marine mammal of the same prey resources as fisheries has led to growing concerns over potential competition between fisheries and marine mammal predators in both directions (Lasalle et al., 2012). Prey depletion as a result of fishing pressure has been cited as the reason for the decline in common dolphins (*Delphinus delphis*, Linnaeus 1758) in the Mediterranean (Bearzi et al., 2008). In contrast, the "whales eat fish" conflict (Morissete et al., 2010) has been used as a reason by some to re-introduce commercial whaling.

Understanding predator prey interactions is therefore important in our understanding of ecosystem functioning. While some have argued that it is time to go beyond examining the taxonomy of prey items to understand predator/prey relationships (e.g., Spitz et al., 2014), for areas where diet is well described and understood, this approach is likely to be useful. But in many areas of the world, diet of predators is not well know, and the traditional approach of reconstructing diet to look at feeding specialisations, prey choice, prey seasonality, annual consumption by predators and examining interactions with commercial fisheries is still both important and relevant.

In animals that expend most of their lives out of our sight, as is the case for marine mammals, the study of foraging ecology has to be addressed using stomach contents and/or other animal tissues (see Chapter 2). The advantage of using stomach contents is that firstly the species-specific identification of prey provides information about individual foraging decisions related to their prey selectivity (Santos et al., 2013); and secondly, stomach content analysis allows the quantification of ingested prey, which are important for developing trophic models to investigate the role of these predators in their ecosystems as well as their interactions with human activities, such as fisheries. One of the disadvantages of this approach is that the animal has to have died to recover the stomach contents.

8.2. Marine mammals in Ireland

Ireland is considered an important area for marine mammals in the North East Atlantic with 25 cetaceans and two seal species described to inhabit or seasonally occur in its waters (Table 1.1; Berrow, 2000, 2001, 2002; Berrow and Rogan, 1997; Evans, 1980; Gordon et al., 2000; Lyons, 2004; O'Cadhla et al. 2004; Rogan and Berrow, 1996; Rogan et al. 2000). However, the role of these species within the ecosystems has not been addressed before.

In Ireland, dietary preferences of the seven marine mammals examined in this study (striped dolphin -*Stenella coeruleoalba*, Meyen 1833-, Atlantic white-sided dolphin -*Lagenorhynchus acutus*, Gray 1828- , white-beaked dolphin -*L.albirostris*, Gray 1846, bottlenose dolphin -*Tursiops truncatus*, Montagu 1821-, harbour porpoise -*Phocena phocoena*, Linnaeus 1758-, grey seal -*Halichoerus grypus*, Fabricius 1791- and harbour seal) differ, however some similarities were detected. Striped dolphins and Atlantic white-sided dolphins are considered the most oceanic species (CODA, 2009; Hammond et al., 2008a, 2008b, 2013a, 2013b), and diet results showed that these species were feeding on prey species that generally occur far from the continental slope. However, the differences in stomach contents between stranded and by caught striped dolphins that showed a more complex situation might occur. Das et al. (2003a, 2003b) and Mendez-Fernandez et al. (2012) indicated that stable isotope analysis carried out on stranded striped dolphins stranded showed that they feed mainly on oceanic species, despite the apparent diet plasticity pattern found analysing stomach contents (Ringelstein et al., 2006; Santos et al., 1996; Spitz et al., 2006a). In the Ligurian Sea, striped dolphins have been reported to undertake inshore movements (Gannier, 1999; Gordon et al, 2000). Thus, it is possible that the differences in diet between stranded and by-caught striped dolphins in Irish waters might reflect this behaviour, as the continental shelf along the west coast of Ireland in parts is narrow.

Atlantic white-sided dolphin is the second species studied that occurs in offshore habitats (CODA, 2009; Hammond et al., 2008a, 2013; O’Cadhla et al. 2004), and stable isotopes analysis was consistent with this (Das et al., 2003a, 2003b); however, diet results in this species showed a mixture of prey species occurring both over the continental shelf and the slope (blue whiting -*Micromesistius poutassou*, Risso 1827-, Atlantic mackerel -*Scomber scombrus*, Linnaeus 1758- and horse mackerel -*Trachurus trachurus*, Linnaeus 1758); it is therefore likely that this dolphin species does over the continental shelf at least some of the time.

The Irish marine mammal species that can be considered coastal are harbour and grey seals, harbour porpoise and bottlenose dolphin. Investigations showed that a niche overlap may exist between seals and harbour porpoises when looking at prey composition (Chapter 6 and 7). Also, comparing the trophic level of these species with those in the North Sea (Das et al., 2003b), the Irish Sea (Chapter 7), and from different Atlantic areas (Pauly et al., 1998), showed that all of them feed at a high trophic level, although some differences were found. Pauly et al. (1998) reported that harbour porpoise generally have a higher trophic level than both seal species, while Das et al. (2003b) and this study (Chapter 7) obtained the opposite result. The explanation by Das et al. (2003b) that porpoises were frequently feeding on planktivorous prey in the south area of the North Sea, could be applicable to Irish porpoises in which 11% of prey

(Chapter 6) comprised small pelagic planktivorous fish (clupeids and horse mackerel). However, Pauly et al. (1998) combined diet information from different areas where the contribution of gadoid species was higher than the contribution detected in Irish waters for harbour porpoises; the assemblage of all diet studies might equalise the tropic level of harbour porpoises with both seals in those models. It is not unusual that same marine mammal species feeds on different prey in different areas. This may be due to prey availability; for example, bottlenose dolphin populations in the North Atlantic waters prefer gadoids in its eastern distribution while it prefers Perciformes fish in its western distribution. Even within European waters they feed on different gadoid species along its distribution (e.g., Chapter 5; Blanco et al., 2001; Santos et al, 2001c; Santos et al., 2007) probably reflecting prey availability (see Chapter 5).

During the last decade a number of genetic studies have investigated the population structure of harbour porpoises in European waters. Andersen et al. (2001) examined the polymorphism of 12 microsatellite loci in more than 800 harbour porpoises from the English Channel to Norway, and they suggested that there were six sub-populations of harbour porpoise including one in southern Irish waters and Irish Sea. More recent studies (Fontaine et al., 2007, 2010) demonstrate that segregation of gene flow exists, probably related to sea surface temperature and primary production. Interestingly, Fontaine et al. (2010) suggested that this segregation could be related to diet preferences, as harbour porpoises have been reported to feed on cold water prey such as clupeids and sandeels. Sandeels are distributed in large aggregations in the North Sea, while in Irish waters they seem to be more dispersed (David Reid, *Pers. comm.*), however, large spawning and nursery grounds of clupeids occur along Irish coasts (Anon. 2009); it is possible that harbour porpoise prey on the more available cold water species and therefore might constitute a different sub-population as Andersen et al. (2001) suggested.

Both harbour and grey seal hunt close to the coast and are therefore sympatric. They usually haul-out in different colonies (Cronin et al., 2004; Kiely et al., 2000; O'Cadhla et al., 2007), but they share the same hunting environment and, therefore, they are potential interspecific competitors. Investigations on the interspecific competition for the same resources between harbour and grey seals indicated that they feed on similar prey (Brown et al., 2012; Sharples et al, 2009); however, Brown et al. (2012) pointed out that although this competition may occur, prey size-selectivity analysis should be investigated to detect any segregation between the two species. In Chapter 6, results of the diet of seals from three relatively close haul-out areas (two for harbour seals and one for grey seals) showed that they mainly feed on benthic fish species (including sandeels, dragonets -*Callionymus* spp., Linnaeus 1758-, and flatfish). The dietary partitioning of these two seal species arise from differences in fish size eaten; for example, grey seals tend to eat much larger prey (larger than 150mm) then harbour seals (smaller than 150mm). Niche partitioning has also been shown in some sympatric baleen whales in the southern ocean. Friedlander et al. (2009) showed that while minke whales and humpback whales both target krill (*Euphausia superba*, Dana 1850), that both species forage at different depths, and are spatially segregated, decreasing the likelihood of resource competition.

8.3 Fisheries and marine mammals

A Total Allowable Catch (TAC) of 1,040,117 tonnes of fish was allocated in Irish waters (ICES sub-areas VI and VII) in 2014, with a quota of 23% to the Irish fleet. Based on the average price obtained in 2012, the total economic value of this activity was estimated to be 1,161 billion Euros for Ireland (MI, 2013). The economic importance to Ireland varies between species. For example, the total Atlantic herring (*Clupea harengus*, Linnaeus 1758) quota for Ireland is 46% of the allocated TAC, of which 86% is allocated to the Celtic Sea. An industrial type fishery for a new species - boarfish (Caproidae species) has recently commenced and Ireland received 69% of the TAC. Other species where Ireland received a high proportion of the TAC were flatfish species (megrim -*Lepidorhombus whiffiagonis*, Walbaum 1792-, European plaice - *Pleuronectes platessa*, Linnaeus 1758- and sole -*Solea solea*, Linnaeus 1758) with a quota of 45%, pelagic species (Atlantic herring, Atlantic mackerel and horse mackerel) with 35%, and demersal fish (cod -*Gadus morhua*, Linnaeus 1758-, haddock - *Melanogrammus aeglefinus*, Linnaeus 1758-, whiting -*Merlangius merlangus*, Linnaeus 1758-, *Pollachius* spp.-Linnaeus 1758- and Ling -*Molva molva*, Linnaeus 1758) with 26% of the total quota. The Dublin Bay prawn, *Nephrops norvegicus* (Linnaeus 1758), is a commercially valuable fishery to Ireland and the *Nephrops* quota for Ireland for ICES VII area was 26% of the TAC (MI, 2013). Apart of these earnings, other fisheries also that contribute to the total income include the inshore fisheries targeting European lobster (*Homarus gammarus*, Linnaeus 1758) and whelk (*Buccinum undatum*, Linnaeus 1758), for example (MI, 2013) and inland fisheries (e.g., salmonids, eels) (Inland Fisheries Ireland, www.fisheriesireland.ie).

In general, apex predators in marine ecosystems compete for the same resources as fisheries, and interactions with them has been largely described (e.g., Northridge, 1984, 1991). This competition can be defined at two levels: 1) direct interaction by incidental catch of predators in nets, trawls, lines and traps, as well as the damage caused to gear by marine mammals, and 2) indirect interaction where both predators and fisheries are "predating" upon the same prey (fish, cephalopods and crustaceans). The latter can be further subdivided into three levels: a) they target the same species and sizes, b) they target the same species but different sizes, and c) predators hunt the prey of fish targeted by fisheries. Indirect interactions have been reported in a few different areas; some studies reported that marine mammal species were feeding on the same species and sizes as those targeted by fisheries (2a) (e.g., Díaz Lopez, 2006; Pierce et al., 2010; Ridoux et al., 2007; Santos et al., 2007; Waring et al., 1990), but other studies reported that they are mainly feeding on non-commercial species (2c) (e.g., Couperus, 1995; Ringelstein et al., 2006) or on smaller sizes of commercial species (2b) (e.g., Jackson et al., 2001; Santos et al., 2001c; Spitz et al., 2006b). A more complex situation implies that predators can be feeding as described by all scenarios (2a, 2b and 2c). In general, small dolphin species and seals in Irish waters seem to preferentially feed on some gadoid species (*Trisopterus* spp. -Rafinesque, 1814-, *Pollachius* spp. and whiting), pelagic fish (Atlantic mackerel, horse mackerel and clupeids) and flatfish species (this study; Davey, 2012); however, all these prey species are relatively abundant in Irish waters (MI, 2013). *Trisopterus* spp. and pollack (*P.pollachius*, Linnaeus 1758) are not commercially important species in Ireland for food consumption, although the latter is targeted by sport fisheries (Inland Fisheries Ireland, www.fisheriesireland.ie); the other gadoid species (saithe -*P.virens*, Linnaeus 1758-, haddock, whiting, and blue whiting), the pelagic fish, and the flatfish species are commercially important, but most of the specimens in the marine mammal stomach contents were found to be below the official landing official. Although these findings may indicate that small cetacean and seals species in Ireland and fisheries are targeting different resources, indirect interaction are likely to occur as the trophic interaction linkages among the different compartments may produce a further effect on either fisheries or apex predators. For example, Norway pout (*Trisopterus esmarkii*, Nilsson 1855) is an important prey item for many fish species that are being caught by fishermen in the North Sea, such as cod and saithe (see Chapter 7; Pauly et al., 1998). Norway pout feeds mainly on krill, which feed on copepods which are prey of most of the commercial fish species in the North Sea (Mackinson and Daskalov, 2007; Pauly et al., 1998). If a high removal of Norway pout occurs, an increase of krill will follow, decreasing the copepod biomass, and therefore potentially negatively affecting other targeted fish species for both fisheries and top predators.

Different small dolphin species within the Irish Sea, Celtic Sea, and west and north -as far as the Hebrides- of Ireland have been reported to directly interact (by caught) with fisheries (Berrow 2000, 2001, 2002; Berrow and Rogan, 1997; Couperus, 1995; Gordon et al., 2000; Rogan and Berrow, 1996; Rogan and Mackey, 2007; Rogan et al. 2000). By-catch has also been reported for grey seals (Berrow et al., 1998; McKibben, 2000; Philpot 2000). Moreover, both grey and harbour seals are known to feed on fish in nets (e.g., Cosgrove et al., 2013; Reeves et al., 2013; Ridoux et al., 2007) and at aquaculture cages (e.g., NSSG and Stewardson, 2007; Kiely et al., 2000). Diet of grey seals in Irish waters may reflect this interaction (Gosch et al., 2014). However, results from the harbour seal diet in Ireland do not reflect this potential prey resource, and this could be due to the small sample size. Therefore, we cannot rule out the possibility that they feed on salmonids more than dietary studies indicate.

One of the reasons for dietary studies of marine mammals lies in the quantification of the diet to examine interactions with fisheries. General equations based on population abundance and energy or food requirements (obtained in the literature) of the species studied are widely used for the estimation of annual food consumption. However, two variations of this equation have been developed recently.

A modification of the general annual food consumption equation used by Kaschner et al. (2006) and Trites et al. (1997) and, is an integration of a residency ratio for each species based on the combination of seasonal species abundance estimations was developed by Col et al. (2012). Pierce et al. (2007) applied two other different approaches to estimate the annual food consumption of marine mammal from the diet.

Dolphin digestive tracts, and sometime scats, may have few or no prey and diet information can be unbalanced as animals might be ill or only part of the faeces was collected. Using the stomach weighting to equalise all samples might give a more realistic approach about the dietary patterns of individual species. It is recognised that marine mammals require different energy and food intake depending on their reproductive stage (juvenile, sub-adults, adult, pregnant, lactating); for example juveniles and pregnant and lactating females have higher energy requirements (e.g., Innes, 1987; Kastelein et al., 2002; Reichsteiner et al., 2013), which is not included in the annual food consumption estimates. The use of estimated body weight of dolphins does incorporate differences in juveniles, sub-adults and adults, but not the adult reproductive stage. In this study, only a few of the cetaceans were pregnant or lactating females and therefore not likely to overly influence the model; however, it would be interesting to include this type information into the annual food consumption equations.

In general, the Pierce et al. (2007) and Col et al. (2012) equations provided a different estimation for the annual food consumption of the dolphin species studied (Table 8.1), but not for seals. One of the reasons for such variation could be that Col et al. (2012) applied an annual residency ratio and for animals that are considered seasonally resident, total annual consumption decreased; in fact, the closest output from both approaches was for striped dolphin, where a residency ratio of 0.93 was used. Area specific residency ratios should be developed for each species. The harbour porpoise residency ratio given by Col et al. (2012), for example, was 0.26, which is likely too low for Irish waters (Berrow et al., 2010; Wall et al., 2013). There was no ratio value for striped dolphins, and the common dolphin ratio estimated for the North East US continental shelf (Col et al., 2012, Res=0.93) was used. Common dolphins are more frequently recorded than striped dolphin over the continental shelf (Hammond et al., 2008a) especially in winter (Wall et al., 2013), and in this study, it is likely that the annual food consumption is overestimated. However, the seasonal movements of striped dolphins at these latitudes are unknown, and while the abundance population for this species have been estimated for summer months, it is unknown to what extent the abundance will vary during the year. Seals are usually concentrated in particular areas during the breeding and moulting time, while they are more dispersed during the remainder of the year, in particular grey seals (Cronin et al., 2012), therefore their residency ratio might be lower than the one used.

8.4. Biases in diet analysis

Biases in the estimation of food consumed by these apex predators have to be considered. The reconstructed size and biomass of prey is done using back-calculation regressions built from fish, cephalopods and crustaceans obtained in surveys. Otoliths, bones, beaks and other hard structures are usually affected by acid fluids in the digestive tract and, therefore, their estimated sizes are probably underestimated. At present, only a few studies on the degradation of otoliths through the digestive systems of grey seals have developed digestion coefficient factors (partly digested structure) and correction factors (full digested structure) (Bowen, 2000; Grellier and Hammond, 2006; Tollit et al., 1997). Depending on the seal species, prey remains appear eroded to some degree in scats with remains found in harbour seal scats more eroded than those found in grey seal scats, therefore it is possible that harbour seal prey were larger than estimated. In addition, those factors have not been developed for many continental and offshore fish species taken by dolphins, or for any other diagnostic bones. In addition, for the purpose of this analysis, it was assumed that if a prey item was present, that all of the prey was present. Therefore, in scenarios where only part of the prey has been consumed, as a result of depredation, as has been reported for polar bears (*Ursus maritimus*, Phipps 1774), where only the energetically fatty belly of reproductively ripe salmon are consumed, the biomass of these species may be overestimated.

Other analysis used during the last few decades to test the confident limits of the diet analysis was bootstrap analysis and Monte Carlo simulations approaches (e.g., Boyd, 2002; Hammond and Rothery, 1996; Santos et al., 2001a). However, the digestion error was found to be the most important source of error (Hammond and Rothery, 1996), and only this approach was used to minimize the errors in the diet analysis in this study.

Secondary prey remains have not been considered in most of dietary studies due to the difficulty to identify them. It is possible that very eroded and small otoliths found in the first stomach might come from secondary prey; in this study a full flatfish was found with a full head and stomach of an Atlantic mackerel containing seven squid in a harbour porpoise first stomach. This finding shows the difficulty to identify prey as a main prey items or secondary items in diet studies.

The importance of using bones in dietary studies in marine mammals should also be considered; some species present very small, fragile otoliths and they usually are found broken or are not found in stomach contents. Also in this study, most of the digestive tract analysed was examined from the oesophagus to the anus; in other areas, probably due to lack of post-mortem laboratory facilities, only stomach contents are collected as representative of the diet. In this study, some dolphins (in particular striped and Atlantic white-sided dolphin) contained most of the otoliths along their intestines, while some bones of those prey species were found in the stomachs. Back-calculation regressions for bones are scarce in the literature (Watt et al., 1991), and regressions for otoliths are only available for some species in the literature (Campana, 2004; Harkönen, 1986; Tuset et al., 2008). For those species where regressions were not available, proportions based on reference material were applied using the most similar size available; however, sizes and biomass could be underestimated if the structure was smaller than the reference one, or overestimated if it was larger. It is clear that regional prey reference collections and the development of back-calculation regressions for bones and otoliths, in particular for mesopelagic fish, as well as the digestion coefficient factors and correction factors, will improve the accuracy of the results of reconstructed biomass using hard remains collected in scats and digestive tracts.

8.5 Energy requirements in marine mammals

Marine mammal surveys for estimation of abundance and distribution of species are usually carried out during the summer months due to weather and oceanographic conditions, therefore abundance estimates of species that only spend part of the year in Irish waters might be overestimated (if they move into Irish waters in summer time) or underestimated (if the move out of Irish waters during the summer months). At present, two multinational surveys have estimated the offshore and inshore populations of cetaceans (CODA, 2009; SCANS II, Hammond et al. 2013a), and abundance of cetaceans given for summer months. A number of projects have used platforms of opportunity to look at distribution and relative abundance in Irish waters, usually with limited sampling effort in the winter months. For example, Wall et al. (2013) reported the distribution of nineteen species of cetaceans in Irish waters from 2005 to 2011, but no abundance estimates were given and sightings were reported as densities. The use of the population abundance of cetacean species given by CODA (CODA, 2009) and SCANS II (Hammond et al., 2013a), should therefore be treated with caution. Col et al. (2012) implemented a value for the general estimation of the annual food consumption of cetaceans based on annual residence ratio for each species, which was calculated based on the abundance of the species and the season. In three chapters of this thesis (Chapter 4, 5 and 6), annual residence ratio was used. The striped dolphin is a warm temperate dolphin whose distributional limit has been described to be north of Ireland and the U.K. (Hammond et al., 2008a; Jefferson et al., 2008; Reid et al., 2003) in European waters. However, Wall et al. (2013) reported only two sightings of striped dolphin in summer months, although strandings of this species occurs during year round (IWDG, www.iwdg.ie; Chapter 3, Appendix II). It is possible that this species does a south to north seasonal movement, increasing seasonally, as has been reported for other species in other areas (e.g., Goold et al., 1998; Reilly, 1990; Würsig et al., 1997). Neumann et al. (2001) suggested that common dolphins in Northern New Zealand follows a seasonal migration moving offshore during autumn and winter months following their prey, similar to the distribution of the fishing fleet. It is possible that striped dolphins in Irish waters might increase in numbers during the spring and summer months, reflecting their prey distribution and biological and oceanographically characteristics (e.g., Gjøsaeter and Kawaguchi, 1980; Staby, 2010; Staby and Aksnes, 2011).

Table 8.1. Annual food consumption estimation using Col et al. (2012) and the un-adjusted Pierce et al. (2007) equations for all marine mammals studied (tonnes). Landings include fish, cephalopods, crustaceans and other molluscs species

	Col et al. (2012)	Pierce et al. (2007) (no adjustments)	Landings 2010 (ICES Catch Statistics 1985-2012)
Striped dolphin	126,963	136,519	
Atlantic white-sided dolphin	27,000	36,220	
Bottlenose dolphin	659	999	
Harbour porpoise	10,852	41,740	
Harbour seal	3,888	3,888	
Grey seal	5,794	5,794	
Total	175,156	225,160	2,053,514

Despite all the biases explained above, and that no seasonal variation was included in the annual food consumptions of all the species studied, the results show that the amount of prey (fish and cephalopods) ingested by these dolphin species in Irish waters annually is very low in comparison to the amount of fish landings allowed for 2014 (~1 million tonnes) or the total catch in 2010 (~2 million tonnes) (Table 8.1). Similar results were also found in other areas around Europe (Lasalle et al., 2012; Santos et al., *in press*).

8.6 Mass-balance models and EAFM

The marine mammals studied are feeding on some important commercial species (such as Atlantic mackerel, whiting, flatfish), however the amount of these species taken does not suggest that it is enough to deplete the stocks. However, most of these apex predators remove prey that are food resources for the more apex fish targeted by fisheries and this might be a conflict point between fisheries and apex predators. This conflict has to be considered within the implementation of the Ecosystem Approach to Fisheries Management (EAFM) strategy and indeed within the Marine Strategy Framework Directive (MSFD). The EAFM is a concept that has been developed to improve the sustainable use of natural resources minimizing the risks to the ecosystems caused by fishing. The Convention on Biological Conservation (2000) defines the Ecosystem Approach (EA) as a "*strategy for the integrated management of land, water and living resources*", in order to obtain a balance between the conservation of biodiversity, the sustainability of ecosystems and the utilization of natural resources using scientific methodologies. ICES (2005b) defined the EA as "*the comprehensive integrated management of human activities based on best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of the marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity*". EA is a framework which considers humans as an important element of the ecosystem and incorporated into ecosystem management. Later, in 2002, FAO (FAO, 2003) adopted the terminology of the Ecosystem Approach to Fisheries (EAF), whose objectives are "*to plan, develop and manage fisheries in a manner that addresses the multiplicity of* *societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems*", and "*strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries*". Therefore, the Ecosystem Approach to Fisheries Management (EAFM) could be defined as a strategy which aims to ensure the health of the ecosystems and the sustainability of fish stocks (including fisheries and aquaculture activities as well as coastal human activities and fisheries research) involving the different societal sectors (local communities, fishermen, stakeholders, and administration), where management is related to human activities (Tasker, 2006). In order to implement the EAFM, different categories have been described (e.g. Crower et al., 2008; Morishita, 2008): by-catch mitigation, multispecies management, protection of vulnerable species, and integrated approach.

The first point to improve the EAFM, is investigating the structure and function of the ecosystem in conflict, related to the available resources and, therefore, investigate if the dynamic of the ecosystem is following a top-down control (predation mortality is the main force leading the ecosystem where fisheries can also have an effect) or a bottom-up control (producers or the limitation entrance of nutrients regulate the ecosystem, where environmental fluctuations are also related) (Cury et al., 2003). Cury et al. (2003) concluded that bottom-up control predominates in marine ecosystems, while top-down occurs in ecosystems where species populations fluctuate. In the Irish waters, fishery catches (ICES Catch Statistics 1950-2010 and 1985-2012) reflects that many fish species have fluctuated since 1950, where some fish stocks have been depleted, and where biomass and recruitment have been reduced, some well beyond sustainable exploitation (such as cod, whiting and sole) while others seem to be stable or in a "healthy" condition (such as Atlantic mackerel, horse mackerel and prawns) (MI, 2013); these fluctuations might be regulated by several weak trophic interactions to maintain the stability of the ecosystem under a top-down control (Cury et al., 2003).

Changes in marine ecosystems have been investigated from lower trophic levels (Mahon et al., 1998; Sherman et al., 1998) to upper trophic levels (top predators) (Bowen et al., 2006; Reid and Croxall. 2001; Reid et al., 2008) and some species can play a more important role than others, known as keystone species. Keystone species has been defined as those species "whose effect is large, and disproportionately large relative to its abundance" and they are usually species situated in high trophic levels (Power et al., 1996). Therefore, apex predators could potentially be indicators or keystone-species within their ecosystems. In large ecosystems, apex predators may influence the function of the ecosystem following the top-down control, as they need larger spaces to obtain their prey and influence the structure of the prey community (Ostman et al., 2007; Ryall and Ferigh, 2001, Verhoef and Morin, 2010); therefore, investigations into apex predators diet to understand trophic ecology and ecosystem functioning are essential. In order words, wildlife management requires an understanding of key ecological parameters and trophic ecology information can be critical to assess the interactions between different compartments (e.g., species and fisheries) in marine ecosystems.

Ecosystems are complex structures with both spatial and temporal interactions among different species (Allen, 1985), where the study of food webs (networks where different elements of the ecosystem are linked by prey-predator associations) is one of the important instruments to investigate this complexity. These food web interactions have been largely studied using single- and multi-species models (e.g., Hassell et al., 1976; Plagányi, 2007; Reynolds and Brassil, 2013). In marine ecosystems, the linkages of apex predators and fisheries within the ecosystem are important to understand the food-web dynamics, and one of the approaches used during the last decade for this purpose was the construction of ecological trophic models using Ecopath with Ecosim (EwE) (e.g., Guénette et al., 2006; Pauly et al., 2000). This type of model provides important insights into the relationship between these apex predators and their prey, as well as into fisheries activities, where the depletion or reduction of one of them might have adverse results over the whole ecosystem (see review in Estes et al. 2009, National Research Council 2003). For example, Pauly et al. (1998) analysed 60 models from different marine ecosystems around the world from 1950 to 1994; they found that stock depletion by fisheries of the large predatory fishes with higher trophic levels, have "lead" fishermen to target other species in lower trophic levels, therefore decreasing the average trophic level of most of the ecosystems by 0.2 (from 3.3 to 3.1). Pauly et al. (1998) reported that in northern temperate ecosystems, where fisheries activities were important, this decrease has been steady. In addition, trophic landings decreased by a rate of 0.1 worldwide from 1950 to 1994 (Pauly et al., 1998). In Chapter 7, when comparing the average trophic level for the Irish Sea between 1973 (Lees and Mackinson, 2007) and 2004 (Chapter 7), an increase of 0.14 was detected; however, this increase could be due to the differences in model structure, as the new trophic level in the new model seemed to be related to the separation of top predators. While the model used in the current study used more detailed information for top predators it is interesting to note that both discarding and by-catch where reported to have decrease from 1973 to 2004 (ICES, 2004), in addition to the general total landings (ICES Catch Statistics 1950-2010 and 1985-2012), and that the model built for 2004 showed (gross efficiency) that fisheries were targeting species in higher trophic levels than in 1973.

