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Impact Assessment of Hand and Mechanical Harvesting of *Ascophyllum nodosum* on Regeneration and Biodiversity

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SUMMARY

This preliminary study assessed over an 18-month period the effect of mechanical and hand harvesting on seaweed regeneration and biodiversity while also assessing the costs and benefits of mechanical means of harvesting *Ascophyllum nodosum* in Ireland. Two study sites were used, one in Clew Bay Co. Mayo and the other in south Connemara, Co. Galway, each typical of different types of shore that harvesting takes place from. Sampling was quantitative, stratified by height on the shore and conducted before and after harvesting. According to the results of this preliminary study traditional hand harvesting was clearly more effective and cost efficient than the mechanical harvesting. However, it is recognised that this trial was a first of its kind for mechanical harvesting of seaweed in Ireland and as such could be expected to encounter various operational and design difficulties that with modification could result in greater harvesting efficiency in the future.

Rare species of fauna were generally typical of sediment and sublittoral rather than *Ascophyllum* biotopes. Species richness differed between the Connemara site with 97 taxa and the Clew Bay site with 87 taxa, and varied from the upper to lower shore at both sites. Richness varied over time but an effect of harvesting was not detected. *Ascophyllum nodosum* cover decreased significantly after harvesting and was nearing recovery after 17 months in Connemara and 11 months in Clew Bay. No significant effects or changes in red algae or *Fucus serratus* could be attributed to harvesting. However, increases in ephemeral algae cover in the midshore after harvesting may have been facilitated by removal of the *Ascophyllum* canopy. *Fucus vesiculosus* significantly increased in cover after harvesting at both sites. At the Connemara site the abundance of the periwinkle *Littorina obtusata* increased in the control and decreased in the hand-harvested sections of seashore during the winter. The species was less abundant at the Clew Bay site and no significant seasonal or harvesting trends were apparent. The numbers and cover of other animals, both mobile and sessile, were low which limited analysis. However, the cover of sessile fauna was significantly variable over time in hand-harvested sections at both sites whereas controls were not.

CONTENTS

1. INTRODUCTION

Harvesting of the perennial brown seaweed *Ascophyllum nodosum* (Linnaeus) Le Jolis (commonly known as Asco) occurs widely along the coasts of countries in the temperate zone on both sides of the North Atlantic. The species is harvested commercially in Canada, the United States, Scotland*[1], France, Norway, Iceland and Ireland. Various harvesting practices are used; however the species is predominantly hand-harvested using sickles and various cutting and raking tools. As the seaweed industry throughout the world is growing, so too are the harvesting and processing technological advances associated with it. Iceland, and Norway have been to the forefront in developing and using mechanical means for harvesting Asco. Interestingly, in Nova Scotia (Canada) they have reverted from Norwegian-type mechanical harvesting to hand cutting and a rake-type method of harvesting following blatant over-exploitation of Asco beds by machine in the early 1990s (Sharp *et al*. 1994). In Ireland, the traditional means of hand harvesting using a sickle or a knife is the current practice, and apparently has been unchanged for centuries. Ireland's resource of Asco could be described as very healthy and currently under-utilised by about 50% (Hession *et al*.,1998). However, while hand gathering has served well to date there is valid concern regarding the continuation of supply by hand harvesting in the future. During the 1990s the decline of young people starting into seaweed harvesting has accelerated due to the economic boom of the later 1990s, and with the ongoing retirement of older harvesters a shortage of harvesters in the near future seems inevitable. A drop in harvesting capacity in the future caused by a lack of an alternative means to hand harvesting would be a potentially serious barrier to the continuation, and development of seaweed-based products in Ireland. Hence the importance of active consideration of mechanisation and its attendant environmental impact assessment.

In Ireland harvesting of Asco is not without its limitations and problems. Seaweed harvesting has at times been a contentious issue in particular bays due to conflict regarding perceived seaweed harvesting rights and a previous lack of clarity regarding State legislation on the matter (Hession *et al*., 1998). In addition, much of the harvesting activity that takes place along the west coast occurs in areas that may*[2] be subject to notifiable action in accordance with Special Areas of Conservation (SAC) legislation in the European Communities (Natural Habitats) Regulations, 1997 (S.I. No. 94 of 1997). To assure long-term conservation and sustainability of the *Ascophyllum nodosum* resource and its associated biodiversity, it is paramount that the effects of harvesting activity are monitored in a comprehensive and definitive manner. The effects of seaweed harvesting, and in particular the harvesting *of Ascophyllum nodosum* (also known as Knotted Wrack or Asco and in Irish as *Feamainn bhuí*) have been reported by few.

Information has become available throughout the years, but no significant or substantial analysis has been carried out on the direct effects of hand and mechanical harvesting on biodiversity and plant regeneration. Ang *et al.* (1993), Ang *et al.* (1996), Bardseth (1955), Cousens (1986), Emerson and Zedler (1978), Lazo *et al*, (1994), Lazo & Chapman 1996, Keser *et al.* (1981), Stengel & Dring (1997)**,** Sharp & Pringle (1990), are just a few of the studies that focus on aspects of the ecology or regeneration of a disturbed *Ascophyllum* bed. However, only two studies looked at the impacts of *A. nodosum* harvesting on associated communities. Black & Miller (1991) examined the possible impact of hand harvesting of *A. nodosum.* Various studies have assessed the impact of

[1] Since 1998 harvesting of Asco in Scotland is greatly reduced with only a fraction of the available biomass harvested.

[2] See section on Special Areas of Conservation (SAC's) on p. 44 for update.

harvesting on re-growth and recruitment of *Ascophyllum* on intertidal abundance of fishes and their gut contents over a six-month period after harvesting**.** Black & Miller (1991) also reported on epifaunal abundance in cleared and unharvested areas. Boaden & Dring (1980) considered the impact of hand harvesting on a shore in Northern Ireland two and a half years after harvesting. There have been no studies on the effects of mechanical harvesting on *Ascophyllum nodosum*.

Human interference with any habitat certainly interrupts the natural cycle of events that occur within and between floral and faunal populations that comprise the habitat in question. The level of interference or impact on the ecology of *Ascophyllum* harvesting is related to the level of exploitation, the harvesting technique involved and the vulnerability of the habitat (Sharp & Pringle, 1990). Many of the projects completed to date on the effects of seaweed harvesting on the flora and fauna of the sea-shore, have academic considerations and are generally purely scientifically based. The present research incorporates interests from a commercial, social, developmental and a conservative viewpoint. This balance of interests and the 18-month time span of the project offered a comprehensive appraisal of the effects of mechanical and traditional seaweed harvesting.

1.1. Aims of the project

- To assess the effect of harvesting on the regeneration and growth of *A. nodosum*
- To examine possible effects of harvesting of *A. nodosum* on the associated biodiversity
- To establish the benefits and the costs associated with the use of mechanical harvesting of *A. nodosum* in Ireland

1.2. Industry background

There are currently 400 people involved in the harvesting and processing of *Ascophyllum nodosum* in Ireland and Arramara Teoranta is one of the largest seaweed processing companies in the country. The company operates two plants one in Kilkieran, Co. Galway and another at Dungloe, Co. Donegal. Seaweed harvesting is an activity that has been of significant economic importance to coastal communities for over fifty years and especially in the two regions mentioned above. It currently contributes in excess of IR£1 million per annum directly to coastal communities, a contribution that is steadily rising.

Fig 1. Climíní (bundles) of harvested *Ascophyllum nodosum* towed to a quay and awaiting collection by truck for delivery to Arramara's factory at Kilkieran, Co. Galway

Over the last number of years, the mean annual harvest of *A. nodosum* on the west coast of Ireland is in the region of 35,000 wet kg per annum (Marine Resource Series No.5, 1998). The entire resource is harvested by hand and harvesting is a year round activity. However, it is more common between the months of June to October and occurs mainly at low spring tides (i.e., in 2 week cycles). Harvesters usually operated in teams of 2, equipped with a boat/engine, sickles, forks, ropes and nets. The seaweed is cut at low tide to a length of ~15-18 cm, it is gathered into rectangular bundles (climíní), bound with ropes and nets in preparation for towing behind a boat to the nearest slipway, landing place, quay or beach **(Fig 1).**

From the quay the seaweed is transported by truck to one of the processing factories mentioned previously. After the seaweed has been delivered to the factory the first step in the process is to remove sand, silt, small stones and any other debris including periwinkles from the harvested weed. The seaweed is then chopped up before drying and milling in rotary driers. Dried material is then sieved through meshes of various sizes tailored to the end use. Quality control within the factory is partly operated by modern electronic systems. High quality meal depends on good clean seaweed raw material, (with low sand and grit content) and upon the skill and experience of the plant operators. Mechanised means of harvesting is anticipated to reduce the amount of sorting and washing of the weed as it should happen *in situ* as the weed is being harvested. It is also thought that a degree of *in situ* chopping of the weed would take place during harvesting so increasing the surface area of the weed for further washing. *A. nodosum* is harvested on 3- or 5-year cycles. The growing period depends on the region/location and the rate of growth associated with individual beds.

The age structure of seaweed harvesters in the Connemara region in 1997-98 (Arramara Teo) is highlighted in **Table 1.** A study of the age profile of harvesters gives rise to concern for the continuation of seaweed harvesting as we know it, particularly as only 13% of those harvesting were under the age of 40, and of that only 3 less than 30 years old.

Table 1. Age structure and harvesting category of the cutters of Connemara Co. Galway. Steady cutter = cuts *Ascophyllum nodosum* all year round. Nearly full time cutter = cuts weed most of the year but is involved in other activities. Rainy-day cutter = cuts weed when weather is not conducive to other activities. Winter = cuts weed only during the winter season. (Source Arramara Teo 1998)

Age Structure (yrs)	No. of Harvesters	% Total	Type of activity	No Harvesters	% Total
<30	3	2.3%	Steady Cutter	26	20%
31-40	13	10%	Nearly full-time cutter	23	17.7%
41-50	71	54.6%	Rainy day cutter	59	45.4%
51-60	40	30.8%	Winter	22	16.9%
61+	3	2.4%			

1.3. Biology and ecology of *Ascophyllum nodosum*

Ascophyllum nodosum is a perennial brown intertidal seaweed species of the order Fucales that occupies the mid-littoral zone (roughly from mean high to mean low tidal levels) in wave-sheltered locations of temperate waters. It is considered the dominant seaweed species on much of the Irish intertidal coastline. An *Ascophyllum* bed is dominated by *Ascophyllum* clumps, or the zone on the shore that is recognised by the biomass of *Ascophyllum*.
Morphologically, the species resembles an intertwined mass of shoots and branches arising from a holdfast that is commonly referred to as a clump or stump. The limits of the holdfast are generally defined by the discontinuity between tissue type, (Baardseth, 1955) and identifies the 'plant' as a composite of shoots and fronds and does not include the holdfast.

The reasons for neglecting the holdfast are related to degree of change in holdfast clump. The degree of change depends on many factors including age and substratum type, especially on the techniques used for harvesting, and whether all the shoots have been harvested and to what degree (Ang *et al.,* 1993). The shoots arising from the holdfast grow from an apical meristem (from the tip) forming one vesicle float or bladder per annum if unbroken (Cousens, 1986). These shoots are referred to as basal shoots. The sections of shoots between successive vesicles, or internodes generally record annual growth increments. In a years' growth 8-15 cm of internodal tissue is generally produced.