Discrepancies between the recent model (2004, this study) and the one that Lees and Mackinson (2007) constructed for 1973, showed the importance of making decissions related to the structure of the models (FG) as well as the use of local information (diet and fisheries information). Future studies using ECOPATH software should take into account this bias for future management of the ecosystems, as local or other information (such as discards) are not always available and estimations from other areas are frequently used.

8.7 Future research

The work undertaken in this thesis was carried out under the remit of a larger project: the Beaufort Ecosystem Approach to Fisheries Management award, to obtain a better understanding of the role of marine mammals as apex predators within Irish ecosystems. Dietary studies of marine mammal species occurring in Irish waters are scarce and only a few studies (Brown, 1999; Brophy et al., 2009; Davey, 2012) have been carried out to date. New diet information of coastal marine mammals was incorporated into a mass-balance model for the Irish Sea, as well as some functional groups were modified to obtain a more realistic scenario, and results provide the baseline to investigate potential future scenarios where stocks of particular species decrease or increase. The model could also be used to investigate the effects of the removal of top predators. For example, the model could be used to examine what happens if the harbour seal population was decimated after a disease outbreak or if it was decided to cull grey seals. The Ecopath model for the Irish Sea is the first step in studying the trophic role of small cetaceans and seals in Irish waters, and diet information of striped and Atlantic white-sided dolphin (besides bottlenose dolphin, harbour porpoise and both seals studied in this thesis and the common dolphin previously studied (Brophy et al., 2009; Davey, 2012) will help to obtain a mass-balance model for other ecosystems in Irish waters, such as the Celtic Sea.

In addition, diet information of by caught dolphins has been described and for striped dolphin was further investigated. To date, only common dolphin (Brophy et al., 2009) and Atlantic white-sided dolphin (Couperus, 1997a) diet obtained from interactions with fisheries has been investigated in Irish waters. A risk assessment framework (Ecological Risk Assessments for the Effects of Fishing -ERAEF) has recently been developed to assess the ecological risk of fishing to cetaceans within an EAFM (e.g., Hobday et al., 2011; Brown et al., 2013). Dietary information of these predators can help to improve data on "encounterability" and the "Potential for Lethal Encounter (PLE)" used in these models. The examination of stranded dolphins is also a way of highlighting fisheries were by-catch in occurring. Under the EU 812 Directive a small number of trawl fisheries are required to carry observers, often with low observer cover. As a result, by-catch is rarely observed in these fisheries. However, results from post mortem examination and diet analysis often provide additional and interesting information, which may be useful for management when assigning observers to fisheries. For example, from 30th January to 6th February 2013 a mass stranding of 13 common dolphin occurred on the coast of Mayo and post mortem examination of five of those dolphins were carried out by the veterinary team from the Institute of Zoology London (IOZ); the post-mortem results showed that animals died as a result of interactions with trawl fisheries (NPWS, 2013). Dietary examination showed that dolphins were feeding on blue whiting, horse mackerel and Atlantic mackerel.

To summarise, it is important to study the trophic ecology of marine mammals in order to understand their role within the ecosystem, as well as their interactions with other predators and fisheries. The collection of data and samples from carcasses stranded along the coasts and dolphins recovered from nets are an excellent resource for these studies. The continuation of stranding programs as well as the establishment of observer programs on fishery boats, and continued co-operation with fishermen to recover dead animals found in nets is important for our continued and improved knowledge of diet of marine mammals. It is also necessary to improve the methodology on the reconstruction of the diet, by constructing back-calculation regressions and digestion coefficient factors, especially for bones, of prey items regularly occurring in the diet of these predators. The annual food consumption models are important for investigating the energy requirements of top predators, however population abundance estimations are generally obtained during summer months and therefore results may be either over-or under-estimated. Col et al. (2012) residency ratio is a useful option for adjusting the annual food consumptions, as it is related to a seasonal abundance of the species. However, year round information on marine mammal relative abundance and distribution is important to further refine the estimates. Finally, multi-species mass-balance models are relative easy tools, with low requirements, for the application of EAFM, which allows the incorporation of the human activity component (fisheries). However, species are usually grouped in major groups depending on their biological characteristics (see Chapter 7) to simplify the model; and the sub-division of top predators, in particular seabirds, might be a possible in the future to improve the model.

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APPENDICES

APPENDIX I. Regression equations used for estimating fish and cephalopod sizes. FL: total length of fish, FW: total fish weight, DML: total dorsal mantle length, W: total cephalopod body weight, OL: otolith length, OR:otolith radius, OW: otolith width, PMXHH: premaxilla height, PMXHL: premaxilla length, VL: vertebra length, IF: dentary Inner fork (Hernandez-Milian et al., 2005), S: dentary symphisis height (Hernandez-Milian et al., 2005), LRL: lower rostral length, HL: lower hood length; all size measurements in mm and weight in grams. Sources are as follows: Ba: Bayhan et al. (2008), Be: Bedford et al. (1986), Br: Brown and Pierce (1998), CL: Clarke (1986), Co: Coull et al. (1989), Do: Dorel (1986), EO: O'Leary (2009), Fb: www.fishbase.org , Fr: Freijser (2012), GHM: *this study*, GJP: Grahm J. Pierce *unpublish*, Ha: Härkonen (1986), Il: Ílkyaz et al. (2010), Pa: Palomares (1991), Sa: Santos et al. (2001c), Sa2: Santos et al. (2007), Su = O'Sullivan (2003), Wa: Watt et al. (1997).

Fish species	**Estimated prey length (mm)**	**Source**	**Estimated prey weight (g)**	**Source**
Scyliorhinus canicula			$FW=0.00364xFL^{1779}$	Do
Anguilla anguilla	FL=-44.211+189.57xOL	Ha	$FW= 0.61215xOL^{2.71}$	Ha
Conger conger	FL=0.1 +15.04xOR	Su	$FW=0.0002xOR^{3.46}$	Su
	$FL=29.14*VR^{0.67}$	Su	$FW=0.002xFL^{3.509}$	Do
Clupea harengus	FL=–87.49+184.39xOW	Ha	$FW=4.910xOW^{5.193}$	Ha
Sprattus sprattus	FL=-25.28+137.24xOW	Ha	$FW=0.0000083xOW^{2.91}$	Ha
Xenodermichthys copei			$FW=0.00003xFL^{3.1654}$	Fr
Argentina silus	FL=14.466+40.03xOL	Ha	$FW=0.5592xOL^{3.173}$	Ha
Salmo salar	Fl=-45.1+88.4xOL	Ha	$FW=16.78xOL^{2.45}$	Ha
	ln FL = 5.4942 + 0.5278 ln PMXHH	Wa	$FW=0.0116xFL^{3.0}$	Pa
	In FL = 4.7643 + 0.8239 In VL	Wa		
Maurolicus muelleri	FL=44.55+11.606xOL	EO	$FW=0.0000078*OL^{2.89}$	EO
	FL=25.207+26.152xOW	EO	$FW=0.377*OW^{2.05}$	EO
Argyropelecus hemigymnus	FL=17.548+41.956xOL	EO	$FW=0.126*OL^{0.78}$	EO
Astronesthesgemmifer			LnFW=-8.701+4.205xLn(FL)	GHM
Chauliodus sloani	FL=-1.7618+207.55xOL	EO	$FW=0.000003xOL^{2.84}$	EO
Arctozemus risso	FL=43.181+50.405xOL	EO	$FW=0.000053xOL^{2.73}$	EO
Paralepis	FL=43.181+50.405xOL	EO	$FW=0.8998xOL^{2.0591}$	EO
			$FW=0.0000053xFL^{2.73}$	EO
Benthosema glaciale	FL=16.603+29.589xOL	EO	$FW=0.0000024xOL^{3.26}$	EO
Diaphusraffinesqui			LnFW=-8.963+5.055xLnFL	GHM
Lampanyctus crocodilus	FL=19.2+41.822xOL	EO	$FW=0.0000016xOL^{3.29}$	EO
Lobianchia gemellari	FL=-11.181+20.759xOL	EO	$FW=0.000018xOL^{2.87}$	EO
Notoscopelus kroyeri	FL=4.7857+24.216xOL	EO	$FW=0.000006xOL^{3.48}$	EO
Gadus morhua	FL=-202.13+48.37xOL	Ha	$FW=0.006855xOL^{4.435}$	Ha
Melanogrammus aeglefinus	FL=8.785+1.38xOL	Ha	$FW=0.002096xOL^{4.58}$	Ha
	FL=-10999+33.521xOL	Sa	$FW=0.01798xFL^{2.827}$	Co
	LnFL=3.7898+1.11xLn(PMXHH)	Wa	$FW=0.01844xFL^{2.827}$	Co
	Ln FL=4.3571+0.9701xLn(VL)	Wa	$FW=0.0062x(FL/10)^{3.115}$	Wa
Pollachius pollachius	$FL=13.20xOL^{1.329}$	Ha	$FW= 0.01192xOL^{4.205}$	Ha
Pollachius virens	$FL=8.97297xOL^{1.53}$	Hä	$FW=0.007288xOL^{4.501}$	Ha
			$FW=0.00771x(FL/10)^{3.048}$	Do
P. pollachius/P. virens	$FL=16.274xOL^{1.197}$	Br	$FW = 0.039122xOL^{3.600289}$	Br
	$FL=49.497xOW^{1.269}$	Br	$FW=1.066829xOW^{3.844856}$	Br
Pollachius spp.	FL=240.764+42.166xS	Unp.		

Appendix I. ***Cont.***

Fish species	Estimated prey length (mm)	Source	Estimated prey weight (g)	Source
Merlangius merlangus	FL=–4.870+19.621xOL	Pi	FW=0.010961xFL/10$^{2.9456}$	Co
	FL=–54.114+19.671xOW	Br	FW=0.790806xOW$^{3.705954}$	Br
	lnFL=3.8872+0.9745xLn(PMXHH)	Wa	FW=0.010961x(FL/10)$^{2.9456}$	Co
	FL=1.906+73.108xVL	Wa	FW=0.0113x(FL/10)$^{2.946}$	Co
Micromesistius poutassou	FL=–40.94+25.394xOL	Ha	FW=0.019350x(FL/10)$^{3.34372}$	Co
	FL=–17.800+70.77xOW	Sa	FW=0.00375x(FL/10)3.892	Do
	LnFL=72.33+48.37xLn(PMXHH)	Wa		
	Ln FL=4.6688+0.8300xLn(VL)	Wa		
M.poutassou/M.merlangus	FL=0.5+20.4xOL	GHM	LnW=-4.42+3.61xLn(OL)	GHM
Trisopterus esmarkii	FL=–42.6+29.522xOL	Ha	FW=0.002805xOL$^{4.729}$	Ha
	ln FL=3.7510+1.1287xLn(PMXHH)	Wa	FW=0.002796x(FL/10)$^{3.40400}$	Co
Trisopterus luscus	FL=–160.42+41.95xOL	Ha	FW = 0.000291 (OL)$^{5.878}$	Ha
	Ln FL=4.3288+0.6810xLn(PMXHH)	Wa	FW=0.002796x(FL/10)$^{3.40400}$	Co
Trisopterus minutus	FL=–49.9+28.091xOL	Ha	FW=0.00354xOL$^{4.57}$	Ha
	FL=23.49+41.13xPMXHH	Wa	FW=0.002796x(FL/10)$^{3.40400}$	Co
	FL=13.51+60.480xVL	Wa		
Trisopterus luscus/minutus	FL=–109.10+36.139xOL	Ha	FW=0.00079xOL$^{5.38000}$	Ha
Unidentified *Trisopterus* spp.	FL=–5.886+23.443xOL	Br	FW=0.033918xOL$^{3.531259}$	Br
	FL=15.515+45.404xOW	Br	FW=0.916531xOW$^{3.157323}$	Br
	TL=0.6593+109.4232xS	GHM		
Gadiculus argenteus	FL=19.449+1.053xOL	Ha	FW=0.0021289xOL$^{3.785}$	Ha
Ciliata mustela	FL=–74.6+92.29xOL	Ha	FW=1.0736x OL$^{3.444}$	Ha
Gaidropsarus vulgaris	FL=–74.6+92.29xOL	Sa	FW= 0.0108x(FL/10)$^{2.959}$	Co
Phycis blennoides	FL=1.555+1.285xOL	Br	W=0.00198xFL$^{4.634}$	Pe
Molva molva	FL=–40.6+95.731xOL	Ha	FW=0.00765xOL$^{4.996}$	Ha
Raniceps raninus	FL=-20.37+22.96xOL	Ha	FW=0.151155xOL$^{2.912}$	Ha
Gadoids	FL=–54.350+76.582xOW	Br	FW=0.016042x(FL/10)$^{3.035950}$	Br
	FL=24.603+18.935xIF	GHM		
	FL=80.79+81.681xS	GHM		
Merluccius merluccius	FL=–68.180+76.276xOW	Sa	FW=0.009740x(FL/10)$^{2.91300}$	Be
	FL=-0.63+23.884xOL	Ha	FW=0.02628xOL$^{3.484}$	Ha
	LnFL=4.5918+0.9314xLn(PMXHH)	Wa	FW=0.00513xFL$^{3.074}$	Do
Atherina presbyter	FL=67.42+15.132xOL	GJP	FW=0.006304x(TL/10)$^{3.01}$	GJP
Trachurus trachurus	FL=–27.020+34.939xOL	Br	FW=0.003400x(FL/10)$^{3.29430}$	Co
Perca fluviatilis	FL=–36.97+33.90xOL	Ha	FW=0.0545xOL$^{3.797}$	Ha
Labrus bergylta	FL=–31.24+ 67.97xOL	Ha	FW=0.695xOL$^{4.205}$	Ha
Labrus mixtus	FL=–4.76+52.12xOL	Ha	FW=0.688xOL$^{3.51}$	Ha
Labrus spp.	FL=154.477+9.254xIF	GHM	FW=0.00480x(FL/10)$^{3.318}$	Fb
Zoarces viviparus	FL=-23.75+179.3xOW	Ha	FW=12.58xOW$^{4.432}$	Ha
Ammodytes spp.	FL=8.776+51.906xOL	Ha	FW=0.61215xOL$^{2.71}$	Ha

Appendix I. ***Cont.***

Fish species	Estimated prey length (mm)	Source	Estimated prey weight (g)	Source
	FL=53.817+30.358xIF	GHM	$FW=0.1248x(FL/10)^{1.75}$	Fb
Callionymus lyra	$FL=44.29xOL^{1.412}$	Ha	$FW=0.482xOL^{4.459}$	Ha
	FL=–68.660+167.3xOW	Br	$FW=0.022000x(FL/10)^{2.590700}$	Co
	FL=82.96+11.413xIF	GHM		
Gobiidae spp.	FL=–6.460+41.77xOW	Ha	$FW=0.232809xOW^{4.17000}$	Ha
Scomber scomberus	FL=41.363+74.075xOL	Br	$FW=0.002709x(FL/10)^{3.29000}$	Co
Triglidae species				
Scophalnmus rhombus	FL=-11.42+54.77xOL	Ha	$FW=1.4xOL^{3.2}$	Ha
Arnoglossus laterna			$FW=0.0073x(FL/10)^{3.011}$	Ba
Platichthys flesus	FL=-51.06+59.10xOL	Ha	$FW=1.578xOL^{2.899}$	Ha
	LnFL=4.3648+1.1389xLn(PMXHL)	Wa	$FW=0.0125x(FL/10)^{2.968}$	Fb
Limanda limanda	FL=-50.96+58.47xOL	Ha	$FW=0.17xOL^{4.117}$	Ha
Hippoglossoides platessoides	FL=–24.52+48.35xOL	Ha	$FW=0.166xOL^{3.788}$	Ha
			$FW=0.0044x(FL/10)^{3.204}$	Co
Glyptocephalus cynoglossus	FL=–100.650+78.29xOL	Ha	$FW=0.077xOL^{4.633}$	Ha
	Ln FL=3.7231+1.0495xLn(PMXHH)	Wa	$FW=0.001700x(FL/10)^{3.300}$	Co
Hippoglossus hippoglossus	FL=–413.93+105.79xOL	Ha	$FW=0.01300x (FL/10)^{3.249}$	Fb
Microstomus kitt	FL=10.93+88.46xOL	Ha	$FW=4.89xOL^{3.45}$	Ha
	LnFL=3.7714+0.9246xLn(PMXHH)	Wa	$FW=0.026520x(FL/10)^{2.764300}$	Co
Solea solea	FL=–12.622+80.901xOL	Ha	$FW=2.535xOL^{3.444}$	Ha
Buglossidium luteum	FL=70.076+34.135xIF	GHM	$FW=0.0101x(FL/10)^{3.008}$	Il
Unidentified Flatfish	FL=–25.95+53.274xOL	Br	$FW=0.009923x(FL/10)^{3.03595}$	Br
Cephalopod species				
Sepiolidae	DML=18.54+1.65xLRL	Cl	$W=0.645454xLRL^{0.35}$	Cl
Alloteuthis subulata			LnW=2.0+2.75xLn(LRL)	Cl
Loligo spp.	DML=–42.220+84.274xLRL	Cl	$W=6.195360xLRL^{3.242}$	Cl
Illex/Todaropsis	DML=-11.3+41.36xLRL	Cl	$W=1.18803xLRL^{2.83}$	Cl
Ommastrephidae			$W=2.33731xLRL^{2.82}$	Br
Chiroteuthis spp.	DML=11.4+24.46xLRL	Cl	$W=0.78584xLRL^{2.7}$	CL
Brahioteuthis riisei	DML=16.31+20.18xLRL	Cl	LnW=0.55+1.41xLn(LRL)	Cl
Teuthowenia megalops	DML=12.2+40.78xLRL	Cl	LnW=0.728+2.34xLn(LRL)	Cl
Gonatus fabricii	DML=-43.4+42.87xLRL	Cl	LnW=1.68+2.85xLn(LRL)	Cl
Histioteuthis reversa	DML=-13.602+22.21xLRL	Cl	$LnW=4.923403xLRL^{2.31}$	Cl
Octupus vulgaris			LnW=1.82+3.03xLn(HL)	Cl
Eledone cirrhosa	DML=3.380+26.57xLHL	Cl	$W=5.365600xLHL^{2.85000}$	Cl

APPENDIX II. Striped dolphin stranding and by-caught records in Ireland. * Stomach contents analyzed. + Stomach contained milk † empty stomachs. c=length without a part of the animal; F: female; M: male; St: Stranded, St+: stranded alive, BC: by-catch. Mat: mature dolphin, Imm: immature dolphin: Pub: at pubertal stage; age in years. Lat: Latitude, long: longitude. Length in cm and weight in Kg.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
	na/8/1912	Wexford	1.88	66.35	F			St	52.33	-6.38	Berrow & Rogan (1997)
	20/10/1984	Cork	238	127.51	M			St	51.62	-8.70	Dorman et.al. (1986) Berrow & Rogan (1997)
	19/09/1985	Derry	204	83.19	M			St	55.19	-6.70	Dorman et.al. (1986) Bruton & Greer (1985) Berrow & Rogan (1997)
	13/10/1985	Mayo	165	46.22	NA			St	54.23	-10.07	Dorman et.al. (1986) Berrow & Rogan (1997)
	11/11/1985	Cork	183	61.57	M			St	51.86	-8.01	Berrow & Rogan (1997)
	25/12/1985	Cork	213	93.76	NA			St	51.65	-8.68	Dorman et.al. (1986) Berrow & Rogan (1997)
	28/01/1986	Antrim	NA	NA	NA			St	55.23	-6.39	Dorman et.al. (1986)
	15/05/1986	Kerry	c130	23.879	NA			St	51.84	-10.20	Berrow et al. (2007)
	21/03/1987	Donegal	208	87.79	M			St	54.65	-8.29	Berrow & Rogan (1997)
	22/03/1987	Mayo	161	43.18	F			St	53.89	-9.77	Berrow & Rogan (1997)
	21/07/1987	Cork	137	27.61	NA			St	51.79	-8.17	Berrow & Rogan (1997)
	24/01/1990	Galway	203	82.07	F			St	53.30	-9.85	Fairley et al. (1990b) Berrow & Rogan (1997)
	31/01/1990	Galway	183	61.57	M			St	53.30	-9.80	Fairley et al. (1990b) Berrow & Rogan (1997)
	na/2/1990	Mayo	200-240	115.99	F			St	53.97	-10.07	Fairley et al. (1990b) Berrow & Rogan (1997)
	24/03/1990	Mayo	163	44.69	F			St			Berrow & Rogan (1997)
	27/09/1990	Cork	NA	NA	NA			St	51.70	-9.46	Berrow & Rogan (1997)
	25/10/1990	Waterford	107	13.93	NA			St	51.95	-7.77	Smiddy et.al (1992) Berrow & Rogan (1997)
	17/03/1991	Waterford	137	27.61	M			St	52.15	-7.12	Berrow et al. (1991) Berrow & Rogan (1997)
	23/03/1991	Mayo	183	61.57	NA			St	53.96	-10.06	Berrow et al. (1991) Berrow & Rogan (1997)

App. II *Cont*.

UCC code	**Date**	**County**	**Size**	**Weight**	**Sex**	**Mat**	**Age**	**St/BC**	**Lat**	**Long**	**Source**
	14/04/1991	Donegal	139	28.74	F			St+	54.56	-8.21	Bruton & Berrow (1992) Berrow & Rogan (1997)
	14/04/1991	Donegal	143	31.09	F			St+	54.56	-8.21	Bruton & Berrow (1992) Berrow & Rogan (1997)
	14/04/1991	Donegal	157	40.28	F			St+	54.56	-8.21	Bruton & Berrow (1992) Berrow & Rogan (1997)
SD 1	15/07/1991	Cork	175	54.40	M		3	St	51.70	-9.44	Berrow & Rogan (1997)
	03/10/1991	Cork	137	27.61	NA			St	51.81	-8.11	Smiddy et.al (1992) Berrow & Rogan (1997)
SD 2	10/10/1991	Cork	183	61.57	M		7	St	51.93	-7.86	Smiddy et.al (1992) Berrow & Rogan (1997)
SD 1/91	20/10/1991	Mayo	191	69.32	M			St	51.93	-7.85	Berrow & Rogan (1997)
SD 32	29/04/1992	Antrim	168	48.59	NA			St	55.22	-6.53	Bruton & Rogan (1995) Berrow & Rogan (1997)
SD 1/92	15/09/1992	Kerry	198	76.59	M			St	52.13	-10.30	Bruton & Berrow (1993) Berrow & Rogan (1997)
SD 2/92*	17/09/1992	Kerry	201	79.85	M	Pub	6	St	52.14	-10.27	Bruton & Berrow (1993) Berrow & Rogan (1997)
SD 1/93*	26/01/1993	Kerry	158	40.99	M	Imm	2	St	52.26	-10.15	Bruton & Berrow (1994) Berrow & Rogan (1997)
SD a/93	30/01/1993	Clare	NA	NA	NA			St	52.68	-9.64	Bruton & Berrow (1993) Berrow & Rogan (1997)
	11/08/1993		190	68.32	M			St	51.04	15.40	Berrow & Rogan (1998)
SD 2/93*	30/08/1993	Clare	187	65.38	M	Pub	4	St	52.61	-9.70	Bruton & Berrow (1994) Berrow & Rogan (1997)
	03/01/1994	Sligo	170	50.21	F			St	54.30	-8.56	Cotton O'Shea (1994) Berrow & Rogan (1997)
SD a/94	06/02/1994	Sligo	170	50.21	M	Imm	2.5	St	54.33	-8.64	Cotton O'Shea (1994) Berrow & Rogan (1997)
	15/02/1994	Sligo	134	25.97	NA			St	53.96	-10.05	Cotton O'Shea (1994) Berrow & Rogan (1997)
SD 1/94*	22/03/1994	Cork	151.5	36.49	F			St	51.93	-7.84	Bruton & Rogan (1995) Berrow & Rogan (1997)

App. II *Cont*.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
SD 2/94*	22/03/1994	Cork	143	31.09	F		2	St	51.93	-7.84	Bruton & Rogan (1995) Berrow & Rogan (1997)
SD 1/95†	16/02/1995	Donegal	191	69.32	F		5	St+	55.10	-8.31	UCC
SD 2/95*	13/10/1995	Galway	221	103.85	M	Mat	25	St+	53.11	-9.67	Bruton & Rogan (1996)
SD 3/95†	21/11/1995	Galway	214	94.99	F		23	St+	53.60	-9.98	Bruton & Rogan (1996)
	28/01/1996	Antrim	NA	NA	NA			St	55.20	-6.64	Berrow & Rogan (1997)
MW T1 H1 SD1*	16/07/1996		197	75.52	M		11	BC	49.22	13.33	UCC
MW T1 H1 SD2*	16/07/1996		NA	NA	NA			BC	49.22	13.33	UCC
MW T1 H1 SD3	16/07/1996		NA	NA	NA			BC	49.22	13.33	UCC
MW T1 H1 SD4*	16/07/1996		218	99.99	M		10	BC	49.22	13.33	UCC
MW T1 H1 SD5*	16/07/1996		172	51.86	M		2	BC	49.22	13.33	UCC
MW T1 H1 SD6	16/07/1996		119.5	18.91	M		0.5	BC	49.22	13.33	UCC
MW T1 H1 SD7*	16/07/1996		117.6	18.09	F		0.5	BC	49.22	13.33	UCC
MW T1 H1 SD8*	16/07/1996		106	13.57	M	Imm	0.5	BC	49.22	13.33	UCC
DOL T1 H1 SD1*	23/07/1996		112	15.80	F		0.5	BC	47.02	12.70	UCC
DOL T1 H1 SD2†	23/07/1996		166.5	47.39	M	Imm	0.5	BC	47.02	12.70	UCC
DOL T1 H2 SD1	24/07/1996		1-2 years	NA	M		1-2yr	BC	47.1	15.33	UCC
DOL T1 H6 SD1+	28/07/1996		2-3years	NA	M		2-3yr	BC	48.02	17.93	UCC
MW T1 H2 SD1	28/07/1996		Large	NA	M			BC	18.00	48.00	UCC
MW T6 H2 SD23	na/08/1996		209	88.97	M		11	BC	50.40	15.40	UCC
SD a/96	06/08/1996	Galway	170	50.21	NA			St	50.40	15.40	UCC
MW T3 H1 SD1†	06/08/1996		115	17.00288	M			BC	50.40	15.40	UCC
SD 1/96†	07/08/1996	Cork	99	11.23	F			St	51.64	-10.05	UCC
MW T3 H2 SD1†	07/08/1996		228	113.21	M	Mat	13	BC	50.40	13.20	UCC
DOL T2 H4 SD1	09/08/1996		~180	58.82	M			BC	50.39	13.29	UCC
DOL T2 H5 SD1	10/08/1996		195	73.42	F		11	BC	51.15	12.47	UCC
HW T1 H1 SD1*	14/08/1996		169	49.39	F		2	BC	51.14	10.44	UCC
MW T4 H2 SD16*	14/08/1996		124	20.95	M	Imm	0.5	BC	51.05	13.04	UCC
MW T4 H2 SD17*	14/08/1996		132	24.91	M	Imm	0.5	BC	51.05	13.04	UCC
MW T4 H2 SD18+	14/08/1996		111	15.42	F		0.5	BC	51.05	13.04	UCC
MW T4 H2 SD19*	14/08/1996		201	79.85	F		14	BC	51.05	13.04	UCC
JB T1 H3 SD1*	15/08/1996		201	79.85	M			BC	50.89	15.9	UCC
JB T1 H3 SD2*	15/08/1996		163.5	45.07	M		3	BC	50.89	15.9	UCC
JB T1 H4 SD F†	16/08/1996		116	17.42	F		0.5	BC	50.74	16.80	UCC

App. II *Cont*.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
JB T1 H4 SD M †	16/08/1996		209.5	89.56	M		18	BC	50.74	16.80	UCC
JB T1 H4 SD juv*	16/08/1996		124	20.95	M	Imm	0.5	BC	50.74	16.80	UCC
JB T2 H2 SD1	25/08/1996		157	40.28	M		2	BC	51.78	12.12	UCC
DOL T3 H1 SD1	27/08/1996		~180	58.82	M			BC	51.26	12.04	UCC
DOL T3 H1 SD2	27/08/1996		~190	68.32	M			BC	51.26	12.04	UCC
DOL T3 H1 SD3	27/08/1996		NA	NA	M			BC	51.260	12.04	UCC
DOL T3 H1 SD4	27/08/1996		~2	78.75	NA			BC	51.26	12.04	UCC
DOL T3 H1 SD5	27/08/1996		~160-170	46.22	F			BC	51.26	12.04	UCC
JB T2 H5 SD1*	28/08/1996		235	123.11	M	Mat		BC	51.84	13.1	UCC
JB T2 H5 SD2*	28/08/1996		170	50.20	M	Imm		BC	51.84	13.1	UCC
DOL T3 H2 SD1	28/08/1996		~160	42.44	M	Imm	4	BC	51.44	12.22	UCC
DOL T3 H2 SD2	28/08/1996		~160	42.44	M			BC	51.44	12.22	UCC
DOL T3 H2 SD3*	28/08/1996		~170	50.21	M		4	BC	51.44	12.22	UCC
JB T2 H1 SD1	30/08/1996		178	57.03	M		3	BC	51.77	12.11	UCC
DOL T3 H7 Sd1	02/09/1996		~215	96.22	F			BC	51.34	12.03	UCC
JB T3 H6 SD1*	07/09/1996		217	98.72	M	Mat	15	BC	51.32	13.02	UCC
DOL T4 H1 SD1	09/09/1996		NA	NA	M			BC	51.23	12.08	UCC
DOL T4 H1 SD2	09/09/1996		NA	NA	F			BC	51.23	12.08	UCC
DOL T4 H1 SD3	09/09/1996		215	96.22	M		25	BC	51.23	12.08	UCC
DOL T4 H1 SD4	09/09/1996		165	46.22	F		2	BC	51.23	12.08	UCC
DOL T4 H2 SD1	10/09/1996		170	50.21	M		2	BC	51.23	12.12	UCC
DOL T4 H2 SD2	10/09/1996		165	46.22	M		2	BC	51.23	12.12	UCC
JB T4 H2 SD1*	12/09/1996		220	102.55	M	Mat	12	BC	51.41	12.99	UCC
JB T4 H2 SD2*	12/09/1996		145	32.31	F			BC	51.41	12.99	UCC
JB T4 H2 SD3	12/09/1996		>200	78.75	M			BC	51.41	12.99	UCC
JB T4 H3 SD1*	13/09/1996		149	34.84	M	Imm	1	BC	51.43	12.90	UCC
JB T4 H4 SD1*	14/09/1996		179	57.92	M	Imm	2	BC	51.17	13.29	UCC
DOL T4 H7 SD1	15/09/1996		160	42.44	F		3	BC	51.11	11.58	UCC
JB T4 H6 SD1*	16/09/1996		123	20.49	M	Imm	0.5	BC	51.25	12.03	UCC
JB T5 H3 SD1†	21/09/1996		117	17.83	M	Imm	0.5	BC	51.48	11.97	UCC
JB T5 H3 SD2*	21/09/1996		133	25.44	F		0.5	BC	51.48	11.97	UCC
JB T5 H3 SD3	21/09/1996		133	25.44	F		0.5	BC	51.48	11.97	UCC
JB T5 H3 SD4	21/09/1996		juvenile	NA	F			BC	51.48	11.97	UCC

App. II *Cont*.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
DOL T1 H8 SD1	30/09/1996		112	15.80	F		0.5	BC	48.28	17.25	UCC
DOL T1 H8 SD2+	30/09/1996		1-2years	NA	M		1-2yr	BC	48.28	17.25	UCC
DOL T1 H8 SD3	30/09/1996		young	NA	M			BC	48.28	17.25	UCC
JB T7 H1 SD1	06/10/1996		~180	58.82	M			BC	51.96	11.99	UCC
JB T7 H1 SD2	06/10/1996		~170	50.21	F			BC	51.96	11.99	UCC
SD 3/96*	31/10/1996	Kerry	192.5	70.84	F		6	St	52.13	-10.36	Bruton & Rogan (1997)
SD 4/96*	20/11/1996	Donegal	174	53.55	F		6	St	54.63	-8.20	UCC
SD b/96	20/12/1996	Antrim	146	32.94	F			St	55.23	-6.39	Bruton & Rogan (1997)
SD 1/97	17/08/1997	Mayo	198	76.59	M	Imm	10	St	53.79	-9.65	UCC
SD 2/97	Winter/1997	Donegal	189	67.33	M			St	54.61	-8.16	UCC
SD 1/98*	21/12/1997	Clare	195	73.42	M			St	52.93	-9.34	UCC
SD 2/98	14/02/1998	Sligo	194	72.38	F			St+	54.33	-8.64	Bruton & Rogan (1998)
	na.early/3/1989	Cork	NA	NA	NA				51.88	-7.86	Smiddy (1989a) Berrow & Rogan (1997)
SD a/98	31/05/1998	Mayo	c200	78.75	M			St	54.28	-9.24	Bruton & Rogan (1998)
SD b/98	27/07/1998	Kerry	c150	35.50	NA			St	52.26	-10.01	Rendle & Rogan (2001)
SD 3/98*	27/07/1998	Kerry	185	63.46	M	Imm		St	51.86	-9.68	Bruton & Rogan (1998)
RM T1 H1 SD1*	01/08/1998		140	29.32	F			BC	49.074	14.16	UCC
RM T1 H1 SD2*	01/08/1998		162	43.93	F			BC	49.074	14.16	UCC
SD 4/98	04/08/1998		150	35.50	F			St	48.51	14.36	UCC
RM T1 H4 SD1	04/08/1998		150	35.50	F			BC	48.51	14.36	UCC
RM T1 H4 SD2	04/08/1998		>220	102.55	M			BC	48.51	14.36	UCC
RM T1 H4 SD3	04/08/1998		~200	78.75	F			BC	48.51	14.36	UCC
RM T1 H4 SD4	04/08/1998		NA	NA	NA			BC	48.51	14.36	UCC
SD 6/98	22/08/1998		110	15.03	F			St	50.41	14.48	UCC
RM T2 H2 SD1	22/08/1998		110	15.03	F			BC	50.41	14.48	UCC
SD 5/98	23/08/1998		96	10.31	F			St	50.76	15.08	UCC
RM T2 H3 SD1*	23/08/1998		148.5	34.52	M			BC	50.76	15.08	UCC
RM T2 H3 SD2*	23/08/1998		201	79.85	F			BC	50.76	15.08	UCC
RM T2 H3 SD3+	23/08/1998		96	10.31	F			BC	50.76	15.08	UCC
RM T3 H2 SD1	07/10/1998		180	58.82	F			BC	51.59	13.89	UCC
RM T3 H2 SD2	07/10/1998		NA	NA	NA			BC	51.59	13.89	UCC
RM T3 H2 SD3	07/10/1998		NA	NA	NA			BC	51.59	13.89	UCC
RM T3 H3 SD1	08/10/1998		~250	146.12	M			BC	51.52	13.88	UCC

App. II *Cont*.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
RM T3 H7 SD1*	12/10/1998		205	84.33	M	Mat		BC	51.09	15.01	UCC
RM T4 H1 SD1*	19/10/1998		155	38.87	F			BC	51.42	15.08	UCC
SD 1/99*	15/02/1999	Sligo	174	53.55	M	Pub		St	54.34	-8.57	Rendle & Rogan (2001)
SD 2/99†	15/04/1999	Sligo	241	132.01	M	Mat	25	St	54.32	-8.64	Rendle & Rogan (2001)
SD 3/99*	15/04/1999	Sligo	223	106.47	M	Mat		St	54.32	-8.64	Rendle & Rogan (2001)
SD 4/99*	21/07/1999	Kerry	162	43.93	F			St+	52.25	-10.08	Rendle & Rogan (2001)
SD 5/99	21/08/1999		154	38.18	M	Imm		St	52.10	17.15	UCC
SD e/00	30/11/1999	Kerry	6+1/2 ft	76.72	NA			St+	52.02	-10.10	UCC
SD a/99	na/12/1999	Clare	213	93.76	F			D	52.67	-9.64	Murphy and Rogan (2004)
SD b/00	28/02/2000	Galway	173	52.70	M			St+	53.53	-10.18	Murphy and Rogan (2004)
SD a/00	13/09/2000	Mayo	197	75.52	M			St	53.81	-9.63	Murphy and Rogan (2004)
SD 1/00*	15/09/2000	Donegal	169	49.39	F			St	55.18	-8.17	Murphy and Rogan (2004)
SD d/00	17/09/2000	Kerry	166	47.00	NA			St	52.17	-10.44	UCC
SD 2/00*	17/09/2000	Kerry	172	51.86	M	Imm		St	52.07	-9.97	Murphy and Rogan (2004)
SD 3/00*	04/11/2000	Kerry	168.5	48.99	F			St	52.17	-10.40	Murphy and Rogan (2004)
SD 4/00*	22/11/2000	Mayo	158	40.99	F			St+	54.23	-9.86	Murphy and Rogan (2004)
SD 5/00*	22/11/2000	Mayo	150	35.50	F			St+	54.23	-9.89	Murphy and Rogan (2004)
	24/01/2001	Dublin	NA	NA	M			St+	53.36	-6.22	Berrow et al. (2007)
SD d/01	29/01/2001	Dublin	young	NA	F			St+	53.45	-6.12	Berrow et al. (2007)
SD 1/01+	24/04/2001	Cork	142	30.50	M	Imm	0.5	St+	51.78	-8.29	Murphy and Rogan (2004)
SD c/01	22/07/2001	Waterford	~177	56.14	M			St	52.15	-7.11	Murphy and Rogan (2004)
SD a/01	11/08/2001	Kerry	181	59.73	NA			St	52.12	-10.37	Murphy and Rogan (2004)
SD b/01	12/08/2001	Cork	195	73.42	M			St+	51.47	-9.42	Murphy and Rogan (2004)
SD a/02	08/06/2002	Mayo	203	82.07	M			St	54.29	-9.84	UCC
SD 1/02*	15/09/2002	Cork	168	48.59	M	Pub		St+	51.64	-8.57	UCC
SD 3/02†	30/10/2002	Mayo	185	63.46	F			St	54.19	-10.09	UCC
SD 2/02*	05/11/2002	Cork	209	88.97	F			St	51.86	-7.99	UCC
SD 4/02†	06/11/2002	Wexford	181	59.73	F			St+	52.26	-6.38	UCC
SD a/03	09/02/2003	Mayo	171	51.03	M			St	54.17	-9.96	Brophy et al. (2006)
SD b/03	09/02/2003	Mayo	174	53.55	M			St	54.17	-9.54	Brophy et al. (2006)
SD c/03	09/02/2003	Mayo	173.5	53.12	F			St	54.16	-9.94	Brophy et al. (2006)
SD 1/03†	14/06/2003	Cork	203	82.07	M			St	51.56	-8.99	Brophy et al. (2006)
SD d/03	16/06/2003	Wexford	NA	NA	NA			St	52.21	-6.72	Brophy et al. (2006)
SD e/03	25/07/2003	Cork	<200	78.75	M			St	51.64	-8.57	Brophy et al. (2006)

App. II *Cont*.

UCC code	Date	County	Size	Weight	Sex	Mat	Age	St/BC	Lat	Long	Source
SD f/03	26/08/2003	Cork	c180	58.82	M			St	51.64	-8.66	Brophy et al. (2006)
SD g/03	29/09/2003	Galway	c220	102.55	F			St	53.45	-10.12	Brophy et al. (2006)
SD h/03	Sp-Oct/2003	Galway	~150	35.50	NA			St	53.25	-9.05	UCC
	25/10/2003	Kerry	NA	NA	NA			St	52.14	-9.98	Berrow et al. (2007)
SD a/04	29/03/2004	Cork	c200	78.75	NA			St	51.59	-8.85	Philpott et al. (2007)
	04/08/2004	Cork	180	58.82	NA			St	51.88	-8.26	Philpott et al. (2007)
	21/09/2004	Donegal	203	82.07	M			St	55.04	-8.34	Philpott et al. (2007)
SD 1/04*	01/11/2004	Cork	210	90.15	M			St	51.77	-8.30	Philpott et al. (2007)
	25/11/2004	Mayo	210	90.15	NA			St	54.19	-10.09	Philpott et al. (2007)
	04/12/2004	Clare	170	50.21	NA			St	52.75	-9.49	Philpott et al. (2007)
	28/08/2005	Donegal	Adult	NA	F			St+	54.96	-8.45	Sleeman et al. (2006) Philpott & Rogan (2007)
	28/08/2005	Donegal	50	1.69	NA			St+	54.97	-8.46	Sleeman et al. (2006) Philpott & Rogan (2007)
	28/10/2005	Kerry	NA	NA	NA			St	52.84	-10.24	Philpott & Rogan (2007)
	11/12/2005	Waterford	NA	NA	M			St	52.15	-7.13	Philpott & Rogan (2007)
	19/02/2006	Wexford	160	42.44	M			St	52.26	-6.38	O'Connel & Berrow (2007)
	27/02/2006	Dublin	NA	NA	NA			St	53.57	-6.08	O'Connel & Berrow (2007)
	03/03/2006	Waterford	c220	102.55	F			St	52.13	-7.40	O'Connel & Berrow (2007)
	11/03/2006	Down	NA	NA	NA			St+	54.07	-6.18	O'Connel & Berrow (2007)
SD 1/06	13/03/2006	Louth	NA	NA	M			St+	54.01	-6.11	O'Connel & Berrow (2007)
	28/03/2006	Kerry	c100	11.55	NA			St+	52.23	-9.90	O'Connel & Berrow (2007)
SD 3/06	29/04/2006	Cork	206	85.47	F			St+	51.85	-8.26	O'Connel & Berrow (2007)
SD 2/06	29/04/2006	Cork	168	48.59	F			St+	51.85	-8.27	O'Connel & Berrow (2007)
	09/08/2006	Galway	NA	NA	M			St	53.25	-9.09	O'Connel & Berrow (2007)
	17/08/2006	Donegal	184	62.51	NA			St	54.85	-8.42	O'Connel & Berrow (2007)
	02/09/2006	Louth	C160	42.44	NA			St	53.75	-6.24	O'Connel & Berrow (2007)
SD 6/06*	11/10/2006	Cork	134.5	26.24	F			St+	51.92	-7.86	O'Connel & Berrow (2007)
SD 5/06*	11/10/2006	Cork	134	25.97	M	Imm		St+	51.92	-7.87	O'Connel & Berrow (2007)
SD 4/06*	11/10/2006	Cork	140	29.32	M	Imm		St+	51.91	-7.87	O'Connel & Berrow (2007)
SD a/06	15/10/2006	Cork	170	50.21	M			St	51.55	-8.95	O'Connel & Berrow (2007)
	16/10/2006	Mayo	c120	19.13	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)

App. II *Cont*.

UCC code	**Date**	**County**	**Size**	**Weight**	**Sex**	**Mat**	**Age**	**St/BC**	**Lat**	**Long**	**Source**
	16/10/2006	Mayo	c200	78.75	F			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	16/10/2006	Mayo	NA	NA	NA			St+	54.16	10.09	O'Connel & Berrow (2007)
	20/10/2006	Mayo	NA	NA	NA			St	54.11	-10.20	O'Connel & Berrow (2007)
	28/12/2006	Kerry	210	90.15	M			St	52.24	-10.11	O'Connel & Berrow (2007)
	30/12/2006	Cork	c150	35.50	NA			St	51.59	-8.86	O'Connel & Berrow (2007)
	05/01/2007	Galway	237	126.03	NA			St	53.37	-9.96	O'Connell & Berrow (2008)
	17/03/2007	Kerry	153	37.50	M			St+	52.50	-9.68	O'Connell & Berrow (2008)
	17/03/2007	Kerry	154	38.18	M			St+	52.51	-9.68	O'Connell & Berrow (2008)
	02/05/2007	Cork	145	32.31	F			St	51.84	-8.00	O'Connell & Berrow (2008)
	03/05/2007	Sligo	167	47.79	M			St	54.33	-8.64	O'Connell & Berrow (2008)
	07/08/2007	Donegal	175	54.40	M			St	55.17	-7.88	O'Connell & Berrow (2008)
	16/09/2007	Waterford	Adult	NA	F			St+	52.15	-7.12	O'Connell & Berrow (2008)
	16/09/2007	Waterford	Calf	NA	F			St+	52.15	-7.12	O'Connell & Berrow (2008)
	05/12/2007	Galway	NA	NA	M			St+	53.26	-9.04	O'Connell & Berrow (2008)
SD 1/08*	06/01/2008	Cork	150	35.50	F			St	51.59	-8.86	O'Connell & Berrow (2008)
	22/01/2008	Galway	210	90.15	NA			St	53.23	-9.43	O'Connell & Berrow (2008)
	08/02/2008	Kerry	192	70.33	F			St	52.12	-10.37	O'Connell & Berrow (2008)
	11/04/2008	Mayo	163	44.69	NA			St	54.17	-9.97	O'Connell & Berrow (2008)
	11/04/2008	Mayo	c160	42.44	NA			St	54.17	-9.96	O'Connell & Berrow (2008)
	06/07/2008	Kerry	c160	42.44	NA			St	52.21	-10.35	O'Connell & Berrow (2008)
	07/07/2008	Clare	200	78.75	NA			St	53.11	-9.28	O'Connell & Berrow (2008)
	08/08/2008	Wexford	c180	58.82	NA			St	52.18	-6.40	O'Connell & Berrow (2008)
	03/11/2008	Clare	NA	NA	NA			St	51.82	-9.74	O'Connell & Berrow (2008)
	14/11/2008	Kerry	c185	63.46	NA			St	52.11	-10.22	O'Connell & Berrow (2008)
	24/11/2008	Kerry	193	71.35	NA			St	51.96	-10.26	O'Connell & Berrow (2008)

App. II *Cont*.

UCC code	**Date**	**County**	**Size**	**Weight**	**Sex**	**Mat**	**Age**	**St/BC**	**Lat**	**Long**	**Source**
	20/08/2008	Cork	185	63.46	NA			St	51.63	-10.05	O'Connell & Berrow (2008)
	02/01/2009	Clare	150	35.50	M			St+	52.93	-9.36	O'Connell & Berrow (2008)
	14/01/2009	Donegal	<180	58.82	NA			St	54.50	-8.26	O'Connell & Berrow (2008)
	25/01/2009	Mayo	150	35.5	NA			St	53.73	-9.89	O'Connell & Berrow (2008)
	29/01/2009	Down	180	58.82	F			St	54.54	-5.47	O'Connell & Berrow (2008)
	27/02/2009	Galway	166	47.00	M			St	53.26	-9.02	O'Connell & Berrow (2008)
	13/03/2009	Mayo	213	93.76	M			St+	53.96	-10.10	O'Connell & Berrow (2008)
	01/07/2009	Waterford	190	68.32	NA			St	52.15	-7.12	O'Connell & Berrow (2008)
	04/07/2009	Kerry	188	66.35	M			St	51.84	-10.21	O'Connell & Berrow (2008)
	10/10/2009	Clare	150	35.50	NA			St	52.67	-9.65	O'Connell & Berrow (2008)
	27/12/2009	Galway	100-150	21.42	NA			St	53.10	-9.63	O'Connell & Berrow (2008)
IWDG	15/01/2010	Sligo	168	48.59	M			St	54.39	-8.56	www.iwdg.ie
IWDG	02/02/2010	Antrim	158	40.99	F			St+	55.23	-6.38	www.iwdg.ie
IWDG	09/03/2010	Clare	135	26.51	F			St+	52.94	-9.37	www.iwdg.ie
IWDG	24/04/2010	Clare	134	25.97	M			St+	52.65	-9.56	www.iwdg.ie
IWDG	27/06/2010	Clare	220	102.55	M			St+	53.11	-9.28	www.iwdg.ie
IWDG	28/06/2010	Clare	164	45.45	M			St	53.12	-9.28	www.iwdg.ie
IWDG	02/08/2010	Kerry	NA	NA	NA			St	52.13	-9.97	www.iwdg.ie
IWDG	09/08/2010	Clare	NA	NA	M			St+	52.63	-9.53	www.iwdg.ie
IWDG	25/09/2010	Derry	NA	NA	NA			St	55.17	-6.72	www.iwdg.ie
IWDG	04/11/2010	Cork	193	71.35	M			St+	51.55	-8.97	www.iwdg.ie
IWDG	16/11/2010	Waterford	NA	NA	NA			St	52.13	-7.36	www.iwdg.ie
IWDG	05/01/2011	Donegal	120	19.13	F			St	54.61	-8.17	www.iwdg.ie
IWDG	29/04/2011	Wexford	200	78.75	NA			St	52.21	-6.79	www.iwdg.ie
IWDG	01/06/2011	Sligo	156	39.57	M			St	54.26	-8.61	www.iwdg.ie
IWDG	02/07/2011	Galway	192	70.33	NA			St	53.44	-10.07	www.iwdg.ie
SD 1/11*	07/09/2011	Kerry	188	66.35	M	Pub		St	52.17	-10.40	www.iwdg.ie
SD 2/11*	10/09/2011	Cork	189	67.33	F			St	51.93	-7.85	www.iwdg.ie
IWDG	18/09/2011	Donegal	NA	NA	NA			St	54.48	-8.27	www.iwdg.ie
IWDG	08/10/2011	Sligo	202	80.95	M			St	54.37	-8.62	www.iwdg.ie
SD 3/11*	10/11/2011	Kerry	200	78.75	M	Imm		St	52.12	-10.37	www.iwdg.ie
IWDG	21/11/2011	Kerry	173	52.70	M			St	52.18	-10.41	www.iwdg.ie
IWDG	05/12/2011	Sligo	197	75.52	M			St	54.26	-8.86	www.iwdg.ie
	Average		**172.4**	**53.60**	**84F:124M**						

APPENDIX III. Atlantic white-sided dolphin stranding and by-caught records in Ireland. * Stomach contents analyzed. † empty stomachs. c=length without a part of the animal; Sex record: F: female; M: male; St/BC: stranding or by caught record: St: Stranded, St+: stranded alive, BC: by-caught., M: mass strandings. Lat: Latitude, long: longitude. Length in cm and weigh in Kg.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WSDaa	--/07/1876	Antrim	NA	NA	NA	St	55.20	-6.68	Ogilby (1889)
WSDab	11/06/1890	Wexford	NA	NA	NA	St	52.17	-6.83	Barret-Hamilton (1890)
WSDac	Spring/1894	Mayo	NA	NA	NA	St	53.96	-10.06	Moffat (1937/38)
WSDad	09/06/1916	Sligo	281.9	114.03	NA	St	54.27	-9.05	Harmer (1927) Berrow & Rogan (1997)
	09/07/1965	Donegal	127	17.06	NA	BC	54.63	-8.48	Hillis (1966)
	--/07/1966	Donegal	230	70.21	NA	BC	54.98	-8.49	Berrow & Rogan (1998)
WSDae	04/10/1967	Kerry	260	94.02	M	St	52.13	-10.37	Greeson (1968) Berrow & Rogan (1997)
WSDaf	04/10/1967	Kerry	250	85.63	M	St	52.12	-10.37	Greeson (1968) Berrow & Rogan (1997)
WSDag	04/10/1967	Kerry	240	77.70	M	St	52.12	-10.37	Greeson (1968) Berrow & Rogan (1997)
WSDah	04/10/1967	Kerry	210	56.53	NA	St	52.12	-10.37	Greeson (1968) Berrow & Rogan (1997)
WSDae	04/10/1967	Kerry	230	70.21	M	St	52.12	-10.37	Greeson (1968) Berrow & Rogan (1997)
WSDaf	10/11/1967	Kerry	251.4	86.83	M	St	52.24	-10.15	Gresson (1969a)
WSDag	10/11/1967	Kerry	182.8	40.66	NA	St	52.23	-10.14	Gresson (1969a)
WSDah	10/11/1967	Kerry	NA	NA	NA	St	52.23	-10.14	Gresson (1969a)
WSDal	02/09/1968	Kerry	259.1	93.23	M	St+	52.23	-10.18	Greeson (1969b) Berrow & Rogan (1997)
WSDam	02/09/1968	Kerry	251.4	86.83	M	St+	52.24	-10.17	Greeson (1969b) Berrow & Rogan (1997)
WSDan	19/08/1977	Mayo	254	88.93	NA	St	53.89	-9.75	Berrow & Rogan (1997)
WSDao	08/04/1981	Kerry	NA	NA	NA	St	52.12	-10.27	www.iwdg.ie
WSDap	15/06/1981	Galway	257	91.45	F	St	53.26	-9.04	Fairley & Dawson (1984) Berrow & Rogan (1997)

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WSDaq	20/04/1984	Wicklow	NA	NA	NA	St	52.79	-6.14	Fairley (1984) Berrow & Rogan (1997)
WSDar	20/04/1984	Wicklow	NA	NA	NA	St	52.79	-6.14	Fairley (1984) Berrow & Rogan (1997)
WSDas	20/04/1984	Wicklow	NA	NA	NA	St	52.78	-6.14	Fairley (1984) Berrow & Rogan (1997)
WSDat	14/08/1984	Antrim	260	94.02	M	St	55.17	-6.72	Berrow & Rogan (1997)
WSDau	22/09/1984	Cork	233	72.412	M	BC	51.86	-7.97	Berrow & Rogan (1997)
WSDav	01/04/1986	Mayo	NA	NA	M	St	53.96	-10.04	Berrow & Rogan (1997)
WSDaw	01/04/1986	Mayo	NA	NA	F	St	53.96	-10.05	Berrow & Rogan (1997)
	15/04/1986	Kerry	c200	50.32	NA	St	51.84	-10.20	Berrow & Rogan (1997)
	21/02/1989	lk	210	56.53	M	St	52.13	-10.27	Quigley & Flannery (2002)
WSDax	28/02/1989	Sligo	220	63.15	NA	St	54.36	-8.66	Berrow & Rogan (1997)
WSDay	08/04/1989	Wexford	236	74.65	M	St	52.20	-6.65	Cotton et al. (1989) Berrow & Rogan (1997)
WSDaz	10/04/1989	Cork	213	58.47	M	St	51.66	-9.50	Cotton et al. (1989) Berrow & Rogan (1997)
WSDba	14/04/1989	Cork	254	88.93	M	St	51.92	-7.87	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbc	23/04/1989	Cork	253	88.10	M	St	51.63	-10.05	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbb	23/04/1989	Cork	260	94.02	M	BC	51.60	-10.06	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbd	23/04/1989	Cork	253	88.10	M	St	52.11	-9.90	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbe	29/04/1989	Kerry	238	76.16	M	St	52.17	-10.44	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbf	29/04/1989	Kerry	207	54.62	F	St	52.17	-10.44	Cotton et al. (1989) Berrow & Rogan (1997)
WSDbg	21/11/1989	Cork	300	NA	NA	St	51.77	-8.31	Berrow & Rogan (1997) Dorman et al. (1991)

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	10/03/1990	Kerry	238	76.16	NA	St	51.83	-10.71	Berrow et. al (2007)
WSDbh	15/03/1990	Galway	248	84.01	M	BC	53.24	-9.30	Berrow & Rogan (1997)
WSD 10*	21/03/1990	Galway	244	80.82	M	St	53.20	-8.98	Farley et al. (1990a) Berrow & Rogan (1997)
WSDbj	21/03/1990	Galway	219	62.47	F	St	53.20	-8.98	Farley et al. (1990a) Berrow & Rogan (1997)
WSDbl	22/03/1990	Galway	244	80.82	M	St	53.54	-10.18	Berrow & Rogan (1997)
WSDbk	22/03/1990	Galway	209	55.89	M	St	53.54	-10.19	Berrow & Rogan (1997)
WSDbm	22/03/1990	Galway	251	86.45	M	St	53.53	-10.15	Berrow & Rogan (1997)
WSDbr	24/03/1990	Galway	261	94.88	M	St	53.40	-10.13	Farley et al. (1990a)
WSDbs	24/03/1990	Galway	250	85.63	M	St	53.40	-10.13	Farley et al. (1990a)
WSD 14*	24/03/1990	Galway	265	98.38	M	St	53.53	-10.16	Farley et al. (1990a)
WSDbu *	24/03/1990	Galway	245	81.61	M	St	53.53	-10.16	Farley et al. (1990a)
WSDbn	24/03/1990	Mayo	260	94.02	M	St	53.97	-10.12	Berrow & Rogan (1997)
WSDbo	24/03/1990	Mayo	254	88.93	M	St	53.97	-10.08	Berrow & Rogan (1997)
WSDbp	30/03/1990	Mayo	NA	NA	NA	BC	53.96	-10.06	Berrow & Rogan (1997)
WSDbq	15/04/1990	Cork	213	58.47	NA	St	51.63	-8.70	Dorman et al. (1991b) Berrow & Rogan (1997)
WSDbv	--/05/1990	Sligo	230	70.21	NA	St	54.30	-8.58	Farley et al. (1990b)
WSDbw	13/08/1990	Cork	254	88.93	M	St+	51.65	-8.67	Farley et al. (1990b)
WSDbx	14/10/1990	Waterford	213	58.47	M	St	52.13	-7.27	Dorman et al. (1991b) Berrow & Rogan (1997)
WSDby	14/10/1990	Waterford	183	40.73	NA	St	52.15	-7.12	Dorman et al. (1991b) Berrow & Rogan (1997)
WSDbz	25/12/1991	Cork	240	77.70	F	St	51.50	-8.13	Smiddy (1992) Berrow & Rogan (1997)
	02/02/1993	Mayo	137	20.43	NA	St	53.96	-10.09	Berrow & Rogan (1997)
WSD b/93	26/03/1993	Clare	Adult	NA	NA	St	52.83	-9.43	UCC
WSDca	03/09/1993	Sligo	230	70.21	NA	St	54.33	-8.64	Berrow & Rogan (1997)
WSD 1/94*	05/01/1994	Galway	247	83.20	M	St	53.24	-9.15	UCC