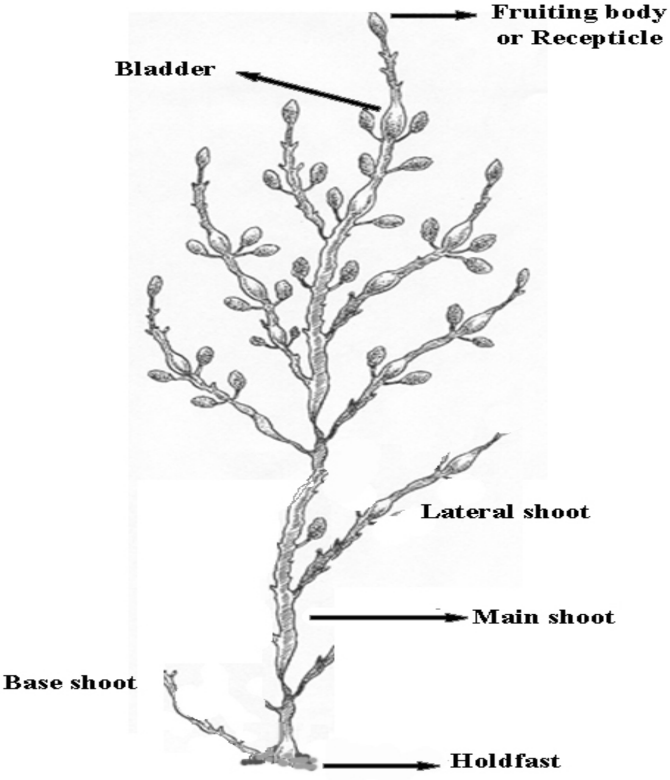

Fig 2. A representative diagram of *Ascophyllum nodosum* showing the various morphological attributes (after Major, 1977).

Vegetative and reproductive laterals shoots are initiated from the side of growing basal shoots **(Fig 2)**. A third shoot type is known as primary shoot, these are dichotomous shoots with laterals.

Ascophyllum regenerates both sexually and asexually. The plant is an isomorphic oogamic haplont, meaning that the life cycle consists of a single phase that is diploid (2n) phase or gametophyte*. Haploid spermatoids and egg cells are released into the water from conceptacles on the surface of club shaped lateral swellings called receptacles **(Fig. 2).**
Gamete release occurs in spring and the golden-brown receptacles are shed at the same time. Constant production of shoots from the base of the plant is clearly more important in maintaining the population of *Ascophyllum* than the regrowth from fertilised eggs (Stengel & Dring, 1997).

The *Ascophyllum* zone supports a diverse epibiota*. These include species living attached (sessile epibiota) to the seaweed and adjacent rocks, mobile fauna living amongst the

seaweed, and large predatory species such as fish, birds and otters that may feed in the *Ascophyllum* biotope.
In Ireland, a typical *Ascophyllum* biotope with steep and vertical surfaces are often characterised by barnacles and limpets such as *Semibalanus balanoides* Linnaeus**,** *Elminius modestus* Darwin and *Patella vulgata* Linnaeus. Large numbers of the winkles *Littorina obtusata* Linnaeus and *Littorina littorea* Linnaeus may be present. *Ascophyllum* is often heavily overgrown by the red algae *Polysiphonia lanosa* (Linnaeus) Tandy and the hydroid *Dynamena pumila* Linnaeus. The brown algae *Fucus vesiculosus* Linnaeus and *Fucus serratus* Linneaus commonly occur alongside *Ascophyllum* while the red algae *Mastocarpus stellatus* (Stackhouse) Guiry*, Chondrus crispus* Stackhouse and Corallinaceae often form beneath the canopy. Ephemeral green algae such as *Cladophora rupestris* (Linnaeus) Kützing*, Ulva sp.* Linnaeus and *Enteromorpha sp*. Link occur in moderate to low densities (Connor *et al*., 1997). Where there are strong tidal currents a rich associated fauna of sponges (e.g., *Leucosolenia* sp. Bowerbank, *Halichondria panicea* Pallas and *Hymeniacidon perleve* Montagu) and ascidians (e.g. *Dendrodoa grossularia* van Beneden and *Ascidiella scabra* O.F. Müller) occur in large numbers on steep surfaces and beneath boulders (Connor *et al.,* 1997). Under these tidal swept conditions other species may include *Lomentaria articulata* (Hudson) Lyngbye and *Membranoptera alata* (Hudson) Stackhouse.

Other mobile species live amongst the seaweed, such as amphipods, isopods and crabs. Smaller fauna such as Foraminifera, Turbellaria, Nematoda, Ostracoda, Halacaridae, Chironomida, Mollusca and Annelida are also present (Johnson & Scheibling, 1987). Rainer (1997) found that up to 31 species of fish and 26 species of birds use the *A. nodosum* zone as a habitat for feeding, reproduction or sheltering purposes. Black & Miller (1991) caught species such as American Flounder *Pseudopleuronectes americanus* Linnaeus, Sculpins *Myoxocephalus* sp., Pollack *Pollachius virens* Linnaeus and Atlantic Tomcod *Microgadus tomcod* Linnaeus in *Ascophyllum* beds in Nova Scotia. Hogans and Trudeau (1988) found that birds were not directly dependent on the *A. nodosum* shore. [3]

1.4. *Ascopyllum nodosum* harvesting impact knowledge

Damage occurs naturally to all of the *Ascophyllum* shoots, which can be due to vigorous water movement, grazing, disease or even ice spells. Natural damage is clearly evident from the omnipresence of *Ascophyllum* in total drift washed up on the shore especially after spells of gales. It is important to monitor the *Ascophyllum* bed prior to harvesting to identify changes hence virgin beds are most appropriate.

[3] * 'Haplont' refers to a single phase in the life history; 'diplont' to a situation where two phases occur in the life history. 'Diploid' is where two identical sets of chromosomes are present; 'haploid' is where only one a single set is apparent
Epibiota* plants and animals growing on the fronds
However, A. nodosum contributes to the pool of dissolved and particulate detritus in near-shore waters (Sieburgh, 1969) that is used by filter feeders (e.g. mussels Mytilus edulis Linnaeus) that are an important food source for birds.

Harvesting could change the original structure that could cause different degrees of impact. The present techniques namely, the amount harvested, the size of areas harvested, the homogeneity of the harvest, the equipment used, all influence the effect of the harvest on the beds regeneration and the recovery of the associate biodiversity**.** Regeneration of *A. nodosum* with regard to post-harvesting re-

growth at areas harvested sequentially is usually higher the first year than successive years and varies under various harvesting regimes depending on the age structure of the population under exploitation, on the extent and pattern of branching, generally determined by the shore type / exposure, and on the presence or absence of grazers (Baardseth, 1955).
Changes in fucoids, ephemeral algae and *Littorina* spp. populations are difficult to predict and are likely to be dependent on the harvesting regime and local environmental factors. Foster & Barilotti (1990) considered seaweed harvesting impacts to be similar to that of natural disturbances, both removing all or portions of populations, and providing space for other resources that initiate succession. Boaden (1980) predicted that the immediate effects of seaweed cutting include

- removal of seaweed from the system;
- destruction of the epifauna and flora;
- increase in desiccation;
- increase in predation;
- increase in erosion;
- contribute to settlement of other species;
- stimulation of bushy *Ascophyllum* growth.

Boaden & Dring (1980) predicted a change in the balance of the community with up to an 80% recovery after a four-year period. A study conducted by Black & Miller (1991) in an area in which harvesting has been carried out continuously for 30 years alongside intense and productive shellfish and finfish fisheries provided no evidence of adverse effects on fish following the removal of patches of *Ascophyllum* over a 6-month period of post-harvesting. Their study looked, however, only at fish greater than 25 mm length.
Boaden & Dring (1980) found that *A. nodosum* harvesting at a site in Northern Ireland reduced *Ascophyllum* and fucoid cover. They also identified an increase in *Enteromorpha* and *Ulva* sp. and in the cover of *Fucus vesiculosus* (Bladder wrack*)*. It appears that *Fucus vesiculosus* cannot compete with dense *A. nodosum* cover. Fucoid growth is expected to increase if *A. nodosum* cover is removed due to its opportunistic nature and faster growth rates; by contrast, *A. nodosum* grows slowly and has low recruitment levels (Jenkins *et al*., 1999)
Grazing pressure from periwinkles is seen as the mechanism by which competitive dominance by ephemeral algae is broken (Lubchenco, 1982; Lubchenco 1983) and succession to perennial fucoid algae occurs (Chapman, 1995). An increase in ephemeral algae may lead to a temporary increase in littorinid and other herbivorous fauna, and these should decrease with the re-establishment of the fucoid canopy. Black & Miller (1991) found that harvesting (total clearing of weed) led to a reduction in the numbers of *Littorina obtusata.* Boaden & Dring (1980) found that green colour morphs dominated *L. obtusata* collections from cut (45%) and uncut (75%) areas, but yellow forms of *L. obtusata* were more common in the cut (33%) than the uncut area (11%) and each form was smaller in the cut area.

There could be short-term increases in species predating and scavenging fauna damaged or displaced during harvesting, algal debris and detritus. This is not evident from previous

studies. Black & Miller (1991) found that harvesting led to a 66% reduction in animal abundance, mostly amphipods, nemerteans and *L. obtusata*. There were no significant differences in the number of other crustaceans, in particular the shore crab, *Carcinus maenas* Linnaeus, and the polychaete *Spirorbis* spp. Boaden & Dring (1980) found that

harvesting lead to increases in the polychaete *Cirratulus* sp. Lamark. On the undersides of boulders total animal cover decreased by two thirds and the number of species, mainly barnacles, mussels and bryozoans decreased by one third. They found that harvesting significantly reduced the cover of sponges notably (*Hymeniacidon* and *Halichondria* species), barnacles and bryozoans, mainly *Schizoporella unicornis* Johnston & Wood. This may have been due to increased erosion and scouring preventing settlement, a reduction in shade, and desiccation. Boaden & Dring (1980) also found that harvesting had led to an increase in the mean diameter of sediment particles. This may be due to an increased scouring and erosion without protection of dense *Ascophyllum* cover. They also found that limpet density increased, while mean size decreased.
Structural diversity can reduce the impact of predation by refuge provision and/or reducing the foraging efficiency of predators (Rosenzweig & MacArthur, 1963). Seaweed harvesting will reduce this structural diversity as over time *Ascophyllum* beds will change from a complex to a more uniform structure (Rainer, 1997). Thus over a longer time period predation may increase leading to changes in community structure.

2. MATERIALS AND METHODS

2.1.Study areas

The current study looked at two contrasting *Ascophyllum* shores in the west of Ireland, one dominated by mud, sand, gravel and boulders and the other dominated by bed rock and boulders **(Table 2).** Both shores were virgin areas (no seaweed harvesting had taken place within the previous 10 years). The sites were chosen in remote locations to minimise anthropogenic influence or interference.

Table 2. Summary details of the two sampling sites

DESCRIPTION	CONNEMARA	CLEW BAY
Topography	Variable	Flat, sloping
Substratum	Predominantly bedrock and boulders	Predominantly sandy mud and gravel
Wave action	Sheltered	Very sheltered
Other influences	*Remote *surrounded by bog & grassland *some sheep grazing	*Oyster farm in close proximity *surrounded by agricultural grassland and grazing cattle

2.1.1. Study site Connemara, Co.Galway

The sample site in Connemara (Grid Reference L 749 411) is west facing onto a sheltered arm of Bertraghbuoy Bay **(Fig. 3)** itself protected to the south by a series of islands at its entrance. There is one large freshwater input that runs from the bog land above. The incline of the shore is relatively gentle but inconsistent. Uneven terrace-like sections are interrupted by sudden drops due to the rock structure. The shore is typical of the type in Connemara where *Ascophyllum* harvesting takes place, i.e. it is difficult to move around the shore by foot and likewise when the tide is in boat access is difficult due to presence of many rocks. High water times are roughly 1 hour ahead of predictions for Galway harbour.