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WSD a/94	17/01/1994	Down	NA	NA	F	St	54.63	-5.85	Berrow & Rogan (1997)
WSD 2/94*	19/04/1994	Cork	255	89.77	M	St	51.47	-9.37	Berrow & Rogan (1997)
WSD b/94	17/06/1994	Down	218	61.79	M	St	54.47	-5.43	UCC
Ross 1 *	28/09/1994	Mayo	185.5	42.06	M	M	54.21	-9.15	Rogan et al. (1997a)
Ross 2 *	28/09/1994	Mayo	274	106.53	M	M	54.21	-9.17	Rogan et al. (1997a)
Ross 3 *	28/09/1994	Mayo	236	74.65	F	M	54.21	-9.17	Rogan et al. (1997a)
Ross 4*	28/09/1994	Mayo	230	70.21	F	M	54.21	-9.17	Rogan et al. (1997a)
Ross 5 *	28/09/1994	Mayo	241	78.47	F	M	54.22	-9.17	Rogan et al. (1997a)
Ross 6*	28/09/1994	Mayo	258	92.30	M	M	54.22	-9.18	Rogan et al. (1997a)
Ross 7 *	28/09/1994	Mayo	266	99.27	M	M	54.22	-9.18	Rogan et al. (1997a)
Ross 8 *	28/09/1994	Mayo	170	34.17	F	M	54.22	-9.18	Rogan et al. (1997a)
Ross 9 *	28/09/1994	Mayo	253	88.10	F	M	54.22	-9.18	Rogan et al. (1997a)
Ross 10*	28/09/1994	Mayo	221	63.84	F	M	54.23	-9.18	Rogan et al. (1997a)
Ross 11 *	28/09/1994	Mayo	270	102.86	M	M	54.21	-9.15	Rogan et al. (1997a)
Ross 12 *	28/09/1994	Mayo	250	85.63	M	M	54.21	-9.15	Rogan et al. (1997a)
Ross 13 *	28/09/1994	Mayo	170	34.17	M	M	54.21	-9.15	Rogan et al. (1997a)
Ross 14 *	28/09/1994	Mayo	221	63.84	F	M	54.21	-9.15	Rogan et al. (1997a)
Ross 15 *	28/09/1994	Mayo	218	61.79	F	M	54.21	-9.15	Rogan et al. (1997a)
Ross 16 *	28/09/1994	Mayo	249	84.82	M	M	54.21	-9.14	Rogan et al. (1997a)
Ross 17 *	28/09/1994	Mayo	158	28.70	F	M	54.21	-9.16	Rogan et al. (1997a)
Ross 18 *	28/09/1994	Mayo	256	90.61	M	M	54.21	-9.16	Rogan et al. (1997a)
Ross 19 *	28/09/1994	Mayo	256	90.61	M	M	54.21	-9.16	Rogan et al. (1997a)
WSDcc	26/03/1995	Sligo	228	68.76	NA	St	54.21	-9.10	Berrow & Rogan (1997)
WSD 3/95	30/03/1995	Kerry	254	88.93	M	St	52.28	-9.88	Berrow & Rogan (1997)
WSD 2/95	05/04/1995	Cork	199	49.73	F	St	51.65	-10.07	Berrow & Rogan (1997)
WSD 1/95	05/04/1995	Cork	216	60.45	M	St	51.64	-9.90	Berrow & Rogan (1997)
WSD B/95	10/05/1995	Donegal	NA	NA	NA	St	54.88	-8.39	Cotton et al. (1995) Berrow & Rogan (1997)
WSD 1/96*	15/06/1996	Donegal	249	84.82	F	St	55.07	-8.33	Bruton & Rogan (1996)
DOL T3H4 *	30/08/1996	SW Ireland	137	20.43	F	BC	52.80	-13.13	UCC
WSD A/96	26/09/1996	Galway	200	50.32	NA	St	53.38	-9.92	Price & Fairley (1996)

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WSD 1/97*	19/03/1997	Cork	182	40.20	M	St	51.63	-9.79	Bruton & Rogan (1997)
WSD 3/97	04/04/1997	Donegal	129.5	17.88	NA	St	54.87	-8.39	Bruton & Rogan (1997)
WSD A/97	04/04/1997	Galway	234	73.15	NA	St	53.60	-9.98	Bruton & Rogan (1997)
WSD 2/97	12/04/1997	Kerry	216	60.45	M	BC	52.15	-10.46	UCC
WSD 4/97	--/05/1997	Donegal	180	39.15	NA	St	55.10	-8.31	UCC
WSD 1/98	--/03/1998	Galway	261	94.88	M	St	53.60	-9.98	Bruton & Rogan (1998)
WSD 2a/98	26/03/1998	Sligo	239	76.93	M	St	54.28	-9.05	Rendle & Rogan (2001)
WSD 2/98	15/04/1998	Mayo	178	38.13	F	St	53.79	-9.59	Rendle & Rogan (2001)
WSD 3/98*	10/05/1998	Louth	250	85.63	M	St+	53.78	-6.23	Bruton & Rogan (1998)
WSD 4/98†	17/05/1998	Louth	223	65.22	M	St+	53.90	-6.36	Rendle & Rogan (2001)
WSD a/98	15/07/1998	Galway	261	94.88	M	S	53.48	-10.02	Bruton & Rogan (1998)
Major 1/98*	28/10/1998	Mayo	169	33.69	M	St+	53.83	-9.60	Rogan et al. (2002)
Major 2/98*	28/10/1998	Mayo	230	70.21	F	St+	53.83	-9.60	Rogan et al. (2002)
Major 3/98*	28/10/1998	Mayo	168	33.22	M	St+	53.83	-9.60	Rogan et al. (2002)
Major 4/98*	28/10/1998	Mayo	231	70.94	F	St+	53.83	-9.59	Rogan et al. (2002)
Major 5/98*	28/10/1998	Mayo	242	79.25	M	St+	53.83	-9.59	Rogan et al. (2002)
WSD B/98	22/12/1998	Donegal	245	81.61	M	St	55.17	-7.89	Rendle & Rogan (2001)
WSD b/99	21/03/1999	Donegal	257	91.45	M	St	55.10	-8.31	Rendle & Rogan (2001)
WSD c/99	24/03/1999	Antrim	190.5	44.82	F	St	55.22	-6.53	Rendle & Rogan (2001)
WSD a/99†	05/10/1999	Donegal	245	81.61	M	St+	55.17	-7.89	UCC
WSD A/00	29/02/2000	Galway	253	88.10	M	St	53.41	-10.17	Murphy & Rogan (2004)
WSD E/00	14/03/2000	Clare	176	37.11	M	BC	53.01	-9.40	Murphy & Rogan (2004)
WSD B/00	05/03/2000	Clare	c243.8	80.66	NA	St	53.10	-9.29	Murphy & Rogan (2004)
WSD 1/00*	15/03/2000	Clare	170	34.17	M	BC	53.01	-9.40	Murphy & Rogan (2004)
WSD C/00	23/04/2000	Clare	>200	50.32	NA	BC	52.68	-9.64	Murphy & Rogan (2004)
WSD D/00	22/11/2000	Mayo	213	58.47	F	St	54.10	-10.06	Murphy & Rogan (2004)
WSD A/01	26/12/2001	Mayo	Adult	NA	F	St	54.24	-9.21	UCC
WSD 1/02*	15/02/2002	Mayo	142.5	22.44	M	St	54.21	-10.05	Murphy & Rogan (2005)
WSD A/02	22/02/2002	Galway	144	23.013	F	St	53.61	-9.83	Murphy & Rogan (2005)
WSD B/02	28/02/2002	Galway	227	68.04	NA	St	53.39	-9.91	Murphy & Rogan (2005)
WSD C/02	01/03/2002	Mayo	213	58.47	NA	St	54.11	-10.21	Murphy & Rogan (2005)

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WSD 2/02*	15/03/2002	Mayo	258	92.30	M	St+	54.20	-10.08	Murphy & Rogan (2005)
WSD 3/02	15/03/2002	Mayo	191	45.10	M	St+	54.20	-10.09	Murphy & Rogan (2005)
WSD A/03	19/03/2002	Mayo	226	67.33	M/NA	St	54.17	-10.08	Murphy & Rogan (2005)
WSD D/02	04/05/2002	Mayo	228	68.76	NA	St	53.89	-9.74	Murphy & Rogan (2005)
WSD E/02	26/12/2002	Waterford	213	58.47	M	St	52.15	-7.13	Murphy & Rogan (2005)
WSD D/03	17/03/2003	Mayo	226	67.33	M	St	54.22	-10.06	Brophy et al. (2006)
WSD B/03	24/03/2003	Mayo	242	79.25	M	St	54.13	-10.12	Brophy et al. (2006)
WSD C/03	30/08/2003	Galway	210	56.53	NA	St	53.24	-9.29	Brophy et al. (2006)
WSD A/04	13/01/2004	Mayo	172	35.13	M	St	54.11	-10.12	www.iwdg.ie
WSD 1/04*	17/01/2004	Sligo	170	34.17	F	St	54.25	-8.62	Philpott et al. (2004)
WSD B/04	18/02/2004	Mayo	NA	NA	NA	St	54.09	-10.11	Philpott et al. (2004)
WSD C/04	17/03/2004	Mayo	240	77.70	M	St	54.10	-10.05	Philpott et al. (2004)
WSD D/04	24/07/2004	Kerry	185	41.79	NA	St	52.30	-10.00	Philpott et al. (2004)
WSD E/04	20/09/2004	Mayo	240	77.70	M	St	54.22	-10.05	UCC
WSD A/05	22/02/2005	Kerry	224	65.92	NA	St	52.37	-9.83	Philpott & Rogan (2007)
WSD B/05	12/03/2005	Antrim	165	31.82	F	St	55.20	-6.22	Philpott & Rogan (2007)
WSD 1/05*	06/05/2005	Mayo	236	74.65	F	St	54.09	-10.11	UCC
WSD C/05	11/06/2005	Donegal	230	70.21	M	St	54.61	-8.58	Philpott & Rogan (2007)
WSD D/05	06/12/2005	Clare	253	88.10	NA	St+	52.68	-9.64	Philpott & Rogan (2007)
WSD E/05	30/12/2005	Kerry	213	58.47	NA	St	52.24	-10.09	Philpott & Rogan (2007)
WSD F/05	31/12/2005	Kerry	244	80.82	M	St	52.24	-9.84	Philpott & Rogan (2007)
	17/02/2006	Galway	280	112.17	M	St	53.44	-10.13	O'Connell & Berrow (2007)
	24/02/2006	Donegal	c150	25.36	NA	St	54.62	-8.55	O'Connell & Berrow (2007)
	06/04/2006	Galway	130	18.03	M	St	53.45	-10.13	O'Connell & Berrow (2007)
	30/05/2006	Galway	210	56.53	F	A?	53.57	-9.98	O'Connell & Berrow (2007)
	19/06/2006	Galway	270	102.86	M	St	53.60	-10.03	O'Connell & Berrow (2007)
	10/07/2006	Down	NA	NA	NA	St	54.45	-5.43	O'Connell & Berrow (2007)
WSD 1/06*	25/07/2006	Kerry	241	78.47	M	St	52.13	-10.29	O'Connell & Berrow (2007)
	03/01/2007	Donegal	250	85.63	M	St+	55.13	-7.46	O'Connell & Berrow (2008)
	24/01/2007	Donegal	c200	50.32	NA	St+	55.15	-8.13	O'Connell & Berrow (2008)
	15/05/2007	Kerry	c250	85.63	NA	St+	52.24	-10.15	O'Connell & Berrow (2008)

APPENDIX III. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	16/05/2007	Kerry	c200-250	66.62	NA	St+	52.30	-10.04	O'Connell & Berrow (2008)
	01/06/2007	Derry	220	63.15	NA	St	55.17	-6.88	O'Connell & Berrow (2008)
	07/07/2007	Derry	c200	50.32	F	St+	55.16	-6.82	O'Connell & Berrow (2008)
	10/07/2007	Donegal	260	94.02	M	St+	55.19	-7.83	O'Connell & Berrow (2008)
	28/07/2007	Kerry	c250	85.63	NA	St	52.12	-9.97	O'Connell & Berrow (2008)
	04/09/2007	Kerry	230	70.21	NA	St	52.30	-10.01	O'Connell & Berrow (2008)
	07/09/2007	Galway	240	77.70	M	St+	53.16	-8.95	O'Connell & Berrow (2008)
	08/09/2007	Donegal	NA	NA	NA	St+	55.00	-8.41	O'Connell & Berrow (2008)
	21/10/2007	Antrim	c280	112.17	NA	St	54.99	-5.99	O'Connell & Berrow (2008)
	13/11/2007	Kerry	c200	50.32	NA	St	52.37	-9.83	O'Connell & Berrow (2008)
WSD 1/08	02/04/2008	Kerry	253	88.10	M	St	52.13	-9.98	O'Connell & Berrow (2009)
WSD 2/08	05/04/2008	Mayo	280	112.17	M	St	53.74	-9.89	O'Connell & Berrow (2009)
WSD 3/08	05/05/2008	Galway	c250	85.63	NA	St	53.62	-10.25	O'Connell & Berrow (2009)
WSD 4/08	06/05/2008	Sligo	254	88.93	M	St	54.33	-8.64	O'Connell & Berrow (2009)
WSD 5/08	20/06/2008	Donegal	NA	NA	NA	St	55.02	-7.54	O'Connell & Berrow (2009)
	02/07/2008	Mayo	c220	63.15	M	St	53.67	-9.90	O'Connell & Berrow (2009)
WSD 7/08	14/07/2008	Donegal	c130	18.03	NA	St+	55.25	-7.69	O'Connell & Berrow (2009)
WSD 6/08	14/07/2008	Galway	250	85.63	M	St	53.21	-8.91	O'Connell & Berrow (2009)
WSD 7/08	07/12/2008	Sligo	c243	80.03	NA	BC	54.35	-8.67	O'Connell & Berrow (2009)
WSD 1/09	19/02/2009	Galway	270	102.86	F	St	53.54	-10.14	O'Connell & Berrow (2010)
WSD 2/09	01/05/2009	Galway	260	94.02	M	St	53.44	-10.07	O'Connell & Berrow (2010)
	Average		**225.8**	**69.7**					

APPENDIX IV. White-beaked dolphin stranding and by-caught records in Ireland. * Stomach contents analyzed. § foetus of WBD 2/93. c=length without a part of the animal; F: female; M: male; St: Stranded, St+: stranded alive, BC: by caught. Lat: Latitude, long: longitude. Length in cm and weight in Kg

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	05/09/1851	Dublin	NA	NA	NA	BC	53.37	-6.14	Moffat (1937/1938) O'Riordan (1972)
	17/04/1883	Down	NA	NA	NA	St	54.66	-5.56	Scharff (1900) O'Riordan (1972)
	.--/--/1889	Galway	NA	NA	NA	St	53.25	-9.06	Moffat (1937/1938) O'Riordan (1972)
	17/12/1901	Dublin	365.8	211.98	M	St	53.38	-6.11	Scharff (1902) O'Riordan (1972)
	01/08/1907	Donegal	NA	NA	NA	St	55.20	-7.62	O'Riordan (1972)
	23/03/1917	Donegal	259.0	93.16	NA	St	55.19	-7.89	O'Riordan (1972)
	26/08/1931	Waterford	NA	NA	NA	St	52.09	-7.61	O'Riordan (1972)
	31/07/1976	Kerry	275.0	107.46	NA	BC	52.19	-10.38	UCC
	23/08/1982	Cork	120.0	14.91	NA	St	51.83	-8.02	Egan (1984)
	23/08/1982	Cork	NA	NA	F	St	51.84	-8.02	Egan (1984)
	21/08/1983	Cork	254.0	88.94	M	St	51.91	-7.89	Smiddy (1991)
	15/04/1989	Cork	213.0	58.47	NA	St	51.58	-8.71	Dorman & Sleeman (1990)
	29/12/1990	Down	210.0	56.53	F	St	54.08	-6.19	Bruton & Berrow (1992)
WBD 1/93	06/05/1993	Kerry	c228	68.77	F	St	51.84	-10.19	Bruton & Berrow (1994)
WBD 2/93*	06/05/1993	Kerry	239.0	76.93	F	St	52.23	-9.91	Bruton & Berrow (1994)
WBD 3/93§	06/05/1993	Kerry	110.5	12.25	F	St	52.23	-9.91	Bruton & Berrow (1994)
WBD 1/94	11/02/1994	Cork	297.0	129.08	F	St	51.64	-9.60	Bruton & Rogan (1995)
WSD 1/96*	25/04/1996	Mayo	198.5	49.44	M	St	54.16	-10.09	Bruton & Rogan (1996)
WBD a/00	--/11/2000	Leitrim	200.0	50.33	NA	St	54.47	-8.32	Lynch & Cotton (2003) Murphy & Rogan (2004)
WBD A/03	06/03/2003	Mayo	180.0	39.16	M	St	54.15	-10.07	Brophy et al. (2006)
WBD 1/04*	17/01/2004	Mayo	215.0	59.79	M	St	53.97	-10.08	Philpot et al. (2004)
WBD A/04	06/02/2004	Kerry	c235	73.90	NA	St	52.13	-9.97	Berrow et al. (2007)
	06/02/2004	Kerry	250.0	85.64	NA	St	52.14	-9.99	Philpott et al. (2007)
WBD B/04	12/12/2004	Galway	176.0	37.12	F	St	53.56	-10.13	Philpot et al. (2007)

APPENDIX IV. *Cont*.

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
WBD A/05	04/09/2005	Clare	NA	NA	NA	St	52.59	-9.87	Berrow et al. (2007)
WBD B/05	13/08/2005	Donegal	NA	NA	F	St	54.61	-8.16	UCC
	23/02/2006	Mayo	NA	NA	NA	St	54.19	-10.04	O'Connel & Berrow (2007)
	03/03/2006	Kerry	234.0	73.15	M	St	52.30	-10.04	O'Connel & Berrow (2007)
	29/09/2006	Sligo	NA	NA	NA	St	54.44	-8.47	O'Connel & Berrow (2007)
	25/03/2007	Antrim	225.0	66.63	M	St	55.22	-6.53	O'Connell & Berrow (2008)
	15/08/2007	Donegal	225.0	66.63	F	St	54.48	-8.28	O'Connell & Berrow (2008)
WBD 1/08	30/10/2008	Kerry	c160	29.58	M	St	51.84	-10.21	O'Connell & Berrow (2009)
WBD 2/08	23/12/2008	Galway	200.0	50.33	NA	St+	53.41	-10.08	O'Connell & Berrow (2009)
WBD 1/09	30/05/2009	Mayo	c200	50.33	NA	St	53.96	-10.05	O'Connell & Berrow (2010)
WBD 2/09	22/10/2009	Donegal	300.0	132.21	M	St	54.87	-8.38	O'Connell & Berrow (2010)
	22/11/2011	Sligo	254	88.94	F	st			www.iwdg.ie
	Average		**224.0**	**71.99**					

Appendix V. Bottlenose dolphin stranding and by-caught records in Ireland. § Stomach contents analyzed. + *Berrow & Rogan Mamm Rev 27(1) 1997; St= Stranded, St+= stranded alive, BC=by-caught, Ki= killed; F=female; M=male; c=length without a part of the animal. Lat: latitude, Long: longitude. Length in cm and weight in kg

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
--/--/1829	Celtic Sea	NA	NA	NA	BC	NA	NA	Moffat (1937/1938) Scott (1960)
--/--/1892	Celtic Sea	NA	NA	NA	NA	NA	NA	Moffat (1937/1938) Scott (1960)
8/12/1895	Down	320	468	NA	St	54.26	-5.59	Scott (1960) Patterson (1900)
28/04/1905	Dublin	320	468	F	BC	53.34	-6.19	Scharff (1905)
28/04/1905	Dublin	300	346.7	F	BC	53.34	-6.19	Scharff (1905)
--/--/1913	Galway	NA	NA	M	Ki	53.22	-9.05	O’Riordan (1981)
--/--/1913	Galway	NA	NA	F	Ki	53.22	-9.05	O’Riordan (1981)
7/08/1918	Kerry	NA	NA	NA	BC	52.39	-9.84	O’Riordan (1972)
20/08/1918	Galway	NA	NA	NA	NA	53.25	-9.22	O’Riordan (1972)
26/08/1918	Kerry	NA	NA	NA	BC	52.39	-9.84	O’Riordan (1972)
--/--/1933	Mayo	NA	NA	NA	NA	53.88	-9.95	Scott (1960)
--/--/1933	Mayo	NA	NA	NA	NA	54.20	-10.10	Scott (1960)
--/--/1933	Mayo	NA	NA	NA	NA	53.78	-9.77	Scott (1960)
--/--/1933	Mayo	NA	NA	NA	NA	54.07	-9.97	Scott (1960)
14/05/1945	Mayo	NA	NA	NA	BC	54.22	-9.99	O’Riordan (1972)
5/06/1945	Mayo	NA	NA	NA	BC	54.22	-9.95	O’Riordan (1972)
21/07/1950	Down	NA	NA	NA	BC	NA	NA	O’Riordan (1972)
2/07/1957	Donegal	NA	NA	NA	BC	54.50	-8.26	O’Riordan (1972)
4/07/1957	Donegal	NA	NA	NA	BC	54.60	-8.48	O’Riordan (1972)
25/10/1960	Antrim	210	89.9	M	NA	54.86	-5.80	Scott (1960) Berrow & Rogan (1997)
18/12/1962	Galway	NA	NA	NA	BC	53.25	-8.99	O’Riordan (1972)
2/02/1974	Down	343	660.8	F	NA	54.36	-5.49	Nash (1974) Berrow & Rogan (1997)

Appendix V. *Cont*.

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
17/12/1977	Wexford	335	586.1	NA	NA	52.67	-6.21	O'Riordan (1982)
19/08/1978	Wexford	NA	NA	NA	NA	52.19	-6.49	O’Riordan (1979) Berrow & Rogan (1997)
27/07/1981	Wexford	NA	NA	NA	NA	52.34	-6.46	O'Riordan (1982)
28/08/1985	Limerick	300	346.7	NA	NA	52.57	-9.30	O’Connor & Fairle (1996)
23/08/1987	Waterford	360-480	852.7-5158.8	NA	NA	51.96	-7.71	Smiddy (1989b) Berrow & Rogan (1997)
28/10/1988	Down	300	346.7	F	St	54.06	-5.99	Bruton & Berrow (1992) Berrow & Rogan (1997)
31/03/1989	Sligo	250	163.8	NA	St	54.27	-8.61	Cotton (1989) Berrow & Rogan (1997)
15/04/1989	Sligo	290	298.4	NA	St	54.29	-8.94	Cotton (1989) Berrow & Rogan (1997)
23/04/1989	Kerry	c400	~1553.8	NA	St	52.09	-9.97	Berrow & Rogan (1997)
24/06/1989	Sligo	370	990.7	NA	NA	54.25	-8.64	Cotton (1989) Berrow & Rogan (1997)
19/07/1989	Sligo	145	33.9	NA	St	54.27	-8.73	Bruton & Rogan (1995) Berrow & Rogan (1997)
8/04/1991	Clare	c262	~196.1	NA	St	52.78	-9.48	Dorman et al. (1991a) Berrow & Rogan (1997)
13/06/1991	Cork	c366	~933.0	NA	NA	51.56	-7.99	Dorman et al. (1991a) Berrow & Rogan (1997)
19/07/1991	Sligo	NA	NA	NA	NA	54.26	-8.73	Bruton & Berrow (1992) Berrow & Rogan (1997)
23/08/1991	Cork	277	245.5	F	St	51.63	-10.07	Bruton & Berrow (1992) Berrow & Rogan (1997)
14/03/1992	Antrim	290	298.4	M	St	55.21	-6.22	Bruton & Berrow (1992) Berrow & Rogan (1997)
29/04/1992	Cork	290	298.4	M	St	21.56	-9.76	Bruton & Berrow (1993) Berrow & Rogan (1997)

Appendix V. *Cont*.

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
15/11/1992	Donegal	299	341.5	M	St+	55.19	-7.83	IWDG (1993) Berrow & Rogan (1997)
29/04/1993	Porcupine	300-400	346.7-1553.8	M	BC	49-02’	12-51’	Berrow & Rogan (1998)
19/06/1993	Limerick	257	181.9	M	St	52.57	-9.36	O’Connor &Fairley (1996) Berrow & Rogan (1997)
23/08/1993	Clare	c200	~77.4	F	St	52.58	-9.73	Bruton & Berrow (1994) Berrow & Rogan (1997)
3/9/1993	Porcupine	300-400	346.7-1553.8	M	BC	49-02’	12-51’	Berrow & Rogan (1998)
19/10/1994	Mayo	301	351.9	M	St	54.24	-9.19	BND 1/94
7/09/1996§	Porcupine	206	84.6	F	BC	51.30	-13.03	JB T3H6
13/09/1996	Porcupine	176	54.0	M	BC	50.97	-12.07	MW T6H4 BND 2/96
13/09/1996	Porcupine	188	64.6	F	BC	50.97	-12.07	MW T6H4 BND 1/96
16/06/1997	Kerry	NA	NA	NA	St	52.24	-10.11	BND a/97
24/07/1997	Clare	343	660.8	F	St	52.61	-9.71	BND 1/97
11/03/1998	Clare	310	402.8	F	NA	52.68	-9.66	Rendle & Rogan (2001)
17/03/1999§	Cork	309	396.8	M	St+	51.65	-10.06	Rendle & Rogan (2001)
1/06/1999	Mayo	NA	NA	NA	NA	53.97	-10.06	BND a/99. Skull with flesh
18/06/1999	Cork	Large	NA	NA	St+	51.64	-8.70	BND b/99. Refloated and found dead 21st. Washed out
18/06/1999	Cork	small	NA	NA	St+	51.64	-8.70	BND c/99. Refloated and found dead 21st. Washed out
3/07/1999	Cork	~335	586.1	NA	St	51.65	-8.58	BND d/99 P.Whooley.Buried
19/07/1999§	Clare	330	543.7	M	NA	52.92	-9.35	Rendle & Rogan (2001)
19/08/1999	Clare	270	221.1	M	St	52.61	-9.40	Berrow et al. (2007) Rendle & Rogan (2001)
22/02/2000	Kerry	NA	NA	NA	St	52.16	-10.46	BND A/00
8/03/2000	Clare	300	346.7	NA	St	52.72	-9.62	Murphy & Rogan (2004)
7/08/2000	Antrim/Kerry	NA	NA	NA	St			BND C/00

Appendix V. *Cont*.

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
23/11/2000	Mayo	NA	NA	F	St	53.76	-9.90	Murphy & Rogan (2004)
12/01/2001	Donegal	c270	~221.1	NA	NA	54.61	-8.62	Murphy & Rogan (2004)
24/07/2001§	Donegal	340	631.7	M	St+	54.96	-7.68	Murphy & Rogan (2004)
29/07/2001	Clare	NA	NA	M	St	52.61	-9.52	Murphy & Rogan (2004)
28/08/2001§	Clare	320	468.0	F	St	52.74	-9.53	Murphy & Rogan (2004)
18/09/2001	Sligo	140	31.5	M	St	54.33	-8.52	Berrow et al. (2007)
28/09/2001	Mayo	340	631.7	F	St	54.26	-9.89	Murphy & Rogan (2004)
5/10/2001	Kerry	288	289.6	F	St+	52.13	-10.37	Murphy & Rogan (2004)
10/07/2002§	Clare	280	256.8	F	St	52.73	-9.52	Murphy & Rogan (2004)
30/07/2002	Mayo	290	298.4	NA	St	54.05	-9.91	BND B/02
4/11/2002	Mayo	NA	NA	F	St	54.10	-9.85	Murphy & Rogan (2004)
16/03/2003	Donegal	c274	~234.7	NA	St	55.16	-8.11	Brophy et al. (2006), BND A/03
6/11/2003	Mayo	c200	~77.4	NA	St	54.22	-9.18	Berrow et al. (2007)
6/11/2003	Mayo	311	408.9	M	St	54.28	-9.24	Brophy et al. (2006)
24/12/2003	Waterford	c150	~36.5	NA	St+	52.16	-7.13	Berrow et al. (2007)
14/04/2004	Mayo	310	402.8	NA	St	53.72	-9.90	Philpott et al. (2007)
5/06/2004	Galway	350	734.0	NA	St	53.53	-10.17	Philpott et al. (2007)
24/06/2004	Waterford	275	238.3	M	St	52.04	-7.57	Philpott et al. (2007)
24/08/2004	Donegal	NA	NA		St	54.34	-8.52	UCC
22/09/2004	Kerry	295	321.7	M	St	52.27	-10.02	Philpott et al. (2007)
3/10/2004	Antrim	c260	~190.3	NA	St	55.21	-6.56	Philpott et al. (2007)
20/10/2004	Galway	330	543.7	M	St	53.42	-10.41	Philpott et al. (2007)
1/11/2004	Galway	370	990.7	M	St	53.40	-9.91	Philpott et al. (2007)
21/11/2004	Mayo	250	163.8	F	St	54.16	-10.09	Philpott et al. (2007)
22/11/2004	Mayo	NA	NA	NA	St	53.73	-9.89	Philpott et al. (2007)
20/12/2004	Galway	255	176.5	M	St	53.56	-10.11	Philpott et al. (2007)
7/01/2005	Cork	c300	~346.7	NA	St	51.63	-10.06	Philpott & Rogan (2007)
21/02/2005	Mayo	c400	~1553.8	NA	St	54.16	-10.10	Philpott & Rogan (2007)

Appendix V. *Cont*.

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
23/04/2005§	Galway	340	631.7	M	St+	53.12	-9.68	O’Brien & Berrow (2007) Philpott & Rogan (2007)
31/05/2005	Clare	c300	~346.7	NA	St	52.74	-9.53	Philpott & Rogan (2007)
25/07/2005	Kerry	NA	NA	F	St	52.58	-9.37	Philpott & Rogan (2007)
15/08/2005§	Clare	250	163.8	F	St	52.74	-9.53	Philpott & Rogan (2007)
29/09/2005	Clare	NA	NA	M	St	52.59	-9.74	Philpott & Rogan (2007)
30/12/2005	Cork	250	163.8	F	St	51.59	-8.87	Philpott & Rogan (2007)
2/04/2006	Kerry	197	74.0	M	St	52.28	-9.84	O’Connell & Berrow (2007)
17/07/2006	Clare	NA	NA	Na	St	52.63	9.58	O’Connell & Berrow (2007)
28/08/2006	Kerry	c180	~57.3	NA	St	51.83	-10.18	O’Connell & Berrow (2007)
8/09/2006	Galway	247	156.6	F	St+	53.21	-8.99	O’Connell & Berrow (2007)
11/09/2006	Kerry	256	179.2	M	St	52.12	-10.22	O’Connell & Berrow (2007)
3/11/2006	Kerry	274	234.7	M	St	52.39	-9.86	O’Connell & Berrow (2007)
24/01/2007	Antrim	c340	~631.7	F	St			O’Connell & Berrow (2008)
2/02/2007	Galway	320-335	468-586.1	NA	St			O’Connell & Berrow (2008)
11/03/2007	Kerry	235	130.8	M	St			O’Connell & Berrow (2008)
18/03/2007	Donegal	NA	NA	NA	St			O’Connell & Berrow (2008)
5/09/2007	Sligo	NA	NA	NA	NA			O’Connell & Berrow (2008)
15/12/2007	Donegal	c300	~346.7	NA	St+			O’Connell & Berrow (2008)
18/12/2007	Mayo	NA	NA	NA	St			O’Connell & Berrow (2008)
21/12/2007	Kerry	232	125.0	F	BC			O’Connell & Berrow (2008)
13/01/2008	Waterford	c250	~163.8	NA	St	52.14	-7.18	O’Connell & Berrow (2009)
2/06/2008	Kerry	240	141.0	M	St	52.25	-10.08	O’Connell & Berrow (2010)
14/07/2008	Donegal	250-300	163.8-346.7	NA	St	55.32	-7.35	O’Connell & Berrow (2010)
3/10/2008§	Galway	310	402.8	M	St+	53.28	-9.55	O’Connell & Berrow (2010)
1/12/2008	Antrim	250	163.8	F	St+	55.51	-6.24	O’Connell & Berrow (2010)
9/12/2008	Galway	c300	~346.7	M	St	53.57	-10.01	O’Connell & Berrow (2010)
10/03/2009	Clare	213	94.0	M	St	52.81	-9.47	O’Connell & Berrow (2010)
14/03/2009	Cork	NA	NA	NA	St+	51.52	-9.17	O’Connell & Berrow (2010)

Appendix V. *Cont*.

Date	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
23/04/2009	Donegal	240	141.0	NA	St+	55.14	-7.53	O’Connell & Berrow (2010)
4/06/2009	Cork	304	368.1	F	St	51.57	-9.01	O’Connell & Berrow (2010)
10/07/2009	Kerry	NA	NA	NA	St+	52.27	-9.79	O’Connell & Berrow (2010)
12/07/2009	Kerry	282	264.7	M	St	52.27	-9.79	O’Connell & Berrow (2010)
13/07/2009	Kerry	NA	NA	NA	St	52.28	-9.87	O’Connell & Berrow (2010)
21/07/2009	Kerry	280	256.8	M	St	52.23	-9.93	O’Connell & Berrow (2010)
21/07/2009	Kerry	290	298.4	M	St	52.23	-9.93	O’Connell & Berrow (2010)
31/07/2009	Sligo	115	21.6	NA	St	54.37	-8.62	O’Connell & Berrow (2010)
14/08/2009	Kerry	321	475.1	M	St+	52.25	-10.16	O’Connell & Berrow (2010)
23/08/2009	Kerry	c300	~346.7	NA	NA	52.28	-9.87	UCC
24/08/2009	Kerry	NA	NA	M	St	52.30	-10.04	O’Connell & Berrow (2010)
27/09/2009	Donegal	NA	NA	NA	St	55.29	-7.27	O’Connell & Berrow (2010)
22/12/2009	Kerry	270	221.1	NA	St	52.25	-10.10	O’Connell & Berrow (2010)
11/10/2010	Mayo	c350	~734.0	NA		53.97	-10.07	www.iwdg.ie
18/10/2010	Mayo	180	57.3	M		53.74	-9.86	www.iwdg.ie
2/12/2010	Clare	120	23.3	F	St+	53.02	-9.04	www.iwdg.ie
16/02/2011	Mayo	NA	NA	NA		53.97	-10.05	www.iwdg.ie
17/05/2011§	Clare	300	346.7	F		52.68	-9.65	www.iwdg.ie
1/06/2011	Cork	340	631.7	M	St+	51.66	-9.86	www.iwdg.ie
4/06/2011	Kerry	224	110.9	M		52.26	-10.01	www.iwdg.ie
26/09/2011	Donegal	NA	NA	NA		55.19	-7.96	www.iwdg.ie
21/10/2011	Galway	320	468.0	M	St	53.25	-8.99	www.iwdg.ie
12/11/2011	Dublin	150	36.5	NA	St	53.41	-6.12	www.iwdg.ie
27/01/2012	Galway	340	631.7	F	St	53.25	-9.20	www.iwdg.ie
8/02/2012	Kerry	240	141.0	F	St	52.13	-10.36	www.iwdg.ie
14/02/2012	Kerry	240	141.0	F	St	52.37	-9.83	www.iwdg.ie
Average		**279.6**	**382.3**	**31F:41M**				

APPENDIX VI. Harbour porpoise stranding and by-caught records in Ireland. c=length without a part of the animal or approximately reported length; Sex record: F: female; M: male; U: Unknown. St/BC: stranding or by caught record: St: Stranded, St+: stranded alive, BC: by-caught., BC*: by caught suspected during post mortem. Lat: Latitude, long: longitude. Length in cm and weigh in Kg. (#, estimated weight using an estimated length)

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	27/03/1914	Dublin	91	10.41	U	St	53.57	-6.09	Anon. 1915 Berrow & Rogan 1997
	29/03/1914	Clare	152	45.86	U	St	52.72	-9.62	Anon. 1915 Berrow & Rogan 1997
	11/06/1914	Donegal	89	9.763	U	St	55.28	-7.44	Anon. 1915 Berrow & Rogan 1997
	24/07/1914	Dublin	178	72.38	U	St	53.38	-6.13	Berrow & Rogan 1997
	13/07/1916	Wexford	121.92	24.24	U	St	52.19	-6.83	Anon. 1917 Berrow & Rogan 1997
	20/03/1917	Donegal	152	45.86	U	St	55.19	-7.83	Anon. 1918 Berrow & Rogan 1997
	28/07/1918	Kerry	NA	NA	U	St	52.24	-10.16	Greeson, 1966 Berrow & Rogan 1997
	15/11/1919	Waterford	NA	NA	U	St	52.09	-7.61	Ano. 1921 Berrow & Rogan 1997
	08/10/1926	Louth	NA	NA	U	St	53.69	-6.24	Berrow & Rogan 1997
	03/11/1928	Antrim	166	59.15	M	St	54.70	-5.73	O'Riordan, 1976 Berrow & Rogan 1997
	02/09/1930	Wexford	152	45.86	F	St	52.34	-6.46	Berrow & Rogan 1997
	25/07/1931	Wexford	173	66.65	U	St	52.19	-6.83	Berrow & Rogan 1997
	03/06/1932	Wexford	168	61.24	U	St	52.34	-6.46	Berrow & Rogan 1997
	08/06/1934	Antrim	126	26.66	M	St	55.21	-6.22	Berrow & Rogan 1997
	--/06/1945	Dublin	NA	NA	U	St	53.33	-6.21	Berrow & Rogan 1997
	--/08/1955	Donegal	NA	NA	U	St	55.19	-7.83	O'Riordan, 1976 Berrow & Rogan, 1997
	07/09/1956	Down	NA	NA	U	St	54.38	-5.55	O'Riordan, 1976 Berrow & Rogan 1997
	11/02/1958	Down	NA	NA	U	St	54.06	-6.00	O'Riordan, 1976 Berrow & Rogan 1997
	19/01/1959	Derry	NA	NA	U	St	55.17	-6.79	O'Riordan, 1976 Berrow & Rogan 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	14/11/1963	Down	NA	NA	U	St	54.06	-6.00	O'Riordan, 1976 O'Riordan, 1976 Berrow & Rogan 1997
	01/04/1964	Kerry	NA	NA	U	St	52.14	-9.98	Berrow & Rogan 1997
	14/04/1966	Dublin	NA	NA	M	St	53.57	-6.09	Berrow & Rogan 1997
	17/05/1966	Down	NA	NA	U	St	54.68	-5.61	O'Riordan, 1976 Berrow & Rogan 1997
	--/11/1969	Antrim	c135	35.55#	U	BC*	55.20	-6.69	Murphy & Rogan, 2004
	--/06/1971	Galway	160	53.18	F	BC	53.25	-9.15	O'Riordan, 1976 Berrow & Rogan, 1997
	14/08/1972	Dublin	NA	NA	U	St	53.39	-6.11	Berrow & Rogan 1997
	30/09/1973	Down	132	30.5	M	St	54.39	-5.46	Nash, 1974 Berrow & Rogan 1997
	18/05/1974	Down	NA	NA	F	St	54.36	-5.49	Nash, 1974. Nash,.1975 Berrow & Rogan 1997
	23/09/1974	Galway	NA	NA	M	St	53.27	-9.05	O'Riordan, 1976 Berrow & Rogan 1997
	18/08/1975	Antrim	NA	NA	U	St	55.20	-6.66	O'Riordan, 1976 Berrow & Rogan 1997
	27/06/1978	Kerry	150	44.13	U	BC	51.74	-10.12	O'Riordan, 1979 Berrow & Rogan, 1997
	09/05/1980	Dublin	NA	NA	F	St	53.53	-6.09	O'Riordan 1979 Berrow & Rogan 1997
	24/05/1981	Down	79.5	7.045	U	St	54.25	-5.77	McKee, 1982
	18/06/1981	Donegal	c90	10.08#	U	St+	54.48	-8.28	McKee, 1982
	10/01/1982	Cork	c150	44.13#	U	St	51.93	-7.87	Smiddy, 1984 Berrow & Rogan, 1997
	--/04/1982	Kerry	NA	NA	U	St	52.38	-9.83	O'Riordan 1979 Berrow & Rogan 1997
	--/04/1982	Kerry	NA	NA	U	St	52.38	-9.83	O'Riordan 1979 Berrow & Rogan 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	--/04/1982	Kerry	NA	NA	U	St	52.38	-9.83	O'Riordan 1979 Berrow & Rogan 1997
	--/04/1982	Kerry	NA	NA	U	St	52.26	-10.01	O'Riordan 1979 Berrow & Rogan 1997
	--/04/1982	Kerry	NA	NA	U	St	52.14	-9.98	O'Riordan 1979 Berrow & Rogan 1997
	--/04/1982	Kerry	NA	NA	U	St	52.148	-9.98	O'Riordan 1979 Berrow & Rogan 1997
	20/01/1983	Cork	131	29.84	U	St	51.91	-7.89	Smiddy, et al., 1984
	23/02/1983	Cork	c183	78.41#	M	St	51.86	-8.01	Smiddy, et al., 1984
	23/02/1983	Cork	c122	24.29#	U	St	51.86	-8.01	Smiddy, et al., 1984
	23/02/1983	Cork	c160	53.18#	U	St	51.86	-8.01	Smiddy, et al., 1984
	24/03/1983	Wexford	130	29.18	U	St	52.19	-6.54	O'Riordan, 1984 Berrow & Rogan. 1997
	15/05/1983	Down	176	70.05	F	St	54.25	-5.68	Berrow & Rogan, 1997
	17/11/1983	Cork	126	26.66	F	St	51.89	-7.87	Smiddy, et al., 1984 Berrow & Rogan, 1997
	26/11/1983	Waterford	c122	24.29#	M	St	52.16	-7.13	Smiddy, et al., 1984 Berrow & Rogan, 1997
	26/11/1983	Waterford	c137	33.96#	M	St	52.16	-7.13	Smiddy, et al., 1984 Berrow & Rogan, 1997
	06/12/1983	Cork	c135	32.55#	M	St	51.85	-8.01	Smiddy, et al., 1984 Berrow & Rogan, 1997
	06/12/1983	Cork	c150	44.13#	M	St	51.86	-8.01	Smiddy, et al., 1984 Berrow & Rogan, 1997
	06/12/1983	Cork	c135	32.55#	M	St	51.86	-8.00	Smiddy, et al., 1984 Berrow & Rogan, 1997
	06/12/1983	Cork	123	24.87	M	St	51.86	-8.00	Smiddy, et al., 1984 Berrow & Rogan, 1997
	07/12/1983	Waterford	136	33.25	M	St	51.95	-7.72	Smiddy, et al., 1984 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	12/12/1983	Cork	c150	44.13#	M	St	51.51	-8.13	Smiddy, et al., 1984 Berrow & Rogan, 1997
	12/12/1983	Cork	c120	23.16#	U	St	51.80	-8.18	Smiddy, et al., 1984 Berrow & Rogan, 1997
	20/12/1983	cork	c155	48.52#	M	St	51.91	-7.89	Smiddy, et al., 1984 Berrow & Rogan, 1997
	20/12/1983	Cork	c120	23.16#	F	St	51.91	-7.89	Smiddy, et al., 1984 Berrow & Rogan, 1997
	20/12/1983	Cork	c125	26.06#	M	St	51.94	-7.85	Smiddy, et al., 1984 Berrow & Rogan, 1997
	28/03/1984	Cork	165	58.13	F	St	51.86	-8.01	Berrow & Rogan, 1997
	30/09/1984	Wexford	NA	NA	U	St	52.21	-6.80	www.iwdg.ie
	09/12/1984	Dublin	NA	NA	U	St	53.57	-6.09	www.iwdg.ie
	09/01/1985	Cork	c150	44.13#	F	St	51.86	-8.00	Smiddy, 1985 Berrow & Rogan, 1997
	07/02/1985	Cork	130	29.18	F	St	51.85	-8.01	Smiddy, 1985 Berrow & Rogan, 1997
	07/02/1985	Cork	140	36.16	F	St	51.85	-8.01	Smiddy, 1985 Berrow & Rogan, 1997
	19/02/1985	Waterford	c137	33.96#	F	St	51.95	-7.72	Smiddy, 1985 Berrow & Rogan, 1997
	21/02/1985	Cork	c130	29.18#	M	St	51.86	-8.01	Smiddy, 1985 Berrow & Rogan, 1997
	27/09/1985	Waterford	c175	68.91#	F	St	51.95	-7.72	Smiddy, 1986 Berrow & Rogan, 1997
	04/10/1985	Cork	c152	45.86#	U	St	51.94	-7.85	Smiddy, 1986 Berrow & Rogan, 1997
	23/10/1985	Cork	c168	61.24#	U	St	51.87	-7.98	Smiddy, 1986 Berrow & Rogan, 1997
	28/10/1985	Waterford	c152	45.86#	F	St	51.95	-7.77	Smiddy, 1986 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	31/10/1985	Cork	c152	45.86#	U	St	51.91	-7.89	Smiddy, 1986 Berrow & Rogan, 1997
	21/11/1985	Waterford	206	110.4	F	St	52.09	-7.61	Smiddy, 1986
	--/12/1985	Cork	NA	NA	U	St	51.81	-8.11	Berrow & Rogan, 1997
	27/01/1986	Cork	c132	30.5#	F	St	51.94	-7.85	Smiddy, 1986 Berrow & Rogan, 1997
	14/02/1986	Cork	124	25.46	F	St	51.93	-7.87	Smiddy, 1986 Berrow & Rogan, 1997
	07/03/1986	Cork	NA	NA	U	St	51.86	-8.01	Smiddy, 1986
	27/06/1986	Cork	c183	78.41#	U	St	51.95	-7.83	Smiddy, 1987 Berrow & Rogan, 1997
	08/09/1986	Cork	c160	53.18#	M	St	51.87	-7.98	Smiddy, 1987 Berrow & Rogan, 1997
	17/10/1986	Cork	c130	29.18#	M	St	51.87	-7.98	Smiddy, 1987 Berrow & Rogan, 1997
	05/12/1986	Cork	c152	45.86#	U	St	51.81	-8.07	Smiddy, 1987 Berrow & Rogan, 1997
	21/01/1987	Cork	c168	61.24#	F	St	51.94	-7.85	Smiddy, 1987 Berrow & Rogan, 1997
	21/01/1987	Waterford	c122	24.29#	M	St	51.95	-7.77	Smiddy, 1987 Berrow & Rogan, 1997
	29/01/1987	Waterford	NA	NA	M	St	51.95	-7.72	Smiddy, 1987 Berrow & Rogan, 1997
	30/01/1987	Cork	c137	33.96#	F	St	51.80	-8.18	Smiddy, 1987 Berrow & Rogan, 1997
	02/02/1987	Cork	c152	45.86#	M	St	51.87	-7.98	Smiddy, 1987 Berrow & Rogan, 1997
	05/02/1987	Cork	120	23.16	M	St	51.94	-7.85	Smiddy, 1987 Berrow & Rogan, 1997
	11/03/1987	Cork	c130	29.18#	F	St	51.86	-8.01	Smiddy, 1987 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	13/03/1987	Cork	c152	45.86#	U	St	51.87	-7.98	Smiddy, 1987 Berrow & Rogan, 1997
	25/09/1987	Cork	c183	78.41#	U	St	51.51	-8.13	Smiddy, 1987 Berrow & Rogan, 1997
	28/09/1987	Waterford	c107	16.63#	F	St	52.16	-7.13	Smiddy, 1988 Berrow & Rogan, 1997
	03/10/1987	Cork	c130	29.18#	M	St	51.90	-7.90	Smiddy, 1987 Berrow & Rogan, 1997
	08/11/1987	Cork	NA	NA	U	St	51.79	-8.19	Smiddy, 1987 Berrow & Rogan, 1997
	07/12/1987	Cork	164	57.12	F	St	51.86	-8.01	Smiddy, 1987 Berrow & Rogan, 1997
	04/01/1988	Cork	c114	19.97#	U	St	51.79	-8.25	Berrow & Rogan, 1997
	11/01/1988	Waterford	c135	32.55#	U	St	52.09	-7.54	Berrow & Rogan, 1997
	29/01/1988	Louth	140	36.16	U	St	53.68	-6.24	www.iwdg.ie
	01/04/1988	Waterford	NA	NA	U	BC	52.15	-6.99	Smiddy, 1988 Berrow & Rogan, 1998
	24/04/1988	Waterford	c121	23.72#	U	St	52.16	-7.13	Smiddy, 1988 Berrow & Rogan, 1997
	12/07/1988	Kerry	176	70.05	F	BC	52.11	-10.51	Quigley et al., 2002
	12/07/1988	Kerry	NA	NA	U	BC	52.11	-10.51	Quigley et al., 2002
	12/07/1988	Kerry	NA	NA	U	BC	52.11	-10.51	Quigley et al., 2002
	12/07/1988	Kerry	NA	NA	U	BC	52.11	-10.51	Quigley et al., 2002
	12/07/1988	Kerry	NA	NA	U	BC	52.11	-10.51	Quigley et al., 2002
	12/07/1988	Kerry	NA	NA	U	BC	52.11	-10.51	Quigley et al., 2002
	--/07/1988	Kerry	NA	NA	U	BC	51.97	-10.26	Berrow & Rogan, 1998
	--/07/1988	Kerry	NA	NA	U	BC	51.97	-10.26	Berrow & Rogan, 1998
	--/07/1988	Kerry	180	74.8	F	BC	52.14	-9.31	Rogan & Berrow, 1996 Berrow & Rogan, 1998
	--/07/1988	Cork	NA	NA	U	St	51.47	-9.42	UCC
	08/11/1988	Cork	130	29.18	M	St	51.86	-8.00	Smiddy, 1990 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	16/11/1988	Waterford	168	61.24	U	St	52.09	-7.54	Smiddy, 1990 Berrow & Rogan, 1997
	18/12/1988	Cork	NA	NA	U	St	51.54	-8.95	Berrow & Rogan, 1997
									Bruton & Rogan, 1996
	--/--/1989	Dublin	NA	NA	U	St	53.57	-6.09	Berrow & Rogan, 1997
	18/01/1989	Cork	NA	NA	U	BC	51.54	-8.95	Berrow & Rogan, 1998
	22/01/1989	Cork	NA	NA	U	St	51.51	-8.13	
	30/01/1989	Cork	146	40.82	F	BC	51.54	-8.95	Berrow & Rogan, 1998
	30/01/1989	Cork	169	62.3	M	BC	51.54	-8.95	Berrow & Rogan, 1998
	13/02/1989	Cork	137	33.96	M	St	51.94	-7.85	Smiddy, 1990 Berrow & Rogan, 1997
	14/02/1989	Cork	152	45.86	U	St	51.91	-7.89	Smiddy, 1990 Berrow & Rogan, 1997
	16/05/1989	Sligo	180	74.75	U	St	54.34	-8.66	Bruton & Berrow, 1992 Berrow & Rogan, 1997
	02/07/1989	Cork	1.2	4E-05	F	BC*	51.59	-9.58	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	23/07/1989	Sligo	NA	NA	U	St	54.47	-8.45	Bruton & Berrow, 1992
	23/07/1989	Sligo	NA	NA	U	St	54.47	-8.45	Bruton & Berrow, 1992
	23/07/1989	Sligo	NA	NA	U	St	54.47	-8.45	Bruton & Berrow, 1992
	23/07/1989	Sligo	NA	NA	U	St	54.47	-8.45	Bruton & Berrow, 1992
	20/10/1989	Cork	176	70.05	F	St	51.78	-8.29	Berrow & Smiddy, 1991 Berrow & Rogan, 1997 Rogan & Berrow, 1996
	17/11/1989	Clare	145	40.01	M	St	52.63	-9.53	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	26/11/1989	Cork	152	45.86	M	St	51.89	-7.87	Smiddy, 1990 Berrow & Rogan, 1997
	01/02/1990	Cork	145	40.01	M	St	51.78	-8.29	Berrow & Rogan, 1997
	07/03/1990	Cork	152	45.86	F	St	51.80	-8.18	Smiddy, 1990 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	07/03/1990	Cork	152	45.86	F	St	51.80	-8.18	Smiddy, 1990 Berrow & Rogan, 1997
	18/03/1990	Waterford	122	24.29	M	St	52.16	-7.13	Smiddy, 1990 Berrow & Rogan, 1997
	18/03/1990	Waterford	137	33.96	M	St	52.16	-7.13	Smiddy, 1990 Berrow & Rogan, 1997
	18/03/1990	Waterford	152	45.86	M	St	52.16	-7.13	Smiddy, 1990 Berrow & Rogan, 1997
	21/04/1990	Cork	123	24.87	F	BC	51.59	-8.71	Rogan & Berrow, 1996 Berrow & Rogan, 1998
	21/05/1990	Sligo	NA	NA	U	St	54.36	-8.67	Bruton & Berrow. 1992
	21/05/1990	Sligo	124	25.46	U	St	54.36	-8.67	Bruton & Berrow. 1992
	03/08/1990	Kerry	136	33.25	F	BC	52.11	-10.51	Rogan & Berrow, 1996 Berrow & Rogan, 1998
	15/09/1990	Kerry	152	45.86	F	BC	52.11	-10.51	Berrow & Rogan, 1998
	20/09/1990	Cork	152	45.86	U	St	51.51	-8.13	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	14/10/1990	Waterford	122	24.29	F	St	52.16	-7.13	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	03/11/1990	Cork	122	24.29	F	St	51.57	-9.01	Berrow & Rogan, 1997
	30/11/1990	Cork	150	44.13	F	St	51.57	-9.01	Berrow & Smiddy, 1991
	21/12/1990	Cork	1.22	24.29	M	St	51.87	-7.98	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	04/01/1991	Cork	145	40.01	F	St	51.86	-8.01	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
HP 15	01/02/1991	Cork	137	33.96	M	BC*	51.78	-8.29	Berrow & Smiddy, 1991 Rogan & Berrow, 1996
	28/02/1991	Cork	NA	NA	M	St	51.81	-8.11	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	28/02/1991	Cork	75	5.95	U	St	51.80	-8.18	Berrow & Smiddy, 1991 Berrow & Rogan, 1997

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	18/06/1991	Antrim	c80	7.17#	M	St	55.22	-6.53	Bruton & Berrow, 1992 Berrow & Rogan, 1997
	27/07/1991	Dublin	NA	NA	M	St	53.57	-6.09	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	05/08/1991	Sea	c140	36.16#	U	BC	52.58N	10.23W	Berrow & Smiddy, 1991 Berrow & Rogan, 1998
	24/09/1991	Dublin	140	36.16	U	St	53.53	-6.09	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
	05/10/1991	Sligo	152.4	46.21	U	St	54.33	-8.65	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
HP 17	16/10/1991	Dublin	125	26.06	F	BC*	53.58	-6.10	Berrow & Smiddy, 1991 Berrow & Rogan, 1997
HP 16	10/12/1991	Cork	138	34.68	M	St	51.63	-8.70	Berrow & Rogan, 1997
HP 17	03/03/1992	Cork	165	58.13	F	St	51.72	-9.49	Berrow & Smiddy, 1991 Berrow & Rogan 1997 Rogan & Berrow, 1996
	31/03/1992	Sligo	NA	NA	U	St	54.44	-8.47	Berrow & Smiddy, 1991
	12/06/1992	Sea	NA	NA	U	BC	52.26	10.10	Berrow & Rogan, 1998
	12/06/1992	Sea	NA	NA	U	BC	52.29	10.10	Berrow & Rogan, 1998
	30/06/1992	Sea	86	8.84	U	BC	52.13	10.19	Berrow & Rogan, 1998
HP-19-92	06/07/1992	Dublin	NA	NA	M	St	53.57	-6.09	Berrow & Rogan, 1997
	08/07/1992	Sea	NA	NA	U	BC	53.04	11.37	Berrow & Rogan, 1998
	12/07/1992	Sea	NA	NA	U	BC	52.35	10.21	Berrow & Rogan, 1998
	21/07/1992	Sea	NA	NA	U	BC	52.39	10.10	Berrow & Rogan, 1998
	22/07/1992	Sea	NA	NA	U	BC	52.42	10.10	Berrow & Rogan, 1998
	22/07/1992	Sea	NA	NA	U	BC	52.38	10.10	Berrow & Rogan, 1998
	20/09/1992	Kerry	NA	NA	U	St	51.76	-10.13	Bruton & Berrow, 1993 Berrow & Rogan, 1997
	22/09/1992	Sea	NA	NA	U	BC	52.44	9.56	Berrow & Rogan, 1998
	07/10/1992	Cork	NA	NA	U	BC	51.59	-10.20	Berrow & Rogan, 1998