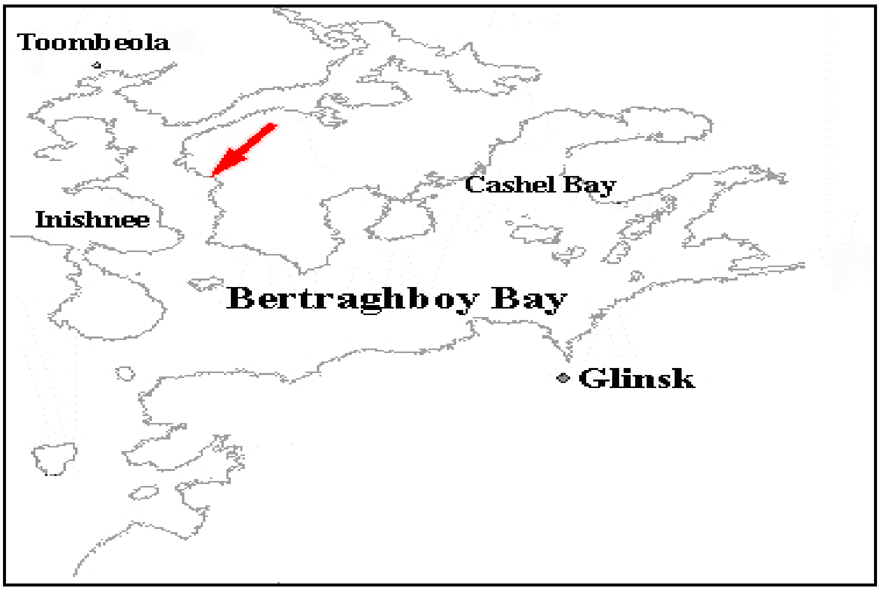

Fig. 3. Sampling site of *Ascophyllum nodosum* beds in Connemara Co. Galway. The red arrow shows the exact location of the beds.

The Clew Bay site (Grid Reference: L 967 920) lies on the south side of the Rossow peninsula between Newport and Westport in Co. Mayo. Access to Clew bay is via narrows called appropriately 'the Carnaslatmara Channel'. The shore is composed of fine sands and mud with rocky substrate randomly distributed for attachment by *A. nodosum*. The aspect of the shore is southerly (**Fig. 4**).

2.1.2. Study site Clew Bay, Co. Mayo

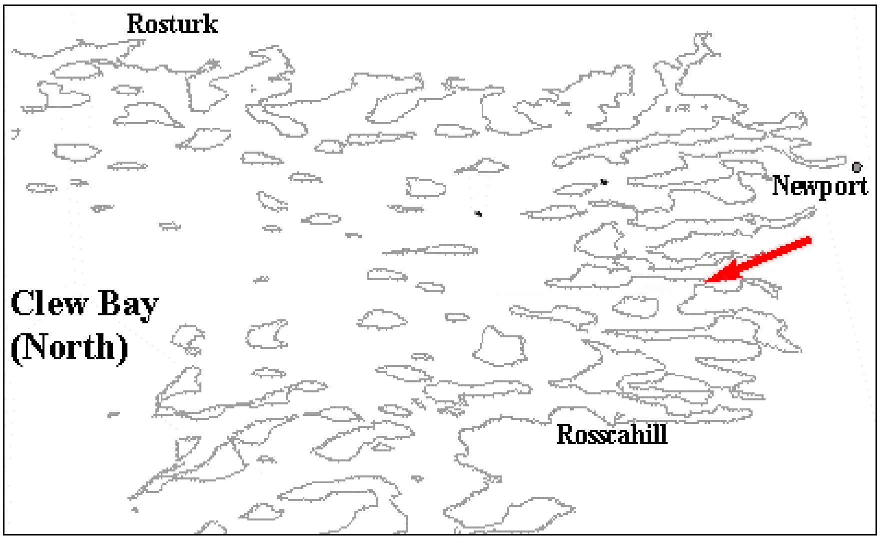

Fig. 4. Sampling site of *Ascophyllum nodosum* beds in Clew Bay Co. Mayo. The red arrow shows the exact location of the beds.

2.2. Sampling

At each location, a 150m stretch of shore was divided into three 50m wide sections. The first section was designated to traditional hand-harvesting, the second mechanical harvesting and the third was not harvested and treated as the control section**.** Each sampling area was further divided into an upper, middle and lower shore dictated by the width of the *Ascophyllum* bed **(Fig. 5).**

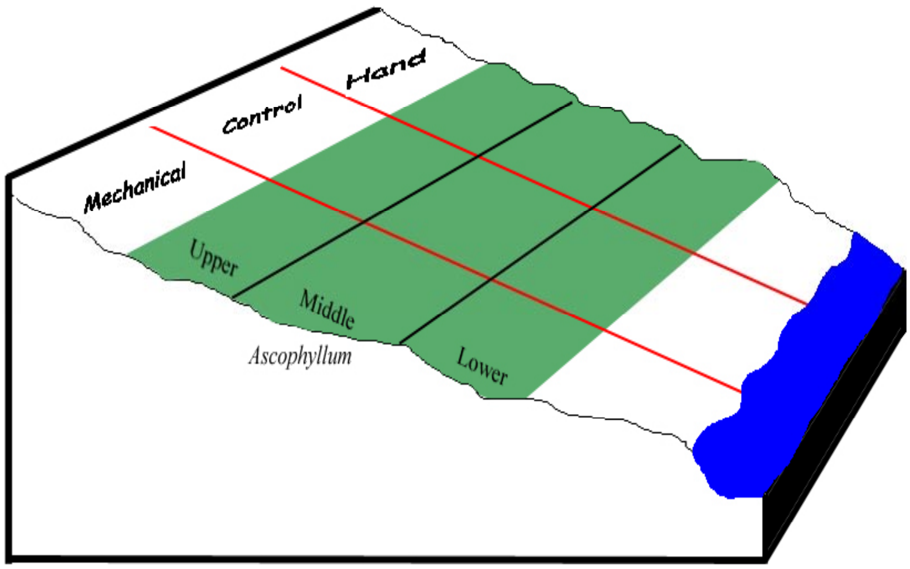

Fig. 5. Generalised profile of shore indicating the 3 treatments at each level (upper, middle and lower of the *A. nodosum* bed highlighted in green).

The upper shore was defined as the upper third of the *Ascophyllum nodosum* zone just below the *Fucus spiralis* and *Pelvetia canaliculata* zone. The lower shore was defined as the lower third of the *Ascophyllum* zone above the *Fucus serratus* belt while the middle shore was measured as the middle third of the *Ascophyllum* zone.

2.2.1. Regeneration sampling

Four randomly taken 0.5 m quadrates were initially taken at each treatment and shore height described in **Fig 5**. Within each quadrate three individuals or clumps were tagged for repetitive sampling using cable ties and labeled plastic markers with waterproof pen **(Fig. 6)**
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Fig 6. Individual *A. nodosum* plants are marked with plastic labels and cable ties.

The main frond was further marked by sewing cat-gut into the centre of the tissue of the main frond and looped and tied. An example of a data sheet is attached in **Appendix 3**. The information on the data sheet is in excess of that which is analysed and is used as reference material. In total 216 plants were marked and the following recorded for analysis:

- Length of main frond (marked with cat-gut)
- Number of lateral shoots along the main frond
- Number of bladders along the main frond
- Number of base shoots

Plant density at both sites was measured at the initial sampling stage using 0.25 m^2 quadrates. Individual clumps were counted and recorded. No differentiation was made between the shore sections and shore heights.

2.2.2. Biodiversity sampling

For biodiversity purposes 4 0.5 m x 0.5 m quadrates (0.25 m^2) were randomly placed within the upper, middle and lower shore within each section. Quadrates were only placed on horizontal surfaces to reduce effects of vertical sides of surfaces, although in the case of boulders in a quadrate, the sides were also studied to a depth of 20 cm. In each quadrate the following were recorded:

- Percentage cover was determined for all algae in the quadrates including the epiphytic species.
- Faunal densities were expressed as numbers per quadrate (i.e. 0.25 m^2)
- Numbers on a logarithmic scale for Spirorbidae were used on a log scale.

Due to difficulties in identification, *Littorina obtusata* and *L. mariae* were combined as one pseudospecies (these will be referred to as *L. obtusata* agg. in this report). A more detailed analysis of *L. obtusata* was based on a study conducted by Boaden & Dring (1980). *Littorina obtusata* agg., recorded in each quadrate were divided into three colour morphs (green, yellow and brown) and four size categories (<2 mm, 2-5 mm, 5-10 mm and >10 mm) based on recommendations by Baker & Crothers (1987).

Species that were not readily identifiable in the field were preserved in 70% ethanol (IMS) and returned to the laboratory for identification. Specimens were identified to the lowest possible taxonomic level possible using: for general fauna, Hayward and Ryland (1995), for marine molluscs, Graham (1988), and for red algae, Hiscock (1986). A voucher collection of representative specimens was made which is held by Ecoserve Ltd. Species nomenclature follows Howson & Picton (1997). A snorkelling survey of the *Ascophyllum* zone was carried out at high tide, twice at Clew Bay (9th July 1998 and 28th July, 1999) and four times at Connemara (21st May 1998, 27th May 1998, 22nd June 1999 and 29th July 1999). Three to four people snorkelled for approximately 15 minutes in each of the three areas (hand, machine and control). Large mobile crustaceans and fish that utilise the zone at high tide were counted to see if there were any changes post-harvesting.
Percentage cover of different substrata was also recorded for each quadrate according to the scale used by Hiscock (1996) (boulders = 256-1024 mm, cobbles = 64-256 mm, pebbles = 16-64 mm, gravel = 4-16 mm, sand = 0.063-4 mm and mud <0.063 mm diameter, see **Fig. 7**.

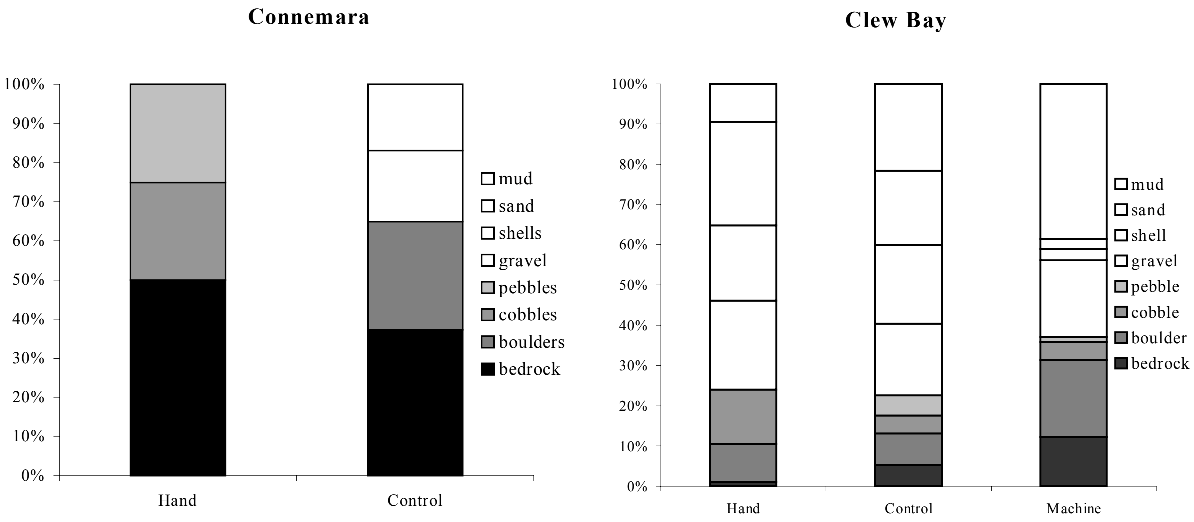


Fig. 7. Substratum type at Connemara and Clew Bay sampling sites.