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP 18	05/12/1992	Cork	124	25.46	F	St	51.81	-8.11	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
HP 19	09/01/1993	Cork	143	38.44	F	St	51.56	-8.97	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
	22/01/1993	Cork	137	33.96	U	St	51.91	-7.89	UCC
HP 21	14/02/1993	Cork	122	24.29	M	St	51.80	-8.25	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
HP 20	15/02/1993	Cork	133	31.17	F	St	51.77	-8.31	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
HP 4/93	16/02/1993	Cork	130	29.18	M	St	51.84	-8.19	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
	21/02/1993	Sligo	NA	NA	U	St	54.33	-8.57	Bruton & Berrow, 1993 Berrow & Rogan, 1997
	--/03/1993	Sligo	132	30.5	U	St	54.26	-8.73	Bruton & Berrow, 1993 Berrow & Rogan, 1997
HP 5/93	20/03/1993	Clare	138	34.68	M	St	52.68	-9.66	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
HP 6/93	29/03/1993	Cork	158	51.29	M	St	51.80	-8.18	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
HP 7/93	29/03/1993	Cork	NA	NA	U	St	51.80	-8.18	UCC
	--/04/1993	Clare	119	22.6	M	BC	52.58	-9.88	Rogan & Berrow, 1996 Berrow & Rogan, 1998
	14/04/1993		NA	NA	U	St	51.08	11.06	Berrow & Rogan, 1998
	14/04/1993		NA	NA	F	St	51.08	11.06	Berrow & Rogan, 1998

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	14/04/1993		151	44.99	F	St	51.07	6.02	Rogan & Berrow, 1996 Berrow & Rogan, 1998 Rogan & Berrow, 1996
	27/04/1993	Sligo	117	21.52	F	BC	54.29	-8.59	Bruton & Berrow, 1993 Berrow & Rogan, 1998 Rogan & Berrow, 1996
	02/05/1993	Sligo	135	32.55	F	St	54.34	-8.66	Bruton & Berrow, 1993 Berrow & Rogan, 1997
	04/05/1993	Cork	152	45.86	U	St	51.51	-8.13	UCC
HP 8/93	06/06/1993	Meath	145	40.01	M	St	53.70	-6.24	Bruton & Berrow, 1994 Berrow & Rogan, 1997 Rogan & Berrow, 1996
	08/06/1993		NA	NA	U	BC	53.36	9.20	Berrow & Rogan, 1998
	13/06/1993		NA	NA	U	BC	49.51	10.10	Berrow & Rogan, 1998
	18/08/1993	Sligo	94	11.43	M	BC	54.27	-8.67	Berrow & Rogan, 1998
	03/09/1993	Dublin	120	23.16	F	St	53.39	-6.11	Rogan & Berrow, 1996
	11/09/1993		U	NA	U	BC	50.57	9.27	Berrow & Rogan, 1998
HP 9/93	15/9/1993	Dublin	120	23.2	F	St	53.99	-6.11	UCC
HP c/93	20/09/1993	Cork	164	57.12	U	St	51.52	-9.54	Berrow & Rogan, 1997
	09/10/1993		NA	NA	U	BC	50.36	9.22	Berrow & Rogan, 1998
	22/10/1993		NA	NA	U	BC	50.37	9.13	Berrow & Rogan, 1998
	24/10/1993		NA	NA	U	BC	50.43	8.56	Berrow & Rogan, 1998
	04/11/1993		NA	NA	U	BC	51.36	6.58	Berrow & Rogan, 1998
	06/11/1993		NA	NA	U	BC	51.36	6.43	Berrow & Rogan, 1998
	06/11/1993		152	45.86	U	BC	51.35	6.47	Berrow & Rogan, 1998
	06/11/1993		121	23.72	M	St	51.36	6.43	Rogan & Berrow, 1996
	17/01/1994		160	53.18	M	BC	52.09	10.47	Berrow & Rogan, 1998
	23/01/1994		130	29.18	M	BC	51.34	8.27	Berrow & Rogan, 1998
	23/01/1994		155	48.52	M	BC	51.34	8.27	Berrow & Rogan, 1998
HP 1/94	03/02/1994	Kerry	133	31.17	F	BC*	52.14	-10.28	Berrow & Rogan, 1997 Rogan & Berrow, 1996
	27/02/1994	Waterford	NA	NA	U	St	52.14	-7.37	UCC

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP a/94	31/03/1994	Donegal	122	24.29	U	St	55.12	-7.20	Bruton & Rogan, 1995 Berrow & Rogan, 1997
	14/04/1994	Clare	133	31.17	F	BC	52.58	-9.88	Rogan & Berrow, 1996 Berrow & Rogan, 1998
HP 2/94	07/05/1994	Kerry	115	20.5	F	St	52.14	-10.28	Bruton & Rogan, 1995 Berrow & Rogan, 1997
	23/09/1994	Waterford	152	45.86	M	St	51.95	-7.76	UCC
	25/09/1994	Cork	NA	NA	M	St	51.51	-8.13	UCC
HP 3/95	27/01/1995	Antrim	145	40.01	F	St	54.99	-5.99	Bruton & Rogan, 1995 Berrow & Rogan, 1997
	12/02/1995	Cork	127	27.28	F	St	51.95	-7.77	UCC
HP b/95	Summer/1995	Mayo	180	74.8	M	BC*	54.16	10.09	Bruton & Rogan, 1995 Berrow & Rogan, 1997
HP c/95	Summer/1995	Cork	121.9	24.2	U	St	51.47	-9.42	UCC
HP 1/95	24/7/1995	Mayo	84	8.26	F	St	53.78	-9.69	Bruton & Rogan, 1996
HP d/95	15/08/1995	Donegal	c100	13.67#	F	St+	55.04	-8.35	Bruton & Rogan, 1996
HP e/95	23/08/1995	Kerry	147	41.63	U	St	51.84	-10.21	Bruton & Rogan, 1996
	23/08/1995	Kerry	c100	13.67#	U	St	51.84	-10.21	Berrow et al., 2007
HP 2/95	21/11/1995	Cork	c145	40.01#	M	St	51.86	-8.00	UCC
	10/12/1995	Cork	123	24.87	U	St	51.86	-8.01	Bruton & Rogan, 1996
HP a/95	12/01/1996	Dublin	120	23.16	M	St	53.53	-6.09	UCC
	12/01/1996	Dublin	120	23.16	M	St	53.53	-6.09	Bruton & Rogan, 1996
HP a/96	28/01/1996	Down	100	13.67	F	St	54.67	-5.66	Bruton & Rogan, 1996
HP 1/96	05/02/1996	Cork	128	27.91	M	St	51.51	-8.13	Bruton & Rogan
HP 2/96	15/02/1996	Waterford	134	31.86	M	St	52.15	-6.99	Bruton & Rogan
HP 3/96	01/03/1996	Waterford	137	33.96	F	St	51.95	-7.72	Bruton & Rogan
HP b/96	16/03/1996	Down	157	50.35	M	St	54.50	-5.46	UCC
UCC?	24/03/1996	Waterford	NA	NA	U	St	52.09	-7.54	UCC
UCC?	24/03/1996	Waterford	NA	NA	U	St	52.16	-7.13	UCC
HP 4/96	25/03/1996	Wexford	110	18.01	M	St	52.48	-6.28	Bruton & Rogan, 1996
	16/04/1996	Down	157	50.35	M	St	54.50	-5.46	Bruton & Rogan, 1996

APPENDIX VI. *Conti.*

UCC code	**Date**	**County**	**Size**	**Weight**	**Sex**	**St/BC**	**Lat**	**Long**	**Source**
HP 4b/96	18/09/1996	Cork	106	16.18	M	St	51.85	-8.27	UCC
HP 5/96	01/10/1996	Wicklow	152	45.86	M	St	53.16	-6.07	Bruton & Rogan, 1997
HP 6/96	02/10/1996	Cork	153	46.73	F	St	51.86	-8.00	UCC
HP 7/96	03/10/1996	Cork	119	22.6	M	St	51.63	-10.06	Bruton & Rogan, 1997
HP 1/97	15/01/1997	Dublin	164	57.12	F	St	53.53	-6.09	Bruton & Rogan, 1997
HP 2/97	15/01/1997	Dublin	28	0.345	M	St	53.53	-6.09	Bruton & Rogan, 1997
HP 3/97	18/01/1997	Cork	143	38.44	F	St	51.86	-8.00	Bruton & Rogan, 1997
HP 4/97	27/01/1997	Waterford	146	40.82	F	St	51.95	-7.72	Bruton & Rogan, 1997
HP 5/97	28/01/1997	Cork	c125	26.1#	F	BC*	51.95	-7.77	Bruton & Rogan, 1997
HP 7/97	09/03/1997	Waterford	125	26.06	F	St	52.09	-7.54	UCC
HP 6/97	13/03/1997	Cork	165	58.13	F	St	51.51	-8.13	Bruton & Rogan, 1997
HP 8/97	08/04/1997	Donegal	117	21.52	F	St	55.26	-8.23	Bruton & Rogan, 1997
Hp 9/97	17/06/1997	cORK	139	35.4	M	Bc	51.81	-8.29	Bruton & Rogan, 1997
HP 10/97	14/08/1997	Dublin	113.5	19.71	M	St	53.33	-6.21	UCC
HP 12/97	--/--/1997	Donegal	147	41.6	F	St	54.61	-8.62	UCC
HP 13/97	--/--/1997	Donegal	117	21.5	F	St	54.62	-8.17	UCC
HP 14/97	--/--/1997	Donegal	158	51.3	F	St	54.62	-8.17	UCC
HP 15/97	06/11/1997	Wexford	121.5	24	M	St	52.20	-6.35	Bruton & Rogan, 1998
HP 16/97	02/12/1997	Dublin	107.5	16.85	F	St	53.53	-6.09	Bruton & Rogan, 1998
HP 17/97	18/12/1997	Wexford	152	45.86	M	St	52.36	-6.42	Bruton & Rogan, 1998
HP 1/98	16/02/1998	Cork	157	50.35	F	St	51.80	-8.18	Bruton & Rogan, 1998
HP 2/98	24/02/1998	Waterford	147	41.63	M	St	51.95	-7.76	Bruton & Rogan, 1998
HP b/98	12/03/1998	Antrim	106.68	16.48	F	St	55.22	-6.53	UCC
	22/03/1998	Sligo	99	13.28		St	54.27	-8.62	UCC
HP a/98	23/03/1998	Clare	163.9	57	U	St	52.76	-9.49	Bruton & Rogan, 1998
HP 3/98	26/03/1998	Sligo	119	22.6	F	St	54.21	-9.12	Bruton & Rogan, 1998
	13/09/1998	Waterford	162	55.13	M	St	52.16	-7.13	Rendle & Rogan, 2001
HP 4/98	18/09/1998	Waterford	162	55.13	M	St	52.16	-7.13	UCC
HP k/98	11/11/1998	Kerry	128	27.91	F	St	52.05	-9.98	Bruton & Rogan, 1998
HP c/98	25/11/1998	Down	adult	NA	U	St	54.38	-5.55	UCC
HP 1/99	13/01/1999	Cork	136	33.25	M	St	51.82	-8.23	Rendle & Rogan, 2001

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP 3/99	28/01/1999	Cork	132	30.5	F	BC*	51.81	-8.29	Rendle & Rogan, 2001
HP 2/99	30/01/1999	Cork	119	22.6	M	BC	51.81	-8.29	Rendle & Rogan, 2001
HP a/99	31/01/1999	Kerry	c120	23.16#	M	St	52.08	-9.97	Rendle & Rogan, 2001
HP 4/99	17/02/1999	Cork	126	26.66	M	St	51.80	-8.18	Rendle & Rogan, 2001
HP 5/99	24/02/1999	Clare	157.5	50.82	M	St	52.68	-9.66	Rendle & Rogan, 2001
HP 6/99	03/03/1999	Cork	95	11.79	M	BC*	51.81	-8.29	Rendle & Rogan, 2001
HP d/99	17/03/1999	Down	122	24.29	F	St	54.25	-5.68	Rendle & Rogan, 2001
HP 7/99	19/03/1999	Cork	125	26.06	M	BC*	51.75	-8.31	Rendle & Rogan, 2001
HP e/99	27/04/1999	Down	c147	45.86#	F	St	54.26	-5.60	UCC
HP 8/99	02/05/1999	Dublin	169	62.3	F	St	53.40	-6.07	Rendle & Rogan, 2001
HP b/99	09/06/1999	Galway	82	7.705	M	St	53.61	-9.91	Rendle & Rogan, 2001
HP 9/99	Jul-99	?	154	47.62	F	St	?	?	UCC
HP 11/99	Jul-99	?	97	12.52	M	St	?	?	UCC
HP 10/99	Jul-99	?	86	8.842	M	St	?	?	UCC
HP 10/99	27/07/1999	Wexford	86	8.842	M	St	52.25	-6.33	Rendle & Rogan, 2001
HP 11/99	28/07/1999	Dublin	97	12.52	M	St	53.57	-6.09	Rendle & Rogan, 2001
HP 9/99	28/07/1999	Wicklow	154	47.62	F	St	53.20	-6.10	Rendle & Rogan, 2001
HP 12/99	21/10/1999	Wicklow	109	17.54	M	St	52.89	-6.06	Rendle & Rogan, 2001
HP 12a/99	06/11/1999	Cork	c124	25.46#	U	St	51.75	-8.31	UCC
HP 13/99	07/12/1999	Cork	137	33.96	F	BC*	51.67	-8.49	Rendle & Rogan, 2001
HP 2/00	19/01/2000	Cork	133	31.17	F	BC*	51.70	-8.52	Murphy & Rogan, 2004
HP 1/00	27/01/2000	Cork	126	26.66	M	BC*	51.65	-9.91	Murphy & Rogan, 2004
HP a/00	08/03/2000	Galway	137	33.96	F	St	53.38	-9.96	Murphy & Rogan, 2004
HP 3/00	15/03/2000	Clare	110	18.01	F	St	52.68	-9.66	Murphy & Rogan, 2004
	31/03/2000	Sligo	NA	NA	U	St	54.46	-8.44	Berrow et al., 2007
UCC??	31/03/2000	Sligo	NA	NA	U	St	54.46	-8.44	UCC
HP 4/00	26/04/2000	Cork	162	55.13	M	St	51.94	-7.86	Murphy & Rogan, 2004
UCC???	Jul-00	Wexford	130	29.18	M	St	52.67	-6.21	UCC
HP 5/00	16/08/2000	Dublin	172	65.5	F	St+	53.57	-6.09	Murphy & Rogan, 2004
HP 6/00	02/11/2000	Kerry	150	44.13	F	BC*	52.14	-10.28	Murphy & Rogan, 2004
HP 7/00	01/12/2000	Cork	c130	29.2#	F	St	51.81	-8.11	Murphy & Rogan, 2004

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP 8/00	01/12/2000	Waterford	117	21.52	M	St	51.95	-7.77	Murphy & Rogan, 2004
HP b/00	03/12/2000	Clare	133	31.17	F	St	52.83	-9.45	Murphy & Rogan, 2004
HP 9/00	12/12/2000	Waterford	122	24.29	F	St	52.14	-7.37	Murphy & Rogan, 2004
HP 10/00	22/12/2000	Cork	127	27.28	F	St	51.95	-7.83	Murphy & Rogan, 2004
HP a/01	01/01/2001	Waterford	130	29.18	M	St	51.94	-7.80	Murphy & Rogan, 2004
HP b/01	01/01/2001	Wicklow	152.4	46.2	M	St	53.16	-6.07	Murphy & Rogan, 2004
HP g/01	--/01/2001	Cork	100	13.67	M	St	51.51	-8.13	Murphy & Rogan, 2004
HP h/01	--/01/2001	Cork	NA	NA	U	St	51.51	-8.13	Murphy & Rogan, 2004
HP 1/01	02/01/2001	Waterford	105	15.74	F	St	51.95	-7.77	Murphy & Rogan, 2004
HP 2/01	13/01/2001	Cork	158	51.29	F	St+	51.83	-8.23	Murphy & Rogan, 2004
HP 3/01	21/01/2001	Cork	126	26.66	M	BC*	51.86	-8.00	Murphy & Rogan, 2004
HP 4/01	22/01/2001	Cork	134	31.86	M	St	51.94	-7.85	Murphy & Rogan, 2004
HP 5/01	23/01/2001	Cork	128.2	28.03	M	St	51.64	-8.64	Murphy & Rogan, 2004
HP d/01	23/01/2001	Cork	NA	NA	M	St	51.56	-9.02	Murphy & Rogan, 2004
HP 6/01	26/01/2001	Cork	138	34.68	F	St	51.95	-7.77	Murphy & Rogan, 2004
HP c/01	30/01/2001	Waterford	130	29.18	U	St	52.07	-7.61	Murphy & Rogan, 2004
HP 8/01	20/02/2001	Cork	173.5	67.21	F	St	51.86	-8.00	Murphy & Rogan, 2004
HP 7/01	20/02/2001	Cork	138.5	35.05	F	St	51.94	-7.85	Murphy & Rogan, 2004
	10/03/2001	Cork	NA	NA	U	St	51.93	-7.87	Murphy & Rogan, 2004
HP e/01	18/03/2001	Cork	NA	NA	U	St	51.86	-8.00	Murphy & Rogan, 2004
HP f/01	21/03/2001	Waterford	100	13.67	U	BC*	52.13	-7.20	Murphy & Rogan, 2004
HP j/01	26/03/2001	Derry	147	41.63	U	St	55.05	-7.25	Murphy & Rogan, 2004
HP k/01	18/04/2001	Derry	160	53.18	F	St+	55.17	-6.88	Murphy & Rogan, 2004
UCC??	22/04/2001	Sligo	120	23.16	M	St	54.37	-8.67	Murphy & Rogan, 2004
HP l/01	25/04/2001	Down	100	13.67	U	St	54.36	-5.49	Murphy & Rogan, 2004
HP i/01	28/04/2001	Donegal	121.9	24.24	U	St	54.56	-8.21	Murphy & Rogan, 2004
HP 9/01	02/05/2001	Clare	119	22.6	M	St	52.74	-9.53	Murphy & Rogan, 2004
HP 10/01	15/06/2001	Waterford	85.5	8.70	M	St*	52.23	-6.32	UCC
HP cobh/01	04/07/2001	Cork	NA	NA	M	BC*	51.85	-8.27	Murphy & Rogan, 2004
HP 11/01	30/07/2001	Cork	129	28.54	M	St	51.59	-8.87	Murphy & Rogan, 2004
HP m/01	17/08/2001	Clare	NA	NA	U	St	52.62	-9.51	Murphy & Rogan, 2004

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP 12/01	28/08/2001	Donegal	118.4	22.28	M	St	54.62	-8.17	UCC
HP n/01	05/09/2001	Louth	NA	NA	M	St	53.98	-6.16	Murphy & Rogan, 2004
HP o/01	30/09/2001	Dublin	129	28.54	M	St	53.61	-6.18	Murphy & Rogan, 2004
HP p/01	30/09/2001	Dublin	91	10.41	F	St	53.61	-6.18	Murphy & Rogan, 2004
HP q/01	30/11/2001	Cork	150	44.13	U	St	51.69	-9.49	Murphy & Rogan, 2004
HP t/01	--/11/2001	Antrim	C135	32.5	U	BC*	55.20	-6.69	Murphy & Rogan, 2004
HP r/01	05/12/2001	Waterford	NA	NA	U	St	52.07	-7.61	Murphy & Rogan, 2004
HP 13/01	16/12/2001	Waterford	175	68.91	F	St	51.95	-7.72	Murphy & Rogan, 2004
HP s/01	24/12/2001	Cork	NA	NA	U	St	51.77	-8.31	Murphy & Rogan, 2004
	--/01/2002	Cork	145	40.01	U	St	51.78	-8.30	UCC
HP 1/02	10/01/2002	Cork	171	64.45	F	St	51.79	-8.29	Murphy & Rogan, 2005
HP 2/02	02/02/2002	Cork	153	46.73	M	St	51.64	-8.64	Murphy & Rogan, 2005
HP a/02	06/02/2002	Derry	146	40.82	M	St	55.17	-6.73	Murphy & Rogan, 2005
HP 12/02	11/02/2002	Donegal	118	22.06	M	St	54.60	-8.48	Murphy & Rogan, 2005
HP b/02	12/03/2002	Galway	127	27.28	F?	St	53.61	-9.99	Murphy & Rogan, 2005
HP c/02	18/03/2002	Clare	150	44.13	U	St	53.94	-9.39	Murphy & Rogan, 2005
HP 4/02	28/03/2002	Waterford	114	19.97	M	BC*	52.14	-7.27	Murphy & Rogan, 2005
HP d/02	28/03/2002	Waterford	90	10.08	M	St	52.14	-7.27	Murphy & Rogan, 2005
HP 3/02	29/03/2002	Waterford	128	27.91	M	St	51.95	-7.72	Murphy & Rogan, 2005
HP 5/02	01/04/2002	Cork	142	37.67	F	St	51.89	-7.87	Murphy & Rogan, 2005
HP f/02	19/04/2002	Cork	NA	NA	M	St	51.79	-8.25	Murphy & Rogan, 2005
HP i/02	21/06/2002	Waterford	123	24.87	U	St	52.13	-7.20	Murphy & Rogan, 2005
HP j/02	29/06/2002	Clare	NA	NA	M	St	53.15	-9.13	Murphy & Rogan, 2005
HP 6/02	07/07/2002	Dublin	81.5	7.57	M	St	53.61	-6.18	Murphy & Rogan, 2005
HP 7/02	10/07/2002	Dublin	134	31.86	F	St	53.53	-6.09	Murphy & Rogan, 2005
HP 8/02	02/09/2002	Cork	131	29.84	M	St	51.59	-8.87	Murphy & Rogan, 2005
HP 9/02	10/09/2002	Wicklow	116	21	F	St	52.89	-6.06	Murphy & Rogan, 2005
HP k/02	18/09/2002	Antrim	NA	NA	U	St	55.29	6.19	Murphy & Rogan, 2005
HP z1/02	21/09/2002	Cork	100	13.67	M	St	51.79	-8.25	Murphy & Rogan, 2005
HP RP/02	21/09/2002	Cork	100	13.67	M	St	51.79	-8.25	UCC
HP z2/02	30/09/2002	Dublin	160	53.18	M	St	53.53	-6.09	Murphy & Rogan, 2005

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP m/02	08/10/2002	Donegal	120	23.16	U	St	55.07	-8.32	Murphy & Rogan, 2005
HP 10/02	10/10/2002	Wicklow	105.5	15.96	F	St	53.07	-6.03	Murphy & Rogan, 2005
HP l/02	21/10/2002	Wicklow	154	47.62	M	St	53.15	-6.07	Murphy & Rogan, 2005
HP 11/02	02/11/2002	Kerry	144	39.22	M	St	52.13	-10.37	Murphy & Rogan, 2005
HP s/03	10/01/2003	Louth	145	40.01	U	St	54.01	-6.11	Brophy et al., 2006
HP 1/03	12/01/2003	Louth	122.5	24.58	F	St	53.99	-6.12	Brophy et al., 2006
HP 2/03	14/01/2003	Kerry	157	50.35	M	St+	51.87	-9.59	Brophy et al., 2006
HP a/03	19/01/2003	Louth	150	44.13	M	St	53.98	-6.15	Brophy et al., 2006
HP 3/03	20/01/2003	Dublin	110	18.01	F	St	53.61	-6.18	Brophy et al., 2006
HP b/03	29/01/2003	Mayo	NA	NA	U	St	54.16	10.09	Brophy et al., 2006
HP c/03	30/01/2003	Wexford	>152	45.86	U	St	52.17	-6.36	Brophy et al., 2006
HP d/03	17/02/2003	Wexford	NA	NA	M	St	51.95	-7.72	Brophy et al., 2006
HP 4/03	21/02/2003	Cork	171	64.45	F	BC*	51.86	-8.00	Brophy et al., 2006
HP 4a/03	21/02/2003	Cork	63.5	3.68	M	St	51.86	-8.00	UCC
HP 5/03	23/02/2003	Dublin	150.6	44.65	F	St	53.36	-6.16	Brophy et al., 2006
HP 5a/03	23/02/2003	Dublin	40	0.968	M	St	53.36	-6.16	UCC
HP e/03	23/02/2003	Wexford	c130	29.18#	M	St	52.17	-6.36	Brophy et al., 2006
HP f/03	24/02/2003	Wexford	150	44.13	F	St	52.18	-6.36	Brophy et al., 2006
HP g/03	25/02/2003	Waterford	160	53.18	M	St	52.16	-7.13	Brophy et al., 2006
HP h/03	14/03/2003	Wexford	120	23.16	M	St	52.22	-6.34	Brophy et al., 2006
HP i/03	19/03/2003	Dublin	135	32.55	M	St	53.58	-6.11	Brophy et al., 2006
HP j/03	23/03/2003	Waterford	NA	NA	U	St	51.97	-7.70	Brophy et al., 2006
HP t/03	27/04/2003	Donegal	143	38.44	M	St	54.50	-8.26	Brophy et al., 2006
HP u/03	04/07/2003	Antrim	NA	NA	U	St	55.20	-6.69	Brophy et al., 2006
HP v/03	08/07/2003	Derry	NA	NA	M	St	55.17	-6.79	Brophy et al., 2006
HP w/03	10/08/2003	Derry	NA	NA	U	St	55.17	-6.88	Brophy et al., 2006
HP x/03	11/08/2003	Derry	NA	NA	U	St	55.17	-6.79	Brophy et al., 2006
HP k/03	03/09/2003	Dublin	156	49.43	M	St	53.58	-6.11	Brophy et al., 2006
HP l/03	07/09/2003	Derry	170	63.37	U	St	55.17	-6.73	Brophy et al., 2006
HP m/03	10/10/2003	Wexford	NA	NA	U	St	52.18	-6.55	Brophy et al., 2006
HP 6/03	11/10/2003	Kerry	160	53.18	M	St	52.14	-10.28	Brophy et al., 2006

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP n/03	27/10/2003	Antrim	85	8.548	U	St	55.20	-6.66	Brophy et al., 2006
HP o/03	08/11/2003	Cork	155	48.52	U	St	51.56	-8.97	Brophy et al., 2006
HP p/03	09/12/2003	Wexford	c122	24.29	U	St	52.64	-6.22	Brophy et al., 2006
HP 7/03	--/--/2003	Cork	166	59.15	F	St	51.91	-7.90	UCC
HP 8/03	12/12/2003	Dublin	153.4	47.09	F	St	53.53	-6.09	Brophy et al., 2006
HP q/03	13/12/2003	Dublin/Wicklow	164	57.12	F	St	53.16	-6.07	Brophy et al., 2006
HP r/03	28/12/2003	Wicklow	130	29.18	U	St	52.84	-6.10	Brophy et al., 2006
	13/01/2004	Cork	NA	NA	U	St	51.64	-8.58	Philpott, et al., 2007
	17/01/2004	Donegal	135	32.55	U	St	55.04	-8.35	Philpott, et al., 2007
	07/02/2004	Meath	150	44.13	M	St	53.72	-6.24	Philpott, et al., 2007
	14/02/2004	Wexford	162	55.13	M	St	52.18	-6.55	Philpott, et al., 2007
HP e/04	15/02/2004	Clare	NA	NA	U	St	53.94	-9.35	Philpott, et al., 2007
HP 1/04	15/02/2004	Waterford	117	21.52	F	BC*	51.95	-7.72	Philpott, et al., 2007
	01/03/2004	Derry	c120	23.16	F	St	55.17	-6.79	Philpott, et al., 2007
	05/03/2004	Antrim	150	44.13	U	St	55.13,8N	6.31,7W	Philpott, et al., 2007
	17/03/2004	Cork	150	44.13	M	St	51.36	8.52,30	Philpott, et al., 2007
	17/03/2004	Wexford	NA	NA	U	St	52.19	-6.48	Philpott, et al., 2007
	17/03/2004	Wexford	NA	NA	U	St	52.19	-6.48	Philpott, et al., 2007
	30/03/2004	Dublin	NA	NA	U	St	53.57	-6.09	Philpott, et al., 2007
	12/04/2004	Wexford	NA	NA	U	St	52.34	-6.46	Philpott, et al., 2007
	14/04/2004	Down	NA	NA	U	St	54.34	-5.53	Philpott, et al., 2007
	15/04/2004	Kerry	NA	NA	U	Ref	51.87	-9.63	Philpott, et al., 2007
	04/06/2004	Galway	NA	NA	U	St	53.54	-10.15	Philpott, et al., 2007
	05/06/2004	Sligo	NA	NA	U	St+	54.27	-8.62	Philpott, et al., 2007
	15/06/2004	Derry	80	7.174	F	St	55.17	-6.73	Philpott, et al., 2007
	16/06/2004	Mayo	185	80.91	U	St	54.13	-9.94	Philpott, et al., 2007
	18/06/2004	Derry	80	7.174	M	St	55.17	-6.73	Philpott, et al., 2007
	25/06/2004	Antrim	120	23.16	F	St	54.85	-5.77	Philpott, et al., 2007
	--/07/2004	Wexford	NA	NA	U	St	52.66	-6.22	Philpott, et al., 2007
	07/07/2004	Wexford	c120	23.16	U	St	52.20	-6.65	Philpott, et al., 2007
	09/07/2004	Donegal	150	44.13	M	St	54.85	-8.45	Philpott, et al., 2007

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	02/08/2004	Kerry	175	68.91	U	St	52.25	-10.07	Philpott, et al., 2007
	09/08/2004	Dublin	136	33.25	M	St	53.36	-6.16	Philpott, et al., 2007
	06/10/2004	Cork	120	23.16	U	St	51.95	-7.84	Philpott, et al., 2007
	14/10/2004	Waterford	130	29.18	F	St	52.16	-7.13	Philpott, et al., 2007
	06/11/2004	Kerry	NA	NA	M	St	52.49	-9.68	Philpott, et al., 2007
	06/11/2004	Kerry	137	33.96	M	St	52.27	-10.16	Philpott, et al., 2007
	07/11/2004	Kerry	167	60.19	F	St	52.27	-10.16	Philpott, et al., 2007
	07/11/2004	Waterford	NA	NA	U	St	52.16	-7.13	Philpott, et al., 2007
	04/12/2004	Cork	NA	NA	F	St	51.79	-8.29	Philpott, et al., 2007
	15/01/2005	Kerry	c130	29.18#	F	St	52.13	-10.37	Philpott & Rogan, 2007
	18/01/2005	Cork	135	32.55	M	St	51.59	-8.87	Philpott & Rogan, 2007
	19/01/2005	Kerry	NA	NA	U	St	52.13	-10.37	Philpott & Rogan, 2007
	23/01/2005	Down	NA	NA	U	St	54.66	-5.90	Philpott & Rogan, 2007
	03/02/2005	Down	NA	NA	U	St	54.67	-5.64	Philpott & Rogan, 2007
	21/02/2005	Mayo	c180	74.75	U	St	54.16	10.09	Philpott & Rogan, 2007
	27/02/2005	Down	133	31.17	M	St	54.64	-5.54	Philpott & Rogan, 2007
	06/03/2005	Dublin	NA	NA	U	St	53.30	-6.16	Philpott & Rogan, 2007
	29/03/2005	Meath	c160	53.18#	U	St	53.64	-6.21	Philpott & Rogan, 2007
	14/05/2005	Dublin	140	36.16	F	St	53.30	-6.13	Philpott & Rogan, 2007
	16/05/2005	Kerry	c105	15.74#	M	St	52.39	-9.84	UCC
	11/06/2005	Down	c120	23.16#	U	St	54.61	-5.23	Philpott & Rogan, 2007
	25/07/2005	Derry	Juvenile	NA	U	BC	55.19	-6.96	Philpott & Rogan, 2007
	27/07/2005	Wexford	110	18.01	F	St	52.35	-6.36	Philpott & Rogan, 2007
	11/08/2005	Kerry	113	19.46	M	St	52.28	-9.86	Philpott & Rogan, 2007
	14/09/2005	Kerry	NA	NA	U	St	52.28	-9.86	Philpott & Rogan, 2007
	16/10/2005	Louth	NA	NA	U	St	53.95	-6.38	Philpott & Rogan, 2007
	11/11/2005	Cork	c100	13.67#	U	St	51.64	-8.58	Philpott & Rogan, 2007
	11/11/2005	Cork	c100	13.67#	U	St	51.64	-8.58	Philpott & Rogan, 2007
	17/11/2005	Wexford	NA	NA	U	St	52.17	-6.36	Berrow et al., 2007
	17/11/2005	Wexford	NA	NA	U	St	52.17	-6.36	Berrow et al., 2007
	21/11/2005	Wicklow	NA	NA	U	St	53.07	-6.03	Philpott & Rogan, 2007

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
HP 2/05	24/11/2005	Cork	132	30.5	F	St	51.85	-8.01	UCC
	20/01/2006	Kerry	NA	NA	U	St	52.20	-10.43	O'Connell & Berrow, 2007
	22/01/2006	Mayo	115	20.48	U	St	53.90	-9.77	O'Connell & Berrow, 2007
	23/01/2006	Cork	160	53.18	F	St	51.64	-8.57	O'Connell & Berrow, 2007
	02/02/2006	Cork	120	23.16	M	St	51.86	-8.00	O'Connell & Berrow, 2007
HP 1/06	03/02/2006	Cork	124.5	25.76	M	St	51.85	-8.01	UCC
	27/02/2006	Wicklow	NA	NA	U	St	53.20	-6.10	O'Connell & Berrow, 2007
	14/03/2006	Waterford	NA	NA	U	St	52.16	-7.13	O'Connell & Berrow, 2007
	24/03/2006	Waterford	NA	NA	U	St	52.16	-7.13	O'Connell & Berrow, 2007
	25/03/2006	Louth	152.5	46.29#	F	St	53.98	-6.15	O'Connell & Berrow, 2007
	29/03/2006	Wexford	c100	13.67#	F	St	52.18	-6.36	O'Connell & Berrow, 2007
	02/04/2006	Meath	c80	7.174#	U	St	53.70	-6.24	O'Connell & Berrow, 2007
	03/04/2006	Down	NA	NA	U	St	54.64	-5.83	O'Connell & Berrow, 2007
	22/05/2006	Antrim	c130	29.18#	U	St	55.23	-6.40	O'Connell & Berrow, 2007
	11/06/2006	Waterford	65	3.937	U	St	52.16	-7.13	O'Connell & Berrow, 2007
	12/06/2006	Kerry	85	8.548	F	St	52.13	-10.37	O'Connell & Berrow, 2007
	26/06/2006	Meath	188	84.76	F	St	53.68	-6.23	O'Connell & Berrow, 2007
	03/07/2006	Sligo	130	29.18	U	St	54.29	-8.59	O'Connell & Berrow, 2007
	13/07/2006	Antrim	Juvenile	NA	F	St*	55.22	-6.53	O'Connell & Berrow, 2007
	15/08/2006	Dublin	c175	68.91	U	St	53.31	-6.19	O'Connell & Berrow, 2007
	30/08/2006	Kerry	NA	NA	U	St	52.24	-10.12	O'Connell & Berrow, 2007
	09/09/2006	Dublin	c140	36.16#	U	BC	53.33	-6.21	O'Connell & Berrow, 2007
HP 2/06	05/10/2006	Sea	137.5	34.32	F	BC	51.25	7.68	UCC
HP 3/06	05/10/2006	Sea	153	46.73	F	BC	51.23	7.62	UCC
	25/12/2006	Waterford	c100	13.67#	U	St	51.95	-7.72	O'Connell & Berrow, 2007
	31/12/2006	Meath	152	45.86	U	St	53.68	-6.23	O'Connell & Berrow, 2007
	11/01/2007	Donegal	130	29.18	U	St	55.13	-7.46	O'Connell & Berrow, 2008
	15/01/2007	Wexford	NA	NA	F	St	52.19	-6.54	O'Connell & Berrow, 2008
	18/02/2007	Wicklow	c150	44.13#	U	St	52.89	-6.06	O'Connell & Berrow, 2008
	20/02/2007	Cork	125	26.06	U	St	51.57	-9.00	O'Connell & Berrow, 2008
	25/02/2007	Wicklow	165	58.13	U	St	52.98	-6.03	O'Connell & Berrow, 2008

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UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	03/03/2007	Dublin	c110	18.01#	U	St	53.29	-6.11	O'Connell & Berrow, 2008
	07/03/2007	Wexford	142	37.67	M	St	52.20	-6.35	O'Connell & Berrow, 2008
	03/04/2007	Clare	NA	NA	U	St	53.16	-9.09	O'Connell & Berrow, 2008
	05/04/2007	Clare	120	23.16	U	St	53.02	-9.40	O'Connell & Berrow, 2008
	15/04/2007	Dublin	145	40.01	U	St	53.33	-6.21	O'Connell & Berrow, 2008
	01/05/2007	Kerry	150	44.13	U	St	52.20	-10.43	O'Connell & Berrow, 2008
	18/05/2007	Cork	130	29.18	M	St	51.47	-9.42	O'Connell & Berrow, 2008
	27/05/2007	Donegal	130	29.18	M	St	55.26	-7.01	O'Connell & Berrow, 2008
	13/06/2007	Kerry	c90	10.08#	U	St	52.13	-10.37	O'Connell & Berrow, 2008
	24/06/2007	Dublin	130	29.18	F	St	53.37	-6.10	O'Connell & Berrow, 2008
	25/06/2007	Antrim	84	8.26	U	St	55.21	-6.63	O'Connell & Berrow, 2008
	31/07/2007	Cork	c105	15.74#	M	St	51.80	-8.18	O'Connell & Berrow, 2008
	03/08/2007	Clare	131	29.84	U	St	52.93	-9.35	O'Connell & Berrow, 2008
	23/08/2007	Antrim	90	10.08	U	St	55.20	-6.69	O'Connell & Berrow, 2008
	05/09/2007	Galway	102	14.48	M	St	53.27	-9.05	O'Connell & Berrow, 2008
	13/10/2007	Down	NA	NA	U	St	54.24	-5.82	O'Connell & Berrow, 2008
	16/10/2007	Wicklow	c100	13.67#	U	St	52.89	-6.06	O'Connell & Berrow, 2008
	19/10/2007	Kerry	120	23.16	M	St	52.13	-10.37	O'Connell & Berrow, 2008
	27/10/2007	Leitrim	178	72.38	U	St	54.47	-8.33	O'Connell & Berrow, 2008
	31/10/2007	Waterford	NA	NA	U	St	52.16	-7.13	O'Connell & Berrow, 2008
	25/11/2007	Kerry	153	46.73	M	St	52.49	-9.68	O'Connell & Berrow, 2008
	28/11/2007	Kerry	155	48.52	M	St	52.13	-10.37	O'Connell & Berrow, 2008
	06/12/2007	Wexford	143	38.44	F	St	52.17	-6.36	O'Connell & Berrow, 2008
	10/12/2007	Cork	180	74.75	U	St	51.81	-9.90	O'Connell & Berrow, 2008
	26/12/2007	Cork	120	23.16	U	St	51.61	-10.13	O'Connell & Berrow, 2008
	27/12/2007	Kerry	150	44.13	M	St	52.14	-10.05	O'Connell & Berrow, 2008
	02/01/2008	Sligo	123	24.87	F	St	54.40	-8.57	O'Connell & Berrow, 2009
	13/01/2008	Clare	165	58.13	F	St	52.87	-9.43	O'Connell & Berrow, 2009
	13/01/2008	Kerry	121	23.72	M	St	52.13	-10.37	O'Connell & Berrow, 2009
	03/02/2008	Kerry	NA	NA	U	St	52.08	-9.97	O'Connell & Berrow, 2009
	24/02/2008	Galway	c180	74.75#	F	St	53.25	-8.96	O'Connell & Berrow, 2009

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	28/02/2008	Dublin	148	42.45	F	St	53.51	-6.11	O'Connell & Berrow, 2009
	01/03/2008	Donegal	105	15.74	U	St	55.19	-7.95	O'Connell & Berrow, 2009
	04/03/2008	Waterford	c100	13.67#	U	St	52.14	-7.37	O'Connell & Berrow, 2009
	11/03/2008	Kerry	164	57.12	U	St	51.97	-10.26	O'Connell & Berrow, 2009
	16/03/2008	Waterford	c100	13.67#	U	St	52.09	-7.54	O'Connell & Berrow, 2009
	18/03/2008	Meath	c150	44.13#	U	St	53.64	-6.21	O'Connell & Berrow, 2009
	25/03/2008	Donegal	c100	13.67#	U	St	55.25	-7.72	O'Connell & Berrow, 2009
	01/04/2008	Antrim	118	22.06	M	St	54.85	-5.79	O'Connell & Berrow, 2009
	15/04/2008	Donegal	120	23.16	U	St	54.56	-8.21	O'Connell & Berrow, 2009
	17/04/2008	Down	80	7.174	U	St	54.25	-5.68	O'Connell & Berrow, 2009
	23/04/2008	Meath	116	21	M	St	53.68	-6.23	O'Connell & Berrow, 2009
	03/05/2008	Louth	c130	29.18#	U	St	53.80	-6.22	O'Connell & Berrow, 2009
	10/05/2008	Down	NA	NA	F	St+	54.25	-5.77	O'Connell & Berrow, 2009
	10/05/2008	Down	NA	NA	U	St+	54.25	-5.77	O'Connell & Berrow, 2009
	13/05/2008	Waterford	c130	29.18#	U	St	52.09	-7.61	O'Connell & Berrow, 2009
	30/05/2008	Antrim	135	32.55	F	St	55.24	-6.45	O'Connell & Berrow, 2009
	16/06/2008	Donegal	160	53.18	U	St	54.50	-8.27	O'Connell & Berrow, 2009
	02/07/2008	Wexford	c160	53.18#	U	St	52.18	-6.55	O'Connell & Berrow, 2009
	15/07/2008	Dublin	c130	29.18#	U	St	53.27	-6.09	O'Connell & Berrow, 2009
	20/07/2008	Dublin	c100	13.67#	U	St	53.28	-6.09	O'Connell & Berrow, 2009
	08/08/2008	Wexford	c130	29.18#	U	St	52.13	-6.93	O'Connell & Berrow, 2009
	13/08/2008	Wexford	175	68.91	U	St	52.18	-6.55	O'Connell & Berrow, 2009
	28/08/2008	Down	NA	NA	M	St	54.25	-5.77	O'Connell & Berrow, 2009
	11/09/2008	Derry	c120	23.16#	U	St	55.19	-6.96	O'Connell & Berrow, 2009
	20/11/2008	Antrim	120	23.16	U	St	55.21	-6.63	O'Connell & Berrow, 2009
	14/12/2008	Clare	95	11.79	F	St	52.81	-9.49	O'Connell & Berrow, 2009
	30/12/2008	Donegal	100	13.67	U	St	54.50	-8.27	O'Connell & Berrow, 2009
	11/01/2009	Donegal	180	74.75	M	St	55.30	-7.15	O'Connell & Berrow, 2010
	22/01/2009	Wexford	158	51.29	F	St	52.20	-6.35	O'Connell & Berrow, 2010
	27/01/2009	Cork	135	32.55	F	St	51.57	-9.00	O'Connell & Berrow, 2010
	04/02/2009	Kerry	180	74.75	F	St	51.84	-10.21	O'Connell & Berrow, 2010

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
	07/02/2009	Wexford	170	63.37	F	St	52.49	-6.26	O'Connell & Berrow, 2010
	15/02/2009	Kerry	NA	NA	U	St	51.94	-10.30	O'Connell & Berrow, 2010
	16/02/2009	Kerry	156	49.43	U	St	51.82	-10.27	O'Connell & Berrow, 2010
	25/02/2009	Mayo	180	74.75	U	St	53.75	-9.90	O'Connell & Berrow, 2010
	09/03/2009	Derry	c150	44.13#	U	St	55.17	-6.73	O'Connell & Berrow, 2010
	24/03/2009	Derry	c100	13.67#	U	St	55.17	-6.88	O'Connell & Berrow, 2010
	01/04/2009	Cork	c150	44.13#	U	St	51.56	-8.97	O'Connell & Berrow, 2010
	06/04/2009	Donegal	166	59.15	M	St	55.16	-7.50	O'Connell & Berrow, 2010
	06/06/2009	Down	NA	NA	U	St	54.03	-6.04	O'Connell & Berrow, 2010
	10/06/2009	Louth	80	7.174	U	St	53.88	-6.34	O'Connell & Berrow, 2010
	11/06/2009	Louth	NA	NA	U	St	53.96	-6.37	O'Connell & Berrow, 2010
	17/06/2009	Dublin	NA	NA	U	St	53.48	-6.11	O'Connell & Berrow, 2010
	23/06/2009	Wicklow	NA	NA	U	St	52.89	-6.06	O'Connell & Berrow, 2010
	30/06/2009	Dublin	NA	NA	U	St	53.54	-6.08	O'Connell & Berrow, 2010
	30/06/2009	Dublin	74	5.727	M	St	53.61	-6.18	O'Connell & Berrow, 2010
	27/07/2009	Donegal	c100	13.67#	U	St	55.19	-7.05	O'Connell & Berrow, 2010
	27/07/2009	Wexford	NA	NA	M	St	52.20	-6.90	O'Connell & Berrow, 2010
	09/08/2009	Dublin	148	42.45	M	St	53.48	-6.11	O'Connell & Berrow, 2010
	14/09/2009	Wicklow	c100	13.67	M	St	52.98	-6.04	O'Connell & Berrow, 2010
	17/09/2009	Meath	NA	NA	U	St	53.68	-6.23	O'Connell & Berrow, 2010
	16/11/2009	Waterford	150	44.13	U	St	52.14	-7.37	O'Connell & Berrow, 2010
	03/12/2009	Antrim	NA	NA	M	St	55.22	-6.53	O'Connell & Berrow, 2010
	10/12/2009	Cork	NA	NA	M	St	51.56	-8.97	O'Connell & Berrow, 2010
IWDG 3462	14/01/2010	Waterford	NA	NA	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3466	16/01/2010	Antrim	145	40.01	M	St	54.75	-5.71	www.iwdg.ie
IWDG 3464	16/01/2010	Cork	NA	NA	U	St	51.64	-8.64	www.iwdg.ie
IWDG 3465	19/01/2010	Waterford	NA	NA	U	St	52.14	-7.27	www.iwdg.ie
IWDG 3467	22/01/2010	Wexford	NA	NA	U	St	52.19	-6.54	www.iwdg.ie
IWDG 3469	30/01/2010	Wexford	NA	NA	U	St	52.17	-6.84	www.iwdg.ie
IWDG 3484	26/04/2010	Waterford	NA	NA	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3481	27/04/2010	Antrim	NA	NA	F	St	55.22	-6.55	www.iwdg.ie

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
IWDG 3487	19/05/2010	Kerry	75	5.953	F	St	52.13	-10.37	www.iwdg.ie
IWDG 3491	07/06/2010	Wexford	136	33.25	M	St	52.19	-6.48	www.iwdg.ie
IWDG 3497	08/06/2010	Antrim	NA	NA	M	St	55.21	-6.61	www.iwdg.ie
IWDG 3498	12/06/2010	Mayo	NA	NA	U	St	54.10	-10.07	www.iwdg.ie
IWDG 3494	16/06/2010	Meath	60	3.124	F	St	53.68	-6.23	www.iwdg.ie
IWDG 3499	20/06/2010	Derry	90	10.08	U	St	55.17	-6.73	www.iwdg.ie
IWDG 3503	02/07/2010	Galway	c130	29.18#	U	St	53.25	-9.15	www.iwdg.ie
IWDG 3517	20/08/2010	Kerry	c150	44.13#	U	St	52.14	-9.98	www.iwdg.ie
IWDG 3526	19/09/2010	Waterford	c100	13.67#	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3532	09/10/2010	Kerry	133	31.17	F	St	52.13	-10.37	www.iwdg.ie
IWDG 3535	09/10/2010	Waterford	120	23.16	F	St	51.95	-7.72	www.iwdg.ie
IWDG 3538	14/10/2010	Mayo	NA	NA	U	St	53.71	-9.91	www.iwdg.ie
IWDG 3555	18/12/2010	Mayo	c130	29.18#	F	St	54.21	-9.12	www.iwdg.ie
IWDG 3556	20/12/2010	Cork	NA	NA	F	St	51.77	-8.31	www.iwdg.ie
IWDG 3557	29/12/2010	Waterford	c130	29.18#	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3558	02/01/2011	Donegal	c180	74.75	F	St	55.23	-6.94	www.iwdg.ie
IWDG 3567	22/01/2011	Kerry	150	44.13	U	St	52.14	-9.98	www.iwdg.ie
IWDG 3569	05/02/2011	Clare	c100	13.67#	M	St	53.11	-9.30	www.iwdg.ie
IWDG 3808	17/02/2011	Down	147	41.63	M	St+	54.22	-5.88	www.iwdg.ie
IWDG 3595	16/03/2011	Dublin	150	44.13	M	St	53.55	-6.08	www.iwdg.ie
IWDG 3593	21/03/2011	Waterford	c125	26.06#	M	St	52.16	-7.13	www.iwdg.ie
IWDG 3594	21/03/2011	Waterford	c135	32.55#	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3600	28/03/2011	Meath	130	29.18	F	St	53.64	-6.21	www.iwdg.ie
IWDG 3612	02/05/2011	Mayo	127	27.28	U	St	54.28	-9.25	www.iwdg.ie
IWDG 3614	08/05/2011	Cork	c90	10.08#	U	St	51.51	-8.13	www.iwdg.ie
IWDG 3613	08/05/2011	Kerry	c100	13.67#	U	St	52.39	-9.84	www.iwdg.ie
IWDG 3616	15/05/2011	Clare	c100	13.67#	U	St	53.15	-9.13	www.iwdg.ie
IWDG 3619	24/05/2011	Donegal	c70	4.877#	F	St+	54.63	-8.49	www.iwdg.ie
IWDG 3618	04/06/2011	Antrim	160	53.18	F	St	54.90	-5.86	www.iwdg.ie
IWDG 3630	14/06/2011	Antrim	73	5.506	M	St	55.21	-6.61	www.iwdg.ie
IWDG 3638	12/07/2011	Kerry	162	55.13	F	St	52.20	-10.43	www.iwdg.ie

APPENDIX VI. *Conti.*

UCC code	Date	County	Size	Weight	Sex	St/BC	Lat	Long	Source
IWDG 3641	14/07/2011	Cork	c113	19.46#	M	BC*	51.70	-8.44	www.iwdg.ie
IWDG 3640	26/07/2011	Wicklow	156	49.43	M	St	53.07	-6.03	www.iwdg.ie
IWDG 3659	06/08/2011	Cork	c180	74.75#	M	St	51.80	-8.18	www.iwdg.ie
IWDG 3656	26/08/2011	Mayo	80	7.174	U	St	53.73	-9.90	www.iwdg.ie
IWDG 3662	13/09/2011	Cork	170	63.37	U	St	51.79	-8.25	www.iwdg.ie
IWDG 3679	07/10/2011	Donegal	NA	NA	U	St	55.07	-8.32	www.iwdg.ie
IWDG 3680	07/10/2011	Mayo	126	26.66	F	St	54.16	10.09	www.iwdg.ie
IWDG 3678	08/10/2011	Wexford	154	47.62	U	St	52.19	-6.48	www.iwdg.ie
IWDG 3682	21/10/2011	Cork	149	43.29	M	St	51.86	-8.26	www.iwdg.ie
IWDG 3688	24/10/2011	Clare	117	21.52	M	St	53.02	-9.40	www.iwdg.ie
IWDG 3690	26/10/2011	Cork	128	27.91	F	St	51.80	-8.18	www.iwdg.ie
IWDG 3692	28/10/2011	Cork	171	64.45	F	St	51.79	-8.25	www.iwdg.ie
IWDG 3693	31/10/2011	Waterford	145	40.01	M	St	52.12	-7.46	www.iwdg.ie
IWDG 3697	01/11/2011	Cork	158	51.29	F	St	51.64	-8.58	www.iwdg.ie
IWDG 3700	06/11/2011	Wexford	160	53.18	M	St	52.39	-6.36	www.iwdg.ie
IWDG 3701	11/11/2011	Cork	120	23.16	U	St	51.77	-8.31	www.iwdg.ie
IWDG 3703	13/11/2011	Waterford	150	44.13	U	St	52.16	-7.13	www.iwdg.ie
IWDG 3705	15/11/2011	Dublin	NA	NA	U	St	53.50	-6.11	www.iwdg.ie
IWDG 3713	04/12/2011	Dublin	174	67.77	F	St	53.50	-6.11	www.iwdg.ie
IWDG 3718	06/12/2011	Donegal	c130	29.18	U	St	54.56	-8.21	www.iwdg.ie
IWDG 3715	09/12/2011	Galway	108	17.08	M	St	53.26	-9.07	www.iwdg.ie
IWDG 3722	16/12/2011	Clare	142	37.67	U	St	53.12	-9.15	www.iwdg.ie
IWDG 3720	20/12/2011	Sligo	150	44.13	M	St	54.47	-8.45	www.iwdg.ie
			132.9	**34.7**	**160F:185M**				

Appendix VII. Annual food consumption (tonnes) of the main prey of bottlenose dolphin (BND), harbour porpoise (HP), harbour seal (CS) and grey seal (GS), after applying equal weighting (E weighting), and after applying the weighting related to the body weight of the animal (D weight and S weigth).

	BND E weighting	BND D weight	HP El weighting	HP D weight	CS E weighting	CS S weight	GS E weighting	GS S weight
Whiting/blue whiting	136.4	57.37	4,496.0	3,546.0	133.02	250.0	658.0,	751.8
Pollack/saithe/haddock	166.5	267.8	2,216.0	2,814.0	222.2	409.7	281.5	316.4
Trisopterus spp.	29.79	32.89	3,614.0	931.2	438.6	285.4	841.1	519.6
Other Gadoids	61.98	64.56	13,637.0	15,558.0	1,264.4	842.0	908.3	511.6
Atlantic hake	211.7	187.3	703.8	66.14	41.4	14.4	69.3	39.5
Pelagic fish	51.57	49.22	16,215.0	18,756.0	363.4	404.6	138.5	250.7
Demersal species	193.8	319.1	857.3	68.56	1,389.2	1,578.1	2,811.6	3,325.2
Cephalopods	147.4	20.9	0	0	35.4	103.5	85.8	79.0
Total	**999.2**	**999.2**	**41,739.0**	**41,739.0**	**3,887.6**	**3,887.6**	**5,793.9**	**5,793.9**

Appendix VIII. Population abundance of seabirds used in the Ecopath model for the Irish Sea, and biomass estimated for the Irish Sea. M: males, F: females; W: weight

Species	**Abundance**	**Weight (M/F)**	**Weight (average)**	**W(tonnes)*num**	**Biomass**	**Source**
Northern fulmar	16,100	880/730	805	12.96	0.0002	Phillips et al. (1999)
Manx shearwater	15,700	420/420	420	6.59	0.0001	Thompson (1987)
Northern Gannet	3,200	3,000/3,000	3,000	9.6	0.0002	Stauss et al. (2012) Hamer et al. (2000)
Great Cormorant	4,500	2,500/2,100	2,300	9.66	0.0002	Kirby et al. (1996) Lilliendhal & Soldmusson (2006) Barret et al. (1990)
European shag	3,000	1,900/1,900	1,900	5.7	<0.0000	Watanuki et al. (2008) Lilliendhal & Soldmusson (2006) Barret et al. (1990)
Black-headed gull	25,500	330/250	290	7.39	0.0001	No information available
Lesser black-backed gull	34,600	830/830	830	28.72	0.0005	Bustness et al. (2010) Campuysen (2013)
Herring gull	37,300	1,200/1,200	1,200	44.76	0.0008	Campuysen (2013)
Great black-backed gull	1,200	1,700/1,700	1,700	2.04	<0.0000	Steenweg et al. (2011)
Black-legged kittiwake	16,000	410/410	410	6.56	0.0001	Phillips et al. (1999)
Common gull	2,805	400/400	400	1.12	<0.0000	
Roseate tern	620	110/110	110	0.07	<0.0000	Newton & Crowe (2000)
Common tern	2,500	130/130	130	0.33	<0.0000	
Arctic tern	160	110/110	110	0.02	<0.0000	Newton & Crowe (2000)
Little tern	50	56/56	56	0.003	<0.0000	Newton & Crowe (2000)
Common guillemot	74,000	690/690	690	51.06	0.0009	Phillips et al. (1999)
Razorbill	8,000	710/710	710	5.68	<0.0000	Phillips et al. (1999)
Black Guillemot	1,700	420/420	420	0.71	<0.0000	Cairns (1987) Ewins (1990)
Atlantic puffin	300	400/400	400	0.12	<0.0000	Phillips et al. (1999)
Total				**193.0971**	**0.0033**	

Appendix IX. Basic input and estimated parameters for the initial Irish Sea model. Biomas in tonees/km2, Production/Biomass and consumption/Biomass per year.