Site details were collected on weather conditions, water and air temperatures. Biodiversity and regeneration sampling occurred in tandem on spring low tides to gain maximum shore exposure time. The sampling times are outlined in **Table 3.**

Table 3. Sampling times in Connemara and Clew Bay 1998 and 1999.

LOCATION	1998								1999								
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Connemara	H																
Clew Bay							H										

H = harvesting undertaken

Sampling dates

2.2.3. Harvesting

After the shores had been initially surveyed to get pre-impact data sets both mechanical and traditional hand harvesting took place. The hand harvesting teams of 3 or 4 persons used sickles in the traditional manner. The mechanical means of harvesting used a *Vaughan vertical wet-well chopper pump* **(Fig. 8)** mounted on a hydraulic arm of a flat bed sea-harvesting vessel of the type used to service salmon cages.
The hydraulic arm used was a fixture of the boat and the pump was maneuvered using the lever control of the hydraulic arm. The chopper pump is one designed for the treatment of slurry material. It contains a rotary blade impeller, the blades rotating parallel with the seawater.

The procedure was as follows: The vessel approached the harvesting area on incoming tidal waters. When sufficient water had filled the area the boat entered, the chopper pump was lowered into the surrounding water and guided towards the floating *A nodosum.* The seaweed was drawn into the pump along with the seawater and then chopped. A plastic flume controlled the exiting mixture of chopped *A. nodosum* and seawater by directing it into a net (1/2 inch mesh). The collector net receiving the cut weed was positioned on the deck of the boat.

2.2. Statistical analysis

Biodiversity data were assessed for normality. They did not follow a normal distribution and therefore non-parametric tests were carried out. The Kruskal-Wallis, a non-parametric version of one-way-ANOVA was used to determine if there were significant differences in abundance of algae and fauna between treatments (control, hand, mechanical), and with time. The computer package, MINITAB for Windows was used.

Growth and regeneration data was assessed for normality. The data followed a normal distribution and a one-way ANOVA test (STATISTICA 4.1, Tulsa, OK, U.S.A) was used to determine if there were significant differences of growth and regeneration between treatments (control, hand, mechanical) with time.

3. RESULTS

3.1.Harvesting

From the results indicated in **Table 4** can be seen that the quantity of hand-harvested weed is greater than that harvested by the mechanical harvester at both sites. At the Connemara site the mechanical harvester was not able to move sufficiently inshore to harveste the zone that was marked for this purpose. Therefore no data are available for the mechanical harvested zone in Connemara.

3.1.1. Harvested material

At both sites the by-products of mechanical harvesting were examined. The weed collected had a large number of periwinkles present (dead, broken, and alive); **Table 5** shows the number in the total mechanically harvested amount of weed at the Clew Bay site. Counts were not taken at Connemara but it was noted visually that littorinid debris was high (. Michael Diver *pers. comm*).

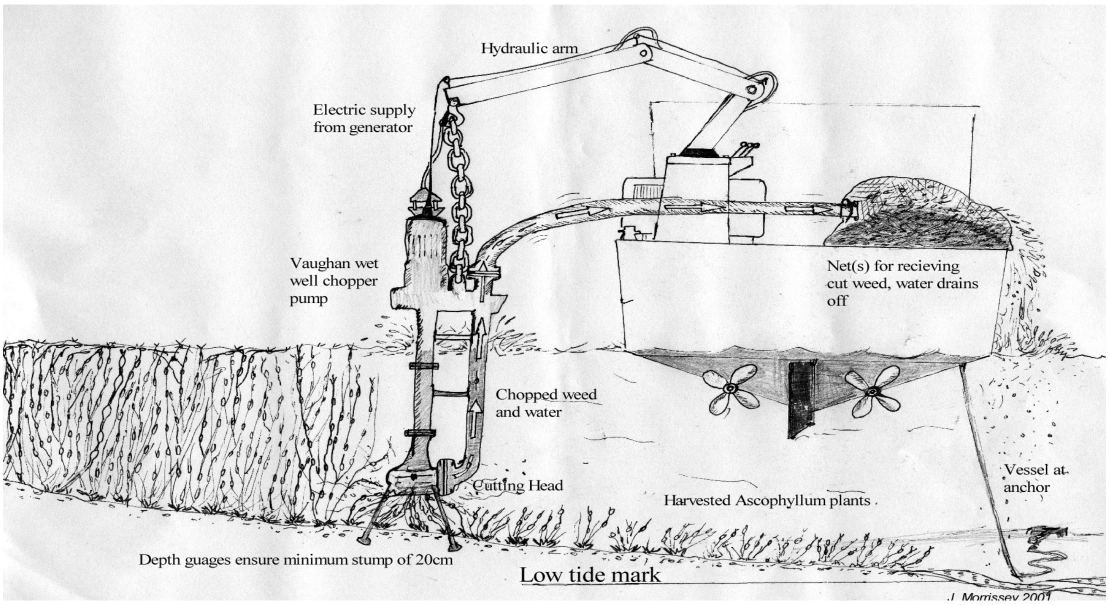


Fig. 8. Diagram of the Vaughan Wet Well Chopper pump deployed in harvesting setup. Illustration by Jim Morrissey (2001)

Table 4: Harvesting data, including the amount of *Ascophyllum nodosum* (Asco), the length of time taken and the amount of shoreline covered.

Location	Connemara	Clew Bay
HAND		
Asco harvested (t)	19.2	16
Time (hrs)	4	5
Length of shore (m)	~50	~50
MECHANICAL		
Asco harvested (t)	2	4.5
Time (hrs)	10	4
Length of Shore (m)	~50	~50

Table 5. Number of Littorinids whole and broken from a count made from Clew Bay mechanically harvested site.

Site	No. whole	No. damaged	Total No.	Weight (t) of weed
Clew Bay Mechanical harvested	289	128	417	4.5

There were no differences in percentage cover of *A. nodosum* between sections at Connemara or Clew Bay *before* harvesting with the exception of the middle zone at Clew Bay **(Fig. 9).** There was no significant difference in percentage cover of *Ascophyllum nodosum* in the control section over time **(Table 6).**

3.2 *Ascophyllum* regeneration

3.2.1. Ascophyllum nodosum *cover*

In general, percentage cover in all zones and sections was nearly 100% at Connemara and 60% at Clew Bay. After harvesting there was a significant reduction in percentage cover of *A. nodosum* **(Table 6)** in the hand-cut section with a gradual increase in cover over the following year. **Figure 9** shows the percentage cover of *A. nodosum* of the three treatment zones (hand, mechanical and control) at Connemara and Clew Bay. This pattern is similar for the other shore levels at both sites. Machine harvesting was not as successful with a significant reduction on the middle zone only **(Table 6).** Mean plant density varied between 25-30 ± 6 plants/m^2 in Connemara to 10-15± 3 plants/m^2 in Clew Bay. Differences in densities and coverage of the two sites might be attributed to different environmental parameters like weather conditions and suitable substratum, influencing growth, regeneration and coverage.

Table 6. Results of the Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of *Ascophyllum nodosum*. Significant differences highlighted in bold.

Treatment	Clew Bay				Connemara			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	0.877	**0.047**	0.318	3	0.213	0.292	0.381
Control x time	7	0.768	0.119	0.348	6	0.092	0.658	0.071
Hand x time	7	**0.003**	**0.002**	**0.013**	6	**0.049**	**0.046**	**0.010**
Machine x Time	7	-	-	-	6	0.162	**0.018**	0.057

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

3.2.2. Standing crop of A. nodosum

The mean initial frond lengths, lateral shoots, base shoots and age structure with standard deviation of 100 pre-harvested plants were measured randomly over the shore and are shown in **Table 7.** A total of 108 plants were tagged and measured at Connemara and 96 in Clew Bay for sampling purposes**. Table 7** shows that the beds in Clew Bay are older, have taller plants and contain more laterals (bushy growth), but have fewer base shoots. Statistical comparisons between the two sites using a t-test, however, showed that only laterals and frond length were significantly larger and more abundant in Clew Bay ($p< 0.05$)

Table 7. Mean values and standard deviation (SD) for the standing crop of *Ascophyllum nodosum* in Connemara and Clew Bay pre-harvesting.

Value/Site	Clew Bay	SD	Connemara	SD
Mean length (m)	85.9	2.7	68.72	26.3
Mean no. bladders/age structure	4.14	1.46	3.77	1.4
Mean no. of lateral shoots	14.7	5.8	9.76	14.7
Mean no. of base shoots	35.8	4.6	44.0	35.8

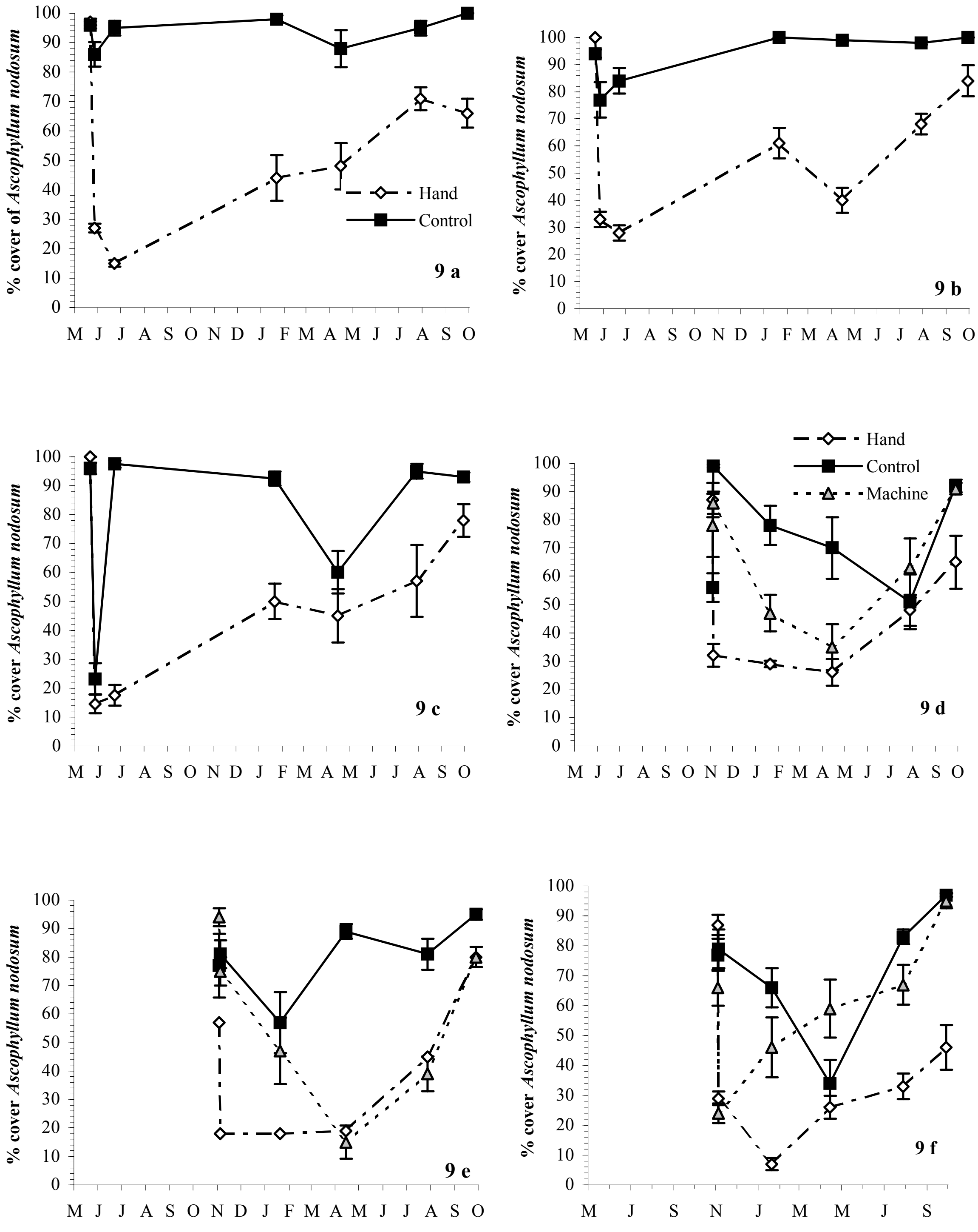


Fig. 9. Percentages of cover of *Ascophyllum nodosum* in the hand, mechanical and control zones at Connemara (a, b, c) and Clew Bay (d, e, f) upper, middle and lower zones over time. Means and standard error bars are shown. For legend see **Fig. 9a** and **d**.

The frond length, number of bladders, number of base shoots and number of laterals have been recorded before and after harvesting. Significant lower values were recorded after harvesting for both sites.

3.2.3. **Ascophyllum nodosum** *growth and regeneration*

The percentage of tagged *Ascophyllum* plants over 100 cm in Connemara was 40.2%. The mean frond length with standard deviation was 90.2 ± 52.3 from all shore levels on all treatment locations of the shore at Connemara. The percentage of *Ascophyllum* plants greater than 100 cm in Clew Bay was 45%**.** The mean frond length with standard deviation was 98.6 ± 28.9. After harvesting the mean lengths decreased in the hand and mechanical harvested zones **(Table 8**). Growth measured as frond length increased significantly over time in the hand-harvested and mechanically harvested zones in Clew Bay ($p<0.05$). There was no significant increase in growth in the hand-harvested zone in Connemara and, remarkably, over two years most plants in the control zones of the two sampling sites decreased significantly in length. This may be due to grazing, disease or weather conditions.

3.3. Biodiversity

3.3.1. Number of species

The two sites studied were typical of *Ascophyllum nodosum* biotopes (Connor *et al*. 1997) with 66% of the species common to both shores. The bivalves, *Cerastoderma edule, Venerupis senegalensi, Anomia ephipium, Chlamys varia* and the polychaetes *Lanice conchilega*, *Arenicola marina* and *Hediste diversicolor* are characteristic of sedimentary biotopes. Other species found that were not typical of *Ascophyllum* biotopes were *Mytilus edulis*, the sea slugs *Onchidoris bilamellata* and *Archidoris pseudoargus*, the anemone *Anemonia viridis*, starfish *Asterina gibbosa*, and lower shore seasquirts and sponges (e.g. *Ascidiella aspersa, Haliclona* sp. and *Mycale* sp.)

Table 8. Mean frond length with standard deviation of *Ascophyllum nodosum* at the Connemara and Clew Bay sites before and after harvesting and at the final sampling date of the project in the control, hand and mechanical harvested zones. Pre-harvesting values are pooled for the three treatments as no harvesting had taken place yet. Hand= hand harvested, Mech = mechanical harvested.

Treatment/Site	**Clew Bay**			**Connemara**	
	Control	Hand	Mech	Control	Hand
Pre-harvesting	98.6 ± 28.9	98.6 ± 28.9	98.6 ± 28.9	90.2 ± 52.3	90.2 ± 52.3
Post-harvesting	92.8 ± 43	17.4 ± 14.3	52 ± 37	75.6 ± 57	23.6 ± 10.1
Final sample date	73.4 ± 50	45.9 ± 33	49.2 ± 29	52.4 ± 36.1	25.3 ± 22

Regeneration was measured as the increase of the numbers of laterals and base shoots after harvesting compared to the final sampling date (**Tables 9 and 10**).

Table 9. Mean number of base shoots with standard deviation of *Ascophyllum nodosum* at the Connemara and Clew Bay sites before and after harvesting and at the final sampling date of the project in the control, hand and mechanical harvested zones. Pre-harvesting values are pooled for the three treatments as no harvesting had taken place yet. Hand= hand harvested, Mech = mechanical harvested.

Treatment/Site	**Clew Bay**			**Connemara**	
	Control	Hand	Mech	Control	Hand
Pre-harvesting	35.6 ± 30.1	35.6 ± 30.1	35.6 ± 30.1	44.7± 36.7	44.7± 36.7
Post-harvesting	35 ± 21.3	36 ± 28.6	25.4 ± 20.4	44.4 ±40.3	44.6 ± 28.4
Final sample date	38.4 ± 24.9	50.7 ± 22.5	50.3 ± 27.4	51.1 ± 38	47.8 ± 24.2

The mean number of base shoots increased over time in the hand harvested and mechanical harvested zones in Clew Bay but not significantly (p>0.05). There was no significant increase in base shoot numbers in the hand-harvested zone in Connemara.

Table 10. Mean number of laterals with standard deviation of *Ascophyllum nodosum* at the Connemara and Clew Bay sites before and after harvesting and at the final sampling date of the project in the control, hand and mechanical harvested zones. Pre-harvesting values are pooled for the three treatments as no harvesting had taken place yet. Hand= hand harvested, Mech = mechanical harvested.

Treatment/Site	**Clew Bay**			**Connemara**	
	Control	Hand	Mech	Control	Hand
Pre-harvesting	11.9 ± 9.1	11.9 ± 9.1	11.9 ± 9.1	7.3 ± 5.6	7.3 ± 5.6
Post-harvesting	11.7 ± 3.6	3.6 ± 3.3	7.5 ± 5.6	6.6 ± 6	3.7 ± 6.8
Final sample date	24.6 ± 24.9	18.8 ± 17.2	11.9 ± 8.4	15.3± 16.7	4.4 ± 7.2

The number of laterals increased significantly over time in the control and hand harvested zones in Clew Bay (p=0.002 and 0.01 resp.). No significant effect was observed for the mechanical harvested zone. The Connemara site showed a significantly increase in the number of laterals over time in the control zone (p=0.012).

Species exclusive to Clew Bay found were the alga *Fucus ceranoides* and the lichen *Verrucaria maura*, the mollusca *Cerastoderma edule, Anomia epphipium, Gibbula magus* and *Venerupis senegalensis,* and the sea squirts, *Ascidiella aspersa* and *Clava multicornis*. Species found at Connemara but not at Clew Bay were the alga *Chorda filum, Cladostephus spongiosus, Porphyra sp., Osmundea pinnatifida*, the whelks *Buccinum undatum, Hinia reticulatus* and *Turritella communis*, the bivalve *Chlamys varia*, the hermit crab *Pagurus bernhardus*, topshell *Gibbula umbilicalis*, and other fauna: *Lanice conchilega, Arenicola marina, Asterina gibbosa, Haliclona* sp., *Mycale* sp. and *Anemonia viridis.* These are sublittoral or sedimentary species not typical of *Ascophyllum* biotopes (see also **Appendix 1**).

A total of 97 species were found at Connemara (36 plants and 61 animals), while a total of 87 species (28 plants and 56 animals) were found at Clew Bay. There were more species on the lower than upper zone, and in Connemara compared to the Clew Bay site (**Appendix 1).**

Prior to harvesting there was no significant differences between the control and harvested sections of shore at Connemara although there were significant differences at Clew Bay in the upper and middle shore **(Table 11).** The number of species at Connemara (middle and lower shore) in the
control site and hand-harvested site showed significant differences over time **(Figs. 10 and 11 and Table 12).** At Clew Bay significant differences were found in the hand-harvested lower shore zone with time and in the control middle shore zone with time. However, differences were also significant at the control site and show a possible seasonal trend.

Table 11: Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in the number of species. Significant differences highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	0.369	1.000	0.082	3	**0.011**	**0.018**	0.217
Control x time	7	0.096	**0.017**	**0.043**	6	0.911	**0.032**	0.649
Hand x time	7	0.167	**0.010**	**0.011**	6	0.367	0.289	**0.021**
Machine x Time	7	-	-	-	6	0.447	0.068	0.604

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

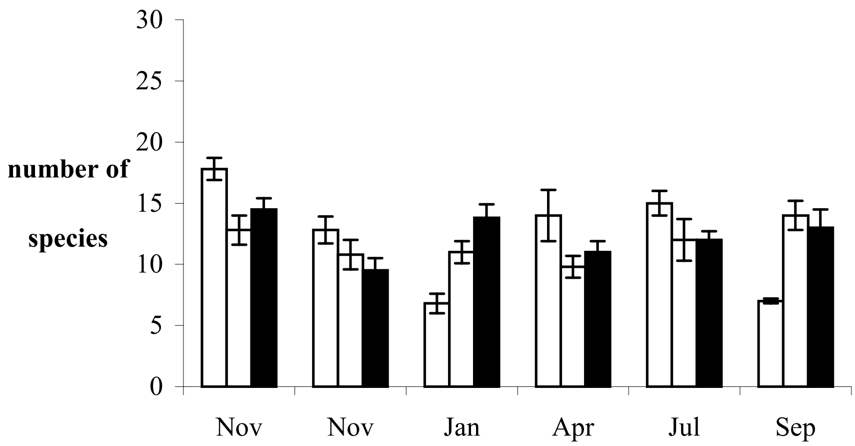


Fig. 10. The number of species in the hand (shaded), mechanical (black) and control (white) zones at Clew Bay lower shore over time. Means and standard error bars are shown

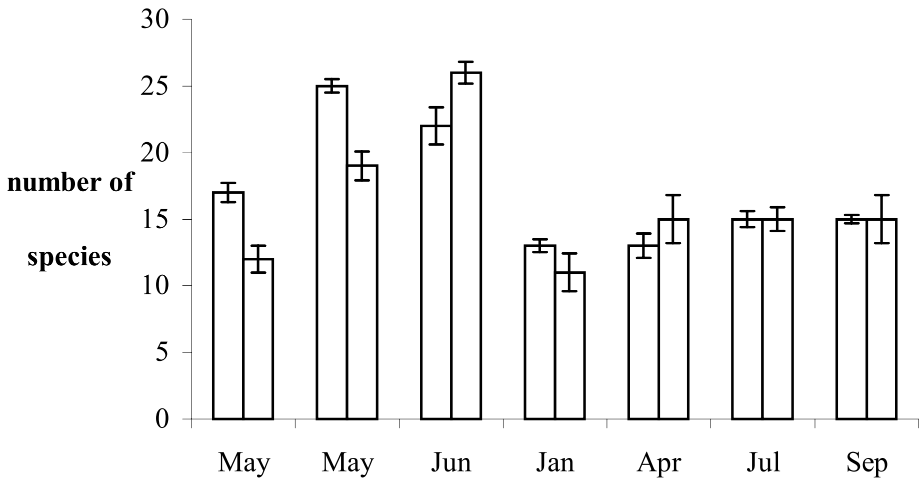


Fig. 11. The number of species in the hand (shaded), and control (white) zones at Connemara lower shore over time. Means and standard error bars are shown

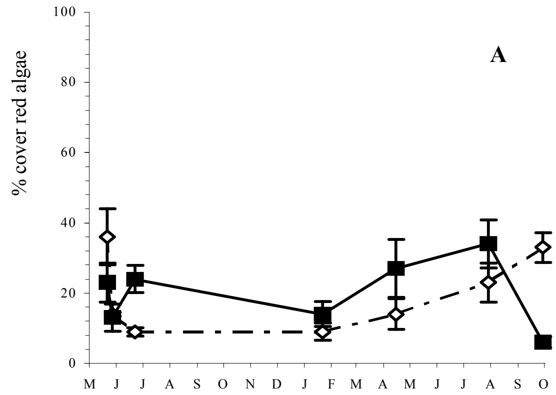
3.3.2. Red algae

The percentage cover of red algae (for species see **Appendix 1**) varied significantly between sections before harvesting at Connemara only **(Table 12).** Percentage cover of red algae was very low at Clew Bay with the only significant difference occurring in the hand-cut section on the upper zone **(Table 12)** where cover was very low. There was evidence of a decrease in cover of red algae in the hand-cut section after harvesting on the middle and lower zone **(Figure 12a and b)** at Connemara with a gradual increase in cover over time. Changes are significant on the upper and lower zone **(Table 12).** However, change in percentage cover of red algae was also significant on the upper zone in the control **(Table 12).**

Table 12. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of red algae (excluding epiphytes). Significant differences highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	**0.044**	0.773	**0.021**	3	0.803	1.000	0.286
Control x time	7	**0.016**	0.688	0.333	6	0.250	0.393	1.000
Hand x time	7	**0.011**	0.379	**0.013**	6	**0.021**	0.801	0.710
Machine x Time	7	-	-	-	6	0.384	0.309	0.564

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.



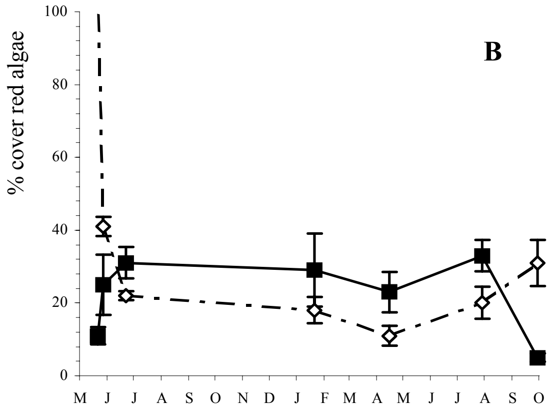


Fig. 12. Percentage cover of red algae at the lower (A, left) and middle (B, right) shore in Connemara. The black line represents the control section, the striped line the hand harvested section. Means and standard error bars are shown (other data not shown).

3.3.3. Ephemeral Algae

Percentage cover of ephemeral algae **(Table 13)** at Connemara was variable before harvesting. There was a low abundance of ephemeral algae at Clew Bay before harvesting **(Figure 13).**

Percentage cover of ephemeral algae was variable over time with lowest cover during winter at both sites **(Figure 13).** Significant differences in cover occurred on the lower zone at Connemara in both control and harvested sections, and on the upper zone in the control section after harvesting. Significant differences were found in the upper zone hand-cut section and middle zone mechanical section at Clew Bay over time **(Table 13).** At Clew Bay there were large increases in ephemeral algae in the summer of 1999 although this was highly variable between zones and sections **(Figure 13d, e, f).**

(Figure 13a, b, c) with significant differences on the lower zone **(Table 13).**

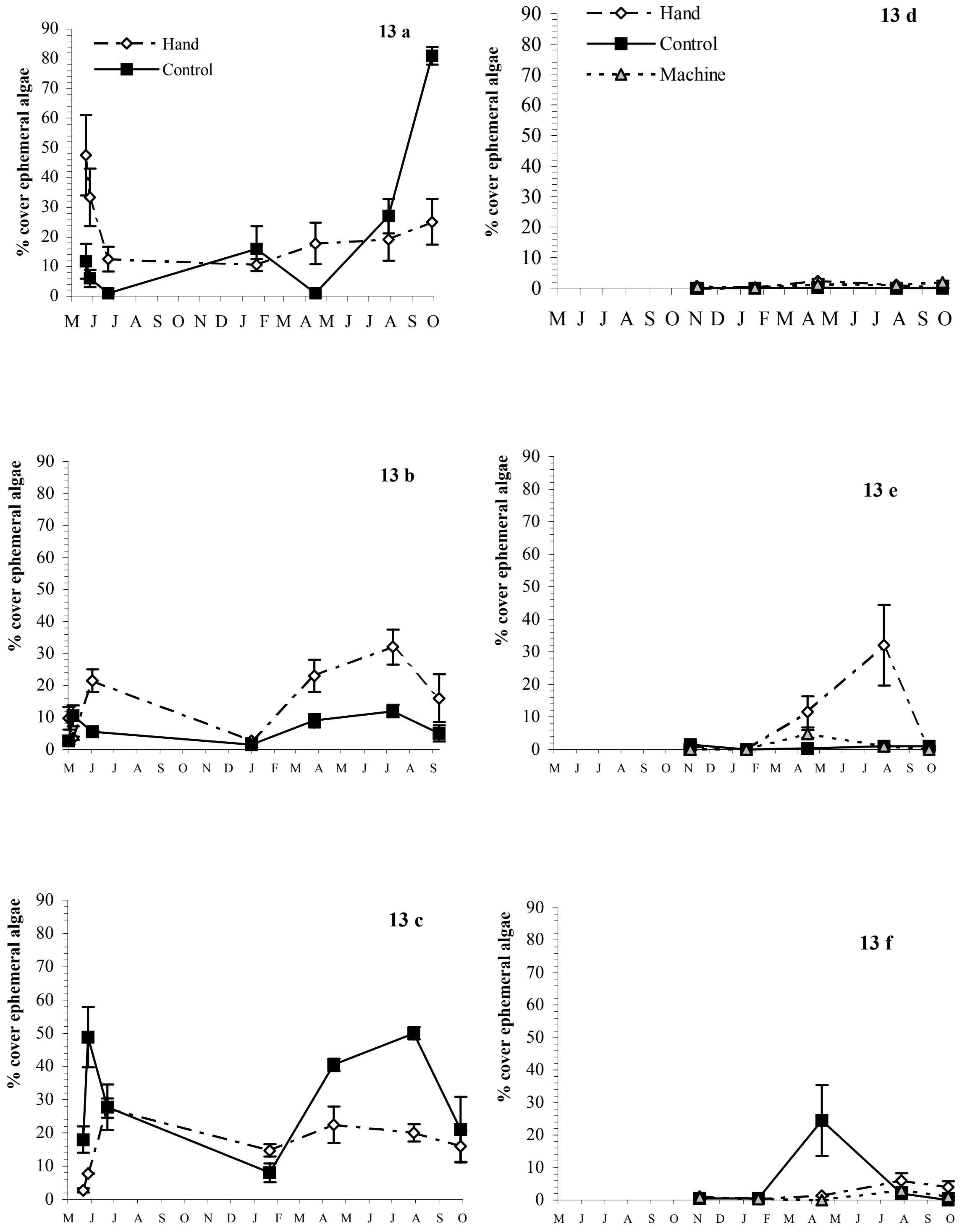


Fig13. Percentage cover of ephemeral algae at the three shore sections (a, b, c) in Connemara and three shore sections (d, e, f) in Clew Bay. See Figs. **13a** and **d** for legend. Means and standard error bars are shown.

Table 13. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of ephemeral algae. Significant differences are highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	0.167	0.375	**0.039**	3	0.368	0.091	0.760
Control x time	7	**0.033**	0.170	**0.043**	6	0.523	0.066	0.492
Hand x time	7	0.949	0.342	**0.042**	6	**0.011**	0.129	0.148
Machine x Time	7	-	-	-	6	0.433	**0.002**	0.361

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

3.3.4. **Fucus** *species*

Fucus vesiculosus

There was no significant difference in percentage cover of *Fucus vesiculosus* between sections before harvesting at either site **(Table 14).** Percentage cover of *Fucus vesiculosus* was variable (patchy distribution across the shore) in both the control and harvested sections over time at both sites **(Figure 14).** However, there was a clear increase in percentage cover in the hand-cut site at Connemara approximately 11 months after harvesting with percentage cover continuing to increase thereafter. These differences were significant on the upper and lower zone and nearly significant on the middle shore (P=0.07, **Table 14).** However, there was also a significant difference in the control section with time on the upper and middle zone (**Figure 14a, b, c, Table 14**) at both sites. At Clew Bay, cover of *Fucus vesiculosus* was patchily distributed and variable throughout the study area over time with significant differences in the control section on the upper and middle zone and in the hand-cut section in the middle zone over time **(Table 14).**

Table 14. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of *Fucus vesiculosus*. Significant differences highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	0.655	0.439	0.850	3	0.650	0.101	0.526
Control x time	7	**0.006**	**0.006**	0.421	6	**0.009**	**0.051**	0.882
Hand x time	7	**0.016**	0.069	**0.030**	6	0.392	**0.040**	0.384
Machine x Time	7	-	-	-	6	0.560	0.473	0.256

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

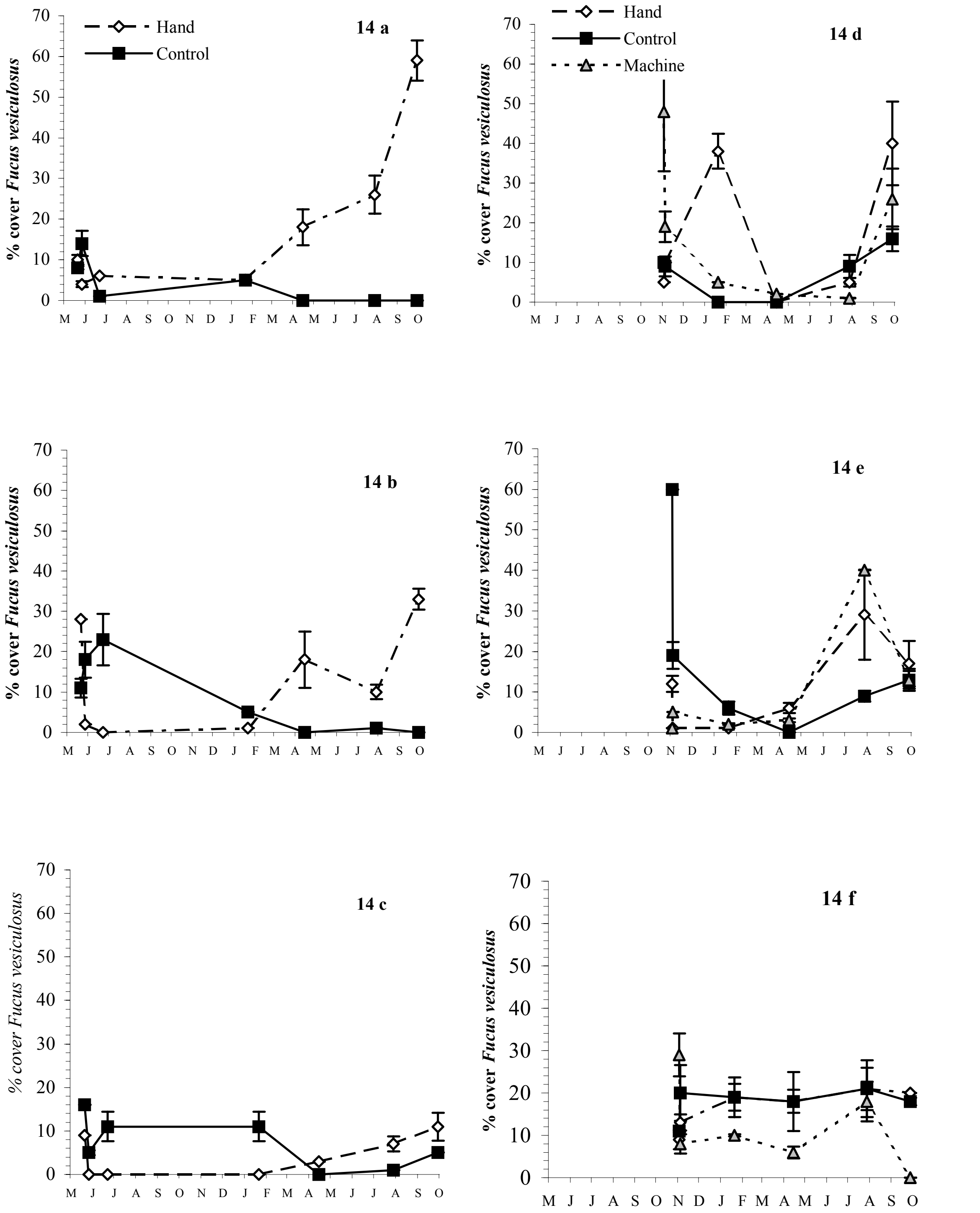


Fig. 14. Percentage cover of *Fucus vesiculosus* at the three shore sections (a, b, c) in Connemara and three shore sections (d, e, f) in Clew Bay. See Figs. **14a** and **d** for legend. Means and standard error bars are shown.

Fucus serratus

Fucus serratus is a species of the lower shore. Therefore the percentage cover of *Fucus serratus* was only present in the lower shore and variable throughout the different treatment zones at Connemara and Clew Bay**.** Harvesting did not have a significant impact on cover of this low-shore species (**Table 15).**

Table 15. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of *Fucus serratus*. Significant differences highlighted in bold.

Treatment	**Connemara**				**Clew Bay**			
	N	**U**	**M**	**L**	**N**	**U**	**M**	**L**
Sections before harvesting	2	-	-	0.091	3	-	-	0.715
Control x time	7	-	-	0.087	6	-	-	0.846
Hand x time	7	-	-	0.356	6	-	-	0.830
Machine x Time	7	-	-	-	6	-	-	0.796

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data

3.3.5. Littorina obtusata

There were significant differences in abundance of *Littorina obtusata* between the hand-cut and control sections on the upper and lower zone at Connemara before harvesting (**Table 16**). During the winter time numbers increased in the control site in all zones while numbers decreased in the hand-cut section (**Figs. 15a, b, c**). There were significant differences in the hand-cut section in the upper and middle zone over time and in the control section in the lower zone over time (**Table 16**).

At Clew Bay, variation between the different sections was not significant before harvesting (**Table 16**). Numbers were consistently highest in the mechanical section (**Fig.15**). Seasonal variation was not as pronounced at Clew Bay although there were significant differences in the control on the upper zone and in the hand-cut section on the upper and middle zone with time and between sections with time (**Table 16**). After mechanical harvesting at Clew Bay, a sample of periwinkles was collected from 4.5 tonnes of cut weed. From a total of 639 winkles, 45% were intact, 40% were broken, while 15% were broken and dead.

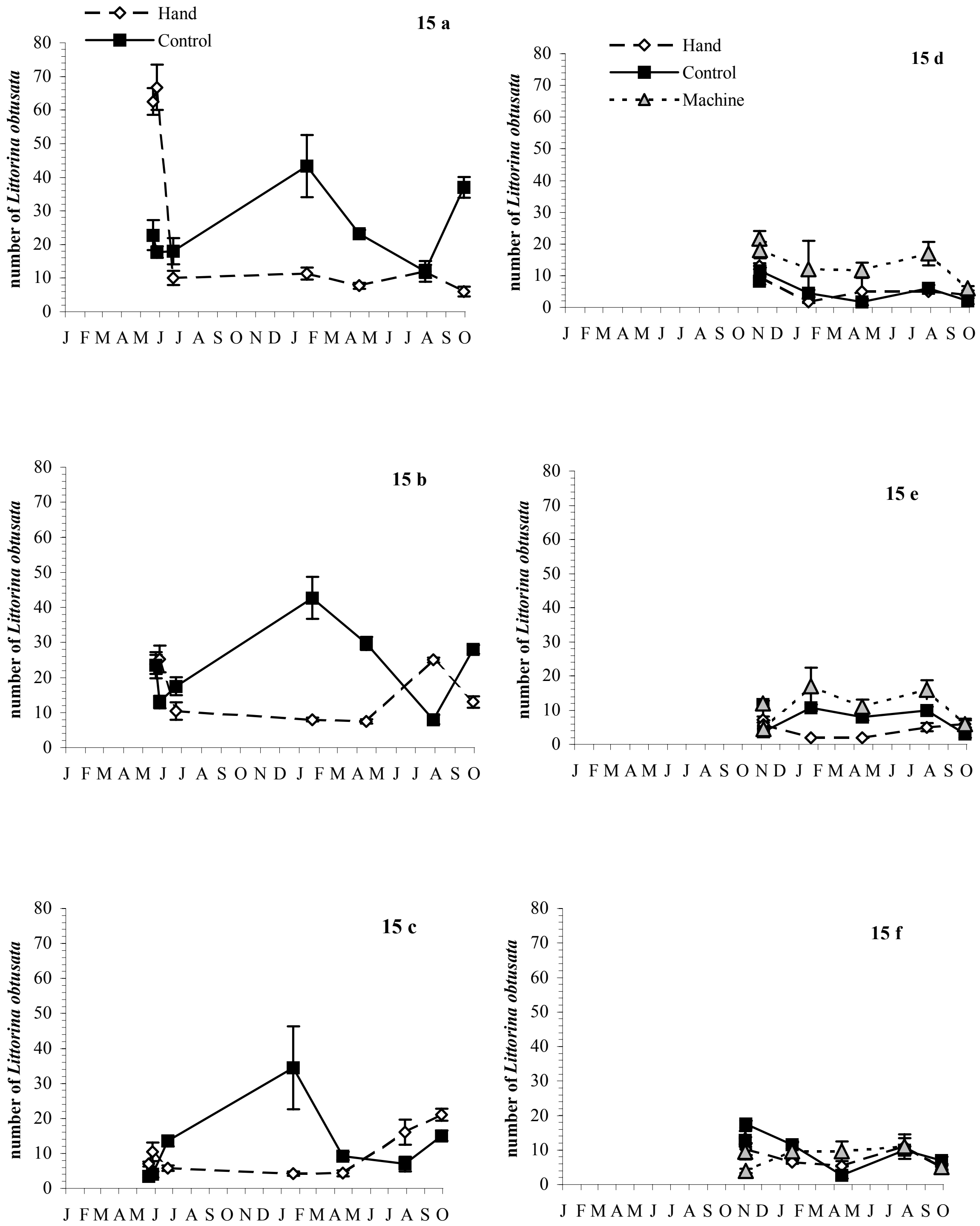


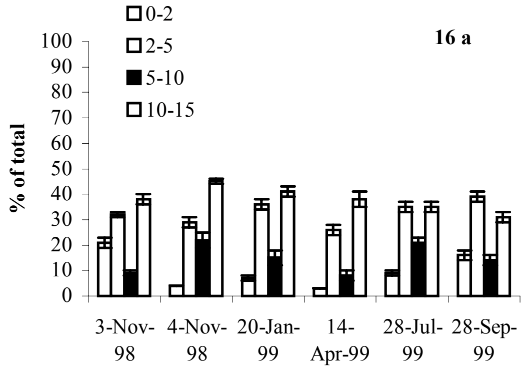
Fig. 15. Number of *Littorina obtusata* at the three shore sections (a, b, c) in Connemara and three shore sections (d, e, f) in Clew Bay. See Figs. **15a** and **d** for legend. Means and standard error bars are shown.

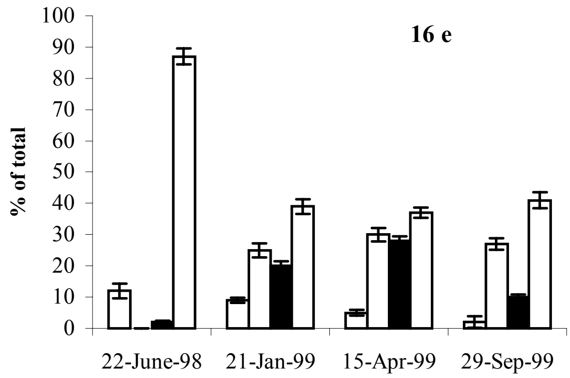
Table 16. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of *Littorina obtusata* agg. Significant differences highlighted in bold.

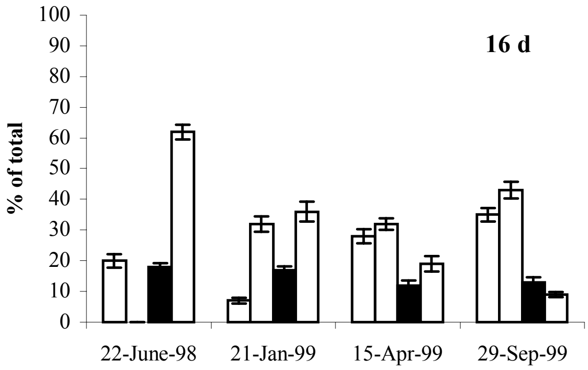
Treatment	Connemara				Clew Bay			
	N	**U**	**M**	**L**	**N**	**U**	**M**	**L**
Sections before harvesting	2	**0.021**	0.885	**0.037**	3	0.151	0.202	0.790
Control x time	7	0.477	0.142	**0.048**	6	**0.008**	0.063	0.156
Hand x time	7	**0.007**	**0.046**	0.096	6	**0.014**	**0.021**	0.428
Machine x Time	7	-	-	-	6	0.169	0.246	0.962

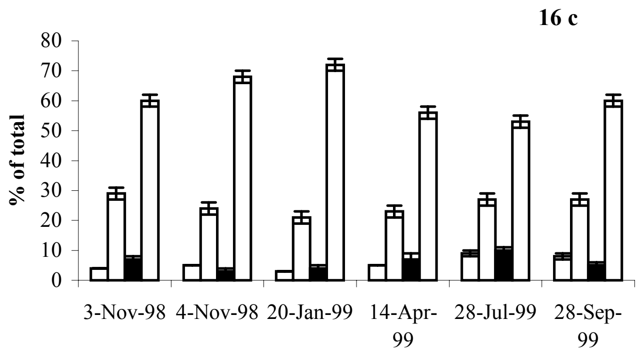
Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

The size distribution of *Littorina obtusata* agg. was plotted over time **(Fig. 16).** This revealed slight differences between sections at Clew Bay with larger winkles dominating in the mechanically harvested section. Over 60% of littorinids were < 10 mm length in the hand-cut section, 50% were < 10 mm length in the control, while only 40% were < 10 mm in the mechanical section. The relative proportion of *Littorina obtusata* agg. occurring in the different size categories was very consistent over time in the hand-cut, mechanical and control sections with no evidence of change after harvesting **(Figure 16 a, b, c).** A full set of data was not collected at Connemara and the impacts of harvesting could not be assessed. However, data from four sampling dates showed a more variable size distribution than Clew Bay **(Figure 16 d, e).**









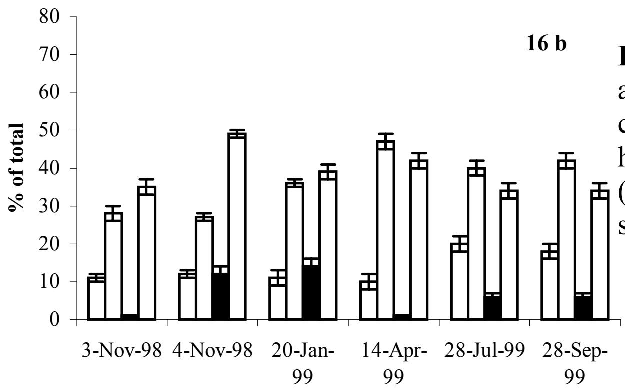


Fig. 16, Percentage size distribution (expressed as percentage of sample) over time in (a) hand-cut section, (b) control, and (c) mechanical harvested section at Clew Bay.(d) hand-cut and (e) control section at Connemara. Means and standard error bars are shown.

A list of species included) between sections at either Connemara or Clew Bay before harvesting **(Table 17).** There was significant variation in the control with time at Connemara showing a seasonal pattern with highest numbers present during the summer. This pattern was also present at Clew Bay although it was not significant (P= 0.054, **Table 17).** There was also significant variation in the hand-cut section at Connemara over time on the lower zone with evidence of a reduction in numbers a month after harvesting.

Table 17. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of herbivorous gastropods (excluding *Littorina obtusata* agg.). U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data. Significant differences highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	0.243	0.082	0.647	3	0.123	0.217	0.699
Control x time	7	0.771	**0.047**	**0.010**	6	0.219	0.054	0.223
Hand x time	7	0.185	0.265	**0.010**	6	0.174	0.153	0.102
Machine x Time	7	-	-	-	6	0.172	0.066	0.465

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

3.3.6. Other fauna

Twenty-seven species of mobile animals such as amphipods, isopods, polychaetes, molluscs and crabs were recorded at Connemara whilst nineteen species were found at Clew Bay during the course of the study. However, numbers were too low to assess the impacts of harvesting. The total percentage cover of sedentary groups such as bryozoans, hydroids, sponges and tunicates was also very low which compromises statistical analysis. A list of species included in this category is provided in **Appendix 1.** At both sites there was no significant variation in cover of sessile fauna between sections prior to harvesting **(Table 18).** There was a significant reduction in cover in the hand-cut section after harvesting over time at both Connemara and Clew Bay but not in the control.

Table 18. Results of Kruskal-Wallis one-way ANOVA showing statistical significance (p) in percentage cover of sessile fauna. Significant differences highlighted in bold.

Treatment	Connemara				Clew Bay			
	N	U	M	L	N	U	M	L
Sections before harvesting	2	-	-	0.102	3	-	-	0.957
Control x time	7	-	-	0.379	6	-	-	0.102
Hand x time	7	-	-	**0.012**	6	-	-	**0.007**
Machine x Time	7	-	-	-	6	-	-	0.201

Note: U = upper zone, M = middle zone, L = lower zone. N = number of observations. - = no data.

3.4. Snorkelling survey

The experience of the snorkellers varied but sometimes additional species were recorded by different surveyors. To account for differences between surveyors the median and maximum number of individuals for each taxon recorded for a section of seashore on the day of survey, where used in data analysis **(Table 19** and **Appendix II).**

Table 19: Results of one-way ANOVA showing statistical significance (p) in number of species and total abundance of taxa identified in snorkelling surveys.

Treatment	**Connemara**			**Clew Bay**		
	N	**No Species**	**Abundance**	**N**	**No Species**	**Abundance**
Before harvesting	**3**	**0.323**	**0.698**	**2**	**0.613**	**0.658***
Control x time	**2**	**0.753**	**0.949**	**4**	**0.42***	**0.517***
Hand x time	**2**	**0.623**	**0.975**	**4**	**0.925**	**0.707***
Machine x Time	**2**	**0.076***	**0.280***	**4**	**-**	**-**

Note: N = number of observations. - = no data. Significant differences highlighted in bold.
* = data not normally distributed

A total of 9 species were identified in the two snorkelling surveys carried out at Clew Bay. Connemara was more diverse with a higher abundance and richness, with 21 taxa groups were found during four snorkelling surveys here **(Appendix II, Fig. 17).** The most abundant species were shore crab *Carcinus maenas*, two-spotted goby *Gobiusculus flavescens*, and other unidentified fish species, the shrimp *Palaemonetes varians*, pollack *Pollachius pollachius* and ten-spined stickleback *Spinachia spinachia* (Table 15). None of these species were very abundant. At Connemara, in addition to those found at Clew Bay, grey mullet *Chelon labrosus* and corkwing wrasse *Crenilabrus melops* were also abundant. There was no significant difference in the number of species or total number of individuals at either Clew Bay or Connemara either between sites or with time **(Table 19, Fig. 17).**

4. DISCUSSION

4.1. Industry and harvesting

(See also **Appendix IV** for additional discussion on the relevance of mechanical harvesting)

The predominance of older seaweed harvesters in Ireland i.e. 84% > 41 years of age, (source Arramara Teo, 1998) and the steady fall in available labour as they approach retirement in the coming decade is a pressing concern for the Irish seaweed industry. For this reason there is need to actively plan ways to safeguard the supply of seaweed raw material for the future. Such concerns should ideally drive research into developing and testing alternative mechanical methods of harvesting of the primary target species, *Ascophyllum nodosum*.

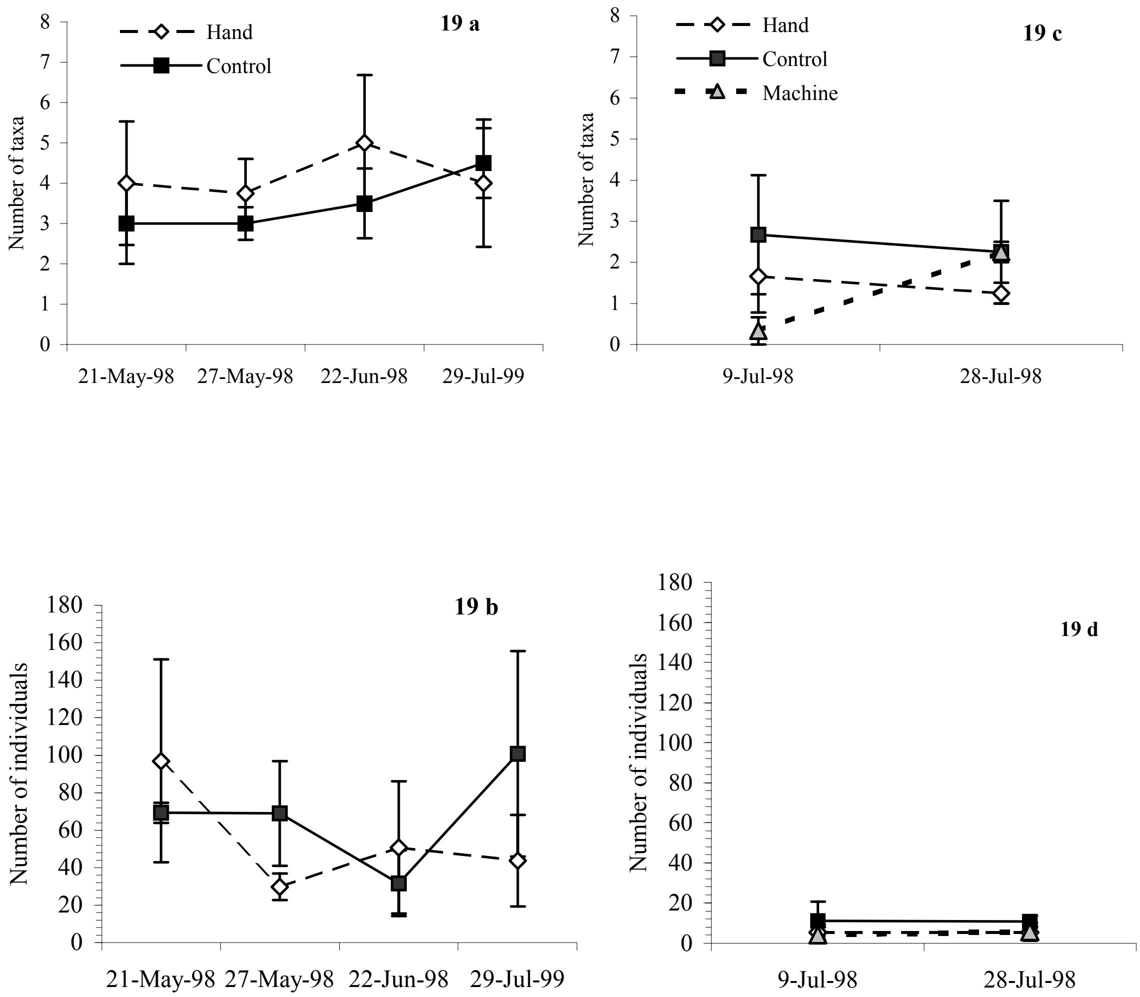


Fig. 17. Total number of taxa found during snorkelling surveys at (a) Connemara, (b) Clew Bay and abundance of taxonomic groups at (c) Connemara and (b) Clew Bay. Means (n=4 except 21-May-98 & 9-Jul-98 where n=3) and standard error bars are shown. See Figs. **19 a** and **b** for legend.

Assessments of harvester age structure carried out by Arramara Teoranta over a number of years in the mid 1990s showed that the age structure is roughly sinusoidal, with harvesters starting young, leaving the practice and returning to it in later life (M. Diver pers. comm.). However, since then change seemingly has accelerated, most recent observations of the harvesters show a sharp decline in young people starting into the practice in the first instance. *Ascophyllum* harvesting is part-time, laborious work and many young people are finding more convenient, profitable, alternative employment in the current favourable economic climate. Most recent trends predict a shortage of harvesters in the future and mechanical harvesting would seem the most obvious solution to predicted supply problems.

One of the goals of this project was to establish the benefits and costs associated with the use of mechanical harvesting. What effective mechanical harvesting should offer is a much greater harvest per unit effort (and cost), and it is clear that this objective has not been realised in the present preliminary trial. An assessment of the results from the preliminary harvest trials and the pre-harvest trials identifies the failure of mechanical harvesting to carry out satisfactory harvesting of *A. nodosum* biomass. This clearly indicates that more trials have to be performed before a satisfactory means of mechanical harvesting is found. Changes in design, for example, a lighter more manoeuvrable harvesting platform, and an elongated hydraulic arm allowing better range of harvesting coverage should result in a marked improvement on the results of future mechanical trials. Preliminary trials by nature are unfamiliar territory where factors such as a lack of fluency in machinery operation, and other inevitable teething problems can influence in a negative way the results.

Historically, one of the prominent issues concerned with harvesting (hand or mechanically) is the right to cut seaweed in titled