Functional Groups	Biomass	Production/Biomass	Consumption/Biomass	Production/Consumption	Ecotrophic Efficiency	Trophic level
Bottlenose Dolphin	0.0016	0.2	13.11	0.0152555	0.0	5.966676
Harbour Porpoise	0.010529	0.2	13.11	0.0152555	0.29725	5.637544
Minke Whale	0.089	0.2	11.38	0.0175747	0.009685	5.78671
Common Seal	0.0004589	0.06	15.93	0.0037664	0.514493	5.529809
Grey Seal	0.004014655	0.06	15.93	0.0037664	0.183707	5.660017
Seabirds	0.0033	1.074632	82.664	0.01300	0.0	5.241061
Basking Shark	0.001564	0.07	3.7	0.0189189	0.000916	4.43257
Adult Cod 2+	0.181533	1.2587	3.6728	0.34270856	8.00706	5.309222
Juvenile Cod 1+	0.069587	2.5174	7.3456	0.34270856	1.11382	4.746251
Adult Haddock 2+	0.050966	1.224	4.8521	0.2522619	29.31494	4.183316
Juvenile Haddock 1+	0.040935	2.448	9.7042	0.2522619	11.41453	4.260849
Adult Plaice 2+	0.152325	0.611	4.438	0.1376746	14.13995	3.943902
Juvenile Plaice 1+	0.028741	1.222	8.876	0.1376746	0.354477	4.125004
Whiting	0.842	0.842	5.941	0.14172698	22.49139	4.496224
Sole	0.068402	0.5094	4.572	0.111417323	45.31525	3.665394
Salmonids	0.0191	0.53	6.67	0.079460269	0.326399	4.72303
Sandeels	2.014	1.287	7.8975	0.16296296	32.00173	5.13222
Small flatfish	0.097	1.5555	11.104	0.14008465	4.102337	4.464752
Medium Flatfish	8.919	1.0072	6.56	0.153536585	0.013981	4.786492
Large Flatfish	0.0794	0.6435	4.3168	0.149068755	0.010528	5.459415
Dragonets	0.171	1.0004	8.3811	0.11936381	0.551492	4.505725
Other Large Demersal	0.199	0.5932	4.1326	0.143541596	0.292401	5.227981
Mackerel	1.623	1.0814	7.0076	0.154318169	0.233459	4.682344
Monkfish	0.652	0.4008	2.0814	0.192562698	22.39125	5.312552
Other Large Gadoids	0.194	0.6969	3.6678	0.190004908	2.471884	4.998682
Other Small Demersal	1.6	1.57	5.421	0.289614462	1.644441	4.146628
Other Small Gadoids	0.974	1.0089	7.21	0.139930652	1.539948	3.950613
Small Pelagic Planktivorous	3.643	0.727	6.516	0.111571516	15.54383	4.145975
Small Sharks	1.874	0.972	9.72	0.1	0.098308	5.186267
Large Sharks	0.115	0.318	3.18	0.1	0.003883	5.259037

Appendix IX. *Cont.*

Functional Groups	**Biomass**	**Production/Biomass**	**Consumption/Biomass**	**Production/Consumption**	**Ecotrophic Efficiency**	**Trophic level**
Skates and Rays	0.714	1.6	16	0.1	0.016508	4.404188
Epifaunal Macrobenthos	9.810	0.561	3.74	0.15	21.97516	4.222087
Epifaunal Mesobenthos	0.6918	1.062	7.08	0.15	12.68784	3.959169
Infauna (Polychaeta)	0.00063	1.683	11.22	0.15	58401.45	2
Infaunal macrobenthos	0.111	0.695	4.63333333	0.15	232.3028	4.31122
Infaunal mesobenthos	0.0605	1.552	10.34666667	0.15	85.16164	3.163234
Lobster and Large crabs	0.0943	0.783	5.22	0.15	0.342941	2.91298
Nephrops	0.203	0.78	5.2	0.15	2.567548	3.223832
Cephalopods	0.25	2.47	15	0.164666667	3.114599	4.552321
Prawns and Shrimp	0.0335	0.959	6.393333333	0.15	619.1182	2.818702
Sessile Epifauna	13.944	0.066	0.44	0.15	0.836439	3.049722
Meiofauna	0.11	17.8	118.666666667	0.15	0.992534	2.10989
Gelatinous zooplankton	1.1	7	23.33	0.300042863	1.747535	4.43257
Carnivorous zooplankton	0.006	18	60	0.3	61.17472	4.189313
Omnivorous zooplankton	0.137	18	60	0.3	28.8718	3.04542
Herbivorous zooplankton	0.076	18	60	0.3	35.12225	2.062977
Seaweed	75	60	-	-	0.0002	1
Microflora	3.92	587		-	0.007395	1
Phytoplankton	9.667	152.5		-	0.004044	1
Particulate organic matter	50	-	-	-	0.004417	1
Dissolved organic matter	50	-	-	-	0.000828	1
Discards	0.290	-	-	-	0.164529	1

Appendix X. Diet matrix included in the final model of the Irish Sea

Predator **Prey**	**Bottlenose Dolphin**	**Harbour Porpoise**	**Minke Whale**	**Common Seal**	**Grey Seal**	**Seabirds**	**Basking shark**
Bottlenose Dolphin	0	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0	0
Juvenile Cod 1+	0	0.0059	0	0	0	0.0105	0
Adult Haddock 2+	0.0593	0	0	0	0	0	0
Juvenile Haddock 1+	0	0.0135	0	0	0	0	0
Adult Plaice 2+	0.0027	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0.0032	0	0	0
Whiting	0.0259	0.5142	0	0.0449	0.0343	0.009	0
Sole	0.0012	0	0	0.11	0.0301	0	0
Salmonids	0.0101	0	0	0.0081	0.1452	0.0114	0
Sandeels	0	0.2465	0.6171	0.1038	0.016	0.2635	0
Small flatfish	0	0	0	0	0	0	0
Medium Flatfish	0.006	0	0	0.0463	0.0205	0.0228	0
Large Flatfish	0.0006	0	0	0	0.0075	0	0
Dragonets	0	0	0	0.0371	0.0055	0	0
Other Large Demersal	0.4606	0	0	0.2795	0.1872	0.0177	0
Mackerel	0.0126	0.0149	0.0583	0	0.0509	0.0455	0
Monkfish	0	0	0	0	0	0	0
Other Large Gadoids	0.3347	0.0671	0.001	0.012	0.188	0.0137	0
Other Small Demersal	0.0001	0.0003	0	0.011	0.0337	0.1094	0
Other Small Gadoids	0.0408	0.0812	0	0.251	0.12	0.1111	0
Small Pel. Planktivorous	0.0207	0.0221	0.3236	0.074	0.1216	0.2349	0
Small Sharks	0.0118	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0	0
Epifaunal Macrobenthos	0	0	0	0	0	0.0397	0
Epifaunal Mesobenthos	0	0	0	0	0	0.0208	0
Infauna (Polychaeta)	0	0	0	0	0	0	0
Infaunal macrobenthos	0	0	0	0	0	0.0007	0
Infaunal Mesobenthos	0	0	0	0	0	0.0007	0
Lobster and Large Crabs	0	0	0	0	0	0	0
Nephrops	0	0	0	0	0	0	0
Cephalopods	0.0129	0.0343	0	0.0191	0.0395	0.0003	0
Prawns and Shrimp	0	0	0	0	0	0	0
Sesile Epifauna	0	0	0	0	0	0	0
Meiofauna	0	0	0	0	0	0	0
Gellatinous Zooplankton	0	0	0	0	0	0	0.25
Carnivorous zzoplankton	0	0	0	0	0	0.0157	0.25
Omnivorous zooplankton	0	0	0	0	0	0	0.25
Herbivorous zooplankton	0	0	0	0	0	0	0.25
Seaweed	0	0	0	0	0	0	0
Microflora	0	0	0	0	0	0	0
Phytoplankton	0	0	0	0	0	0	0
Particulate organic matter	0	0	0	0	0	0	0
Dissolved organic matter	0	0	0	0	0	0	0
Discards	0	0	0	0	0	0.0726	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont.*

Predator Prey	Adult Cod 2+	Juvenile Cod 1+	Adult Haddock 2+	Juvenile Haddock 1+	Adult Plaice 2+	Juvenile Plaice 1+	Whiting
Bottlenose Dolphin	0	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0	0
Juvenile Cod 1+	0.0075	0	0	0	0	0	0
Adult Haddock 2+	0	0	0	0	0	0	0
Juvenile Haddock 1+	0.005	0	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0	0	0
Whiting	0	0	0	0	0	0	0
Sole	0	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0	0
Sandeels	0.2067	0	0.0207	0	0.0043	0	0
Small flatfish	0	0	0	0	0	0	0
Medium Flatfish	0.0105	0	0	0	0	0	0
Other Large Flatfish	0	0	0	0	0	0	0
Dragonets	0.0026	0	0	0	0.0043	0	0
Other Large Demersal	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0
Monkfish	0	0	0	0	0	0	0
Large Gadoids	0	0	0	0	0	0	0
Other Small Demersal	0.1006	0	0.0207	0	0.0043	0	0.1836
Other Small Gadoids	0.1787	0	0	0	0	0	0
Small Pel. Planktivorous	0.1351	0	0.0207	0	0	0	0.1834
Small Sharks	0	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0	0
Epifaunal Macrobenthos	0.109	0.1	0.1568	0.14	0.0845	0.027	0
Epifaunal Mesobenthos	0	0	0	0	0	0	0.0617
Infauna (Polychaeta)	0.0035	0.05	0.1371	0.1	0.4256	0.174	0.037
Infaunal macrobenthos	0.0009	0.05	0.0227	0.1	0.1581	0.1507	0.042
Infaunal Mesobenthos	0	0	0	0	0	0	0.022
Lobster and Large Crabs	0.0131	0	0	0	0	0	0
Nephrops	0	0	0	0	0	0	0
Cephalopods	0.1552	0	0	0	0	0	0
Prawns and Shrimp	0.042	0	0.0949	0	0	0	0.1853
Sesile Epifauna	0.0026	0	0	0	0.0039	0	0
Meiofauna	0	0	0	0	0	0	0
Gellatinous Zooplankton	0	0	0	0	0	0	0
Carnivorous zzoplankton	0.0192	0.595	0.1504	0.18	0.0456	0.0929	0.095
Omnivorous zooplankton	0.0078	0.1	0.2015	0.305	0.2409	0.4923	0.095
Herbivorous zooplankton	0	0.1	0.1745	0.17	0.0285	0.0581	0.095
Seaweed	0	0	0	0	0	0	0
Microflora	0	0	0	0	0	0	0
Phytoplankton	0	0.005	0	0.005	0	0.005	0
Particulate organic matter	0	0	0	0	0	0	0
Dissolved organic matter	0	0	0	0	0	0	0
Discards	0	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*..

Predator **Prey**	**Sole**	**Salmonids**	**Sandeels**	**Small flatfish**	**Medium Flatfish**	**Large Flatfish**	**Dragonets**
Bottlenose Dolphin	0	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0.002	0.01	0
Juvenile Cod 1+	0	0.0053	0	0	0	0.1	0
Adult Haddock 2+	0	0	0	0	0.002	0.01	0
Juvenile Haddock 1+	0	0	0	0	0	0.1	0
Adult Plaice 2+	0	0	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0	0	0
Whiting	0	0.0048	0.0194	0	0.002	0	0
Sole	0	0	0	0	0	0	0
Salmonids	0	0	0	0	0	0	0
Sandeels	0.1275	0.1327	0.3613	0	0.02	0.28	0
Small flatfish	0	0	0.0257	0	0.002	0	0
Medium Flatfish	0	0.0526	0	0	0.002	0	0
Large Flatfish	0	0	0	0	0	0	0
Dragonets	0	0	0	0	0.135	0	0
Other Large Demersal	0	0.021	0	0	0	0	0
Mackerel	0	0	0	0	0.005	0	0
Monkfish	0	0	0	0	0.1	0	0
Other Large Gadoids	0	0	0	0	0.001	0	0
Other Small Demersal	0	0.0625	0.0242	0.067	0.05	0.001	0
Other Small Gadoids	0	0.143	0.0132	0	0.0646	0.177	0
Small Pel. Planktivorous	0	0.1646	0.0691	0	0.038	0.122	0
Small Sharks	0	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0	0
Epifaunal Macrobenthos	0.108	0.0015	0.0444	0.2	0.154	0.025	0.642
Epifaunal Mesobenthos	0	0	0	0	0.0021	0.025	0
Infauna (Polychaeta)	0.7532	0.0741	0.0284	0.2	0.114	0.025	0.286
Infaunal macrobenthos	0.0113	0	0.0675	0	0	0.025	0
Infaunal Mesobenthos	0	0	0	0	0	0	0
Lobster and Large Crabs	0	0	0	0	0	0	0
Nephrops	0	0	0	0	0.0009	0	0
Cephalopods	0	0.0005	0	0.2	0.007	0.1	0
Prawns and Shrimp	0	0.0892	0.0493	0	0.107	0	0
Sesile Epifauna	0	0	0	0	0.0004	0	0
Meiofauna	0	0	0	0	0	0	0
Gellatinous Zooplankton	0	0.0005	0	0	0	0	0
Carnivorous zzoplankton	0	0.093	0.11	0.111	0.0745	0	0.024
Omnivorous zooplankton	0	0.0834	0.1461	0.111	0.0745	0	0.024
Herbivorous zooplankton	0	0.0018	0.0145	0.111	0.042	0	0.024
Seaweed	0	0.0059	0	0	0	0	0
Microflora	0	0	0	0	0	0	0
Phytoplankton	0	0.0059	0.018	0	0	0	0
Particulate organic matter	0	0.0577	0.0089	0	0	0	0
Dissolved organic matter	0	0	0	0	0	0	0
Discards	0	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*.

Predator **Prey**	**Other Large Demersal**	**Mackerel**	**Monkfish**	**Large Gadoids**	**Other Small Demersal**	**Other Small Gadoids**
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0.0998	0.05	0	0
Juvenile Cod 1+	0.0362	0.0019	0	0	0	0
Adult Haddock 2+	0	0	0.0998	0.05	0	0
Juvenile Haddock 1+	0.1837	0.0006	0	0	0	0
Adult Plaice 2+	0	0	0.095	0	0	0
Juvenile Plaice 1+	0	0.0001	0	0	0	0
Whiting	0.0432	0.0002	0.01	0.001	0	0
Sole	0	0	0.0798	0.069	0	0
Salmonids	0	0	0	0	0	0
Sandeels	0	0.2028	0	0.045	0	0
Small flatfish	0	0	0.0858	0.001	0	0.002
Medium Flatfish	0	0.0003	0.0768	0	0	0.003
Large Flatfish	0	0	0	0	0	0
Dragonets	0	0.001	0.096	0.001	0	0.015
Other Large Demersal	0.0005	0	0	0	0	0
Mackerel	0.1313	0.0009	0.124	0.122	0	0
Monkfish	0	0	0	0	0	0
Other Large Gadoids	0.0001	0	0.01	0.014	0	0
Other Small Demersal	0.0488	0.0012	0.038	0.022	0	0.023
Other Small Gadoids	0.2023	0.0401	0.134	0.134	0	0.008
Small Pel. Planktivorous	0.3461	0.0707	0	0.2033	0	0.007
Small Sharks	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0
Epifaunal Macrobenthos	0	0.0246	0.01	0.015	0.033	0.098
Epifaunal Mesobenthos	0	0	0	0.01	0.013	0.087
Infauna (Polychaeta)	0	0.0035	0.01	0	0	0.023
Infaunal macrobenthos	0	0.0001	0	0	0	0
Infaunal Mesobenthos	0	0	0	0	0	0
Lobster and Large Crabs	0	0	0.007	0	0	0
Nephrops	0	0	0.005	0.0007	0	0
Cephalopods	0.001	0.0077	0	0.018	0	0.002
Prawns and Shrimp	0.006	0.0203	0.019	0.076	0.003	0.121
Sesile Epifauna	0	0.0021	0	0	0	0
Meiofauna	0	0	0	0	0	0
Gellatinous Zooplankton	0	0.0196	0	0	0	0
Carnivorous zzoplankton	0.0008	0.2003	0	0.056	0.317	0.149
Omnivorous zooplankton	0	0.2005	0	0.056	0.317	0.149
Herbivorous zooplankton	0	0.2009	0	0.056	0.317	0.149
Seaweed	0	0.0003	0	0	0	0
Microflora	0	0	0	0	0	0
Phytoplankton	0	0.0003	0	0	0	0
Particulate organic matter	0	0	0	0	0	0.164
Dissolved organic matter	0	0	0	0	0	0
Discards	0	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*.

Predator Prey	Small Pelagic Planktivorous	Small Sharks	Large Sharks	Skates and Rays	Epifaunal Macrobenthos
Bottlenose Dolphin	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0
Minke Whale	0	0	0	0	0
Common Seal	0	0	0	0	0
Grey Seal	0	0	0	0	0
Seabirds	0	0	0	0	0
Basking Shark	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0
Juvenile Cod 1+	0	0	0	0	0
Adult Haddock 2+	0	0	0	0	0
Juvenile Haddock 1+	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0
Whiting	0	0	0	0.008	0
Sole	0	0	0	0	0
Salmonids	0	0	0	0	0
Sandeels	0	0	0.134	0.004	0
Small flatfish	0	0	0.134	0.001	0
Medium Flatfish	0	0	0	0.003	0
Large Flatfish	0	0	0	0	0
Dragonets	0	0	0	0.018	0
Other Large Demersal	0	0	0	0	0
Mackerel	0	0	0	0.006	0
Monkfish	0	0	0	0	0
Other Large Gadoids	0	0	0	0	0
Other Small Demersal	0.01	0	0.034	0.057	0
Other Small Gadoids	0	0	0.174	0.007	0
Small Pel. Planktivorous	0.002	0	0.154	0.008	0
Small Sharks	0	0	0	0.006	0
Large Sharks	0	0	0	0	0
Skates and Rays	0	0	0	0.003	0
Epifaunal Macrobenthos	0.028	0.665	0.314	0.251	0.16
Epifaunal Mesobenthos	0.006	0.015	0	0.031	0.16
Infauna (Polychaeta)	0.002	0.035	0	0.021	0.16
Infaunal macrobenthos	0	0.2	0.001	0	0.16
Infaunal Mesobenthos	0	0	0.001	0	0.16
Lobster & Large Crabs	0	0	0.04	0	0
Nephrops	0	0	0	0.001	0
Cephalopods	0.001	0.085	0	0.007	0
Prawns and Shrimp	0.006	0	0.001	0.453	0
Sesile Epifauna	0	0	0	0	0.006
Meiofauna	0	0	0	0	0
Gellatinous Zooplankton	0	0	0.01	0	0.019
Carnivorous zooplankton	0.315	0	0.001	0.036	0.019
Omnivorous zooplankton	0.315	0	0.001	0.036	0.019
Herbivorous zooplankton	0.315	0	0.001	0.036	0.019
Seaweed	0	0	0	0	0.018
Microflora	0	0	0	0	0.018
Phytoplankton	0	0	0	0	0.019
Particulate organic matter	0	0	0	0.007	0.026
Dissolved organic matter	0	0	0	0	0.019
Discards	0	0	0	0	0.018
Sum	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*.

Predator **Prey**	**Epifaunal Mesobenthos**	**Infauna Polychaeta**	**Infaunal macrobenthos**	**Infaunal Mesobenthos**	**Lobster and Large Crabs**
Bottlenose Dolphin	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0
Minke Whale	0	0	0	0	0
Common Seal	0	0	0	0	0
Grey Seal	0	0	0	0	0
Seabirds	0	0	0	0	0
Basking Shark	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0
Juvenile Cod 1+	0	0	0	0	0
Adult Haddock 2+	0	0	0	0	0
Juvenile Haddock 1+	0	0	0	0	0
Adult Plaice 2+	0	0	0	0	0
Juvenile Plaice 1+	0	0	0	0	0
Whiting	0	0	0	0	0
Sole	0	0	0	0	0
Salmonids	0	0	0	0	0
Sandeels	0	0	0	0	0
Small flatfish	0	0	0	0	0
Medium Flatfish	0	0	0	0	0
Large Flatfish	0	0	0	0	0
Dragonets	0	0	0	0	0
Other Large Demersal	0	0	0	0	0
Mackerel	0	0	0	0	0
Monkfish	0	0	0	0	0
Other Large Gadoids	0	0	0	0	0
Other Small Demersal	0	0	0	0	0
Other Small Gadoids	0	0	0	0	0
Small Pel. Planktivorous	0	0	0	0	0
Small Sharks	0	0	0	0	0
Large Sharks	0	0	0	0	0
Skates and Rays	0	0	0	0	0
Epifaunal Macrobenthos	0	0	0.132	0	0.05
Epifaunal Mesobenthos	0.32	0	0.132	0.025	0.05
Infauna (Polychaeta)	0.32	0	0.133	0.025	0
Infaunal macrobenthos	0	0	0.124	0	0.05
Infaunal Mesobenthos	0.32	0	0.1258	0.025	0.05
Lobster and Large Crabs	0	0	0	0	0.03
Nephrops	0	0	0	0	0
Cephalopods	0	0	0	0	0
Prawns and Shrimp	0	0	0	0	0.15
Sesile Epifauna	0	0	0	0.01	0
Meiofauna	0	0	0.0112	0.015	0
Gellatinous Zooplankton	0	0	0.069	0.1	0
Carnivorous zzoplankton	0	0	0.068	0.1	0
Omnivorous zooplankton	0	0	0.069	0.1	0
Herbivorous zooplankton	0	0	0.068	0.1	0
Seaweed	0.04	0	0	0	0
Microflora	0	0.33	0	0.1	0
Phytoplankton	0	0	0	0.1	0
Particulate organic matter	0	0.34	0.068	0.1	0.62
Dissolved organic matter	0	0.33	0	0.1	0
Discards	0	0	0	0.1	0
Sum	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*.

Predator / Prey	***Nephrops***	**Cephalopods**	**Prawns and Shrimp**	**Sesile Epifauna**	**Meiofauna**	**Gelatinous Zooplankton**
Bottlenose Dolphin	0	0	0	0	0	0
Harbour Porpoise	0	0	0	0	0	0
Minke Whale	0	0	0	0	0	0
Common Seal	0	0	0	0	0	0
Grey Seal	0	0	0	0	0	0
Seabirds	0	0	0	0	0	0
Basking Shark	0	0	0	0	0	0
Adult Cod 2+	0	0	0	0	0	0
Juvenile Cod 1+	0	0.01	0	0	0	0
Adult Haddock 2+	0	0	0	0	0	0
Juvenile Haddock 1+	0	0.01	0	0	0	0
Adult Plaice 2+	0	0	0	0	0	0
Juvenile Plaice 1+	0	0.01	0	0	0	0
Whiting	0	0.01	0	0	0	0
Sole	0	0.01	0	0	0	0
Salmonids	0	0	0	0	0	0
Sandeels	0	0.01	0	0	0	0
Small flatfish	0	0	0	0	0	0
Medium Flatfish	0	0.01	0	0	0	0
Large Flatfish	0	0	0	0	0	0
Dragonets	0	0	0	0	0	0
Other Large Demersal	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0
Monkfish	0	0	0	0	0	0
Other Large Gadoids	0	0	0	0	0	0
Other Small Demersal	0.007	0.01	0	0	0	0
Other Small Gadoids	0.002	0.01	0	0	0	0
Small Pel. Planktivorous	0	0.03	0	0	0	0
Small Sharks	0	0	0	0	0	0
Large Sharks	0	0	0	0	0	0
Skates and Rays	0	0	0	0	0	0
Epifaunal Macrobenthos	0.07	0.02	0	0	0	0
Epifaunal Mesobenthos	0.07	0.02	0	0	0	0
Infauna (Polychaeta)	0.05	0.01	0	0	0.01	0
Infaunal macrobenthos	0.07	0.02	0	0	0	0
Infaunal Mesobenthos	0.07	0.02	0	0	0	0
Lobster and Large Crabs	0	0	0	0	0	0
Nephrops	0	0	0	0	0	0
Cephalopods	0	0	0	0	0	0
Prawns and Shrimp	0	0	0	0	0	0
Sesile Epifauna	0.161	0	0	0	0	0
Meiofauna	0	0	0	0	0.09	0
Gellatinous Zooplankton	0	0.19	0	0	0	0.25
Carnivorous zooplankton	0	0.2	0.13	0.1667	0	0.25
Omnivorous zooplankton	0	0.2	0.13	0.1667	0	0.25
Herbivorous zooplankton	0	0.2	0.13	0.1666	0	0.25
Seaweed	0	0	0	0	0	0
Microflora	0	0	0	0.125	0.7	0
Phytoplankton	0	0	0.01	0.125	0	0
Particulate organic matter	0	0	0.08	0.125	0.2	0
Dissolved organic matter	0	0	0.52	0.125	0	0
Discards	0.5	0	0	0	0	0
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Appendix X. *Cont*..

Predator / Prey	Carnivorous zooplankton	Omnivorous zooplankton	Herbivorous zooplankton
Bottlenose Dolphin	0	0	0
Harbour Porpoise	0	0	0
Minke Whale	0	0	0
Common Seal	0	0	0
Grey Seal	0	0	0
Seabirds	0	0	0
Basking Shark	0	0	0
Adult Cod 2+	0	0	0
Juvenile Cod 1+	0	0	0
Adult Haddock 2+	0	0	0
Juvenile Haddock 1+	0	0	0
Adult Plaice 2+	0	0	0
Juvenile Plaice 1+	0	0	0
Whiting	0	0	0
Sole	0	0	0
Salmonids	0	0	0
Sandeels	0	0	0
Small flatfish	0	0	0
Medium Flatfish	0	0	0
Large Flatfish	0	0	0
Dragonets	0	0	0
Other Large Demersal	0	0	0
Mackerel	0	0	0
Monkfish	0	0	0
Other Large Gadoids	0	0	0
Other Small Demersal	0	0	0
Other Small Gadoids	0	0	0
Small Pel. Planktivorous	0	0	0
Small Sharks	0	0	0
Large Sharks	0	0	0
Skates and Rays	0	0	0
Epifaunal Macrobenthos	0	0	0
Epifaunal Mesobenthos	0	0	0
Infauna (Polychaeta)	0	0	0
Infaunal macrobenthos	0	0	0
Infaunal Mesobenthos	0	0	0
Lobster and Large Crabs	0	0	0
Nephrops	0	0	0
Cephalopods	0	0	0
Prawns and Shrimp	0	0	0
Sesile Epifauna	0	0	0
Meiofauna	0	0	0
Gellatinous Zooplankton	0.225	0	0
Carnivorous zooplankton	0.225	0.166	0.01
Omnivorous zooplankton	0.225	0.166	0.01
Herbivorous zooplankton	0.225	0.166	0.01
Seaweed	0	0	0
Microflora	0	0	0
Phytoplankton	0	0.166	0.035
Particulate organic matter	0.0475	0.166	0.9
Dissolved organic matter	0.0525	0.17	0.035
Discards	0	0	0
Sum	**1**	**1**	**1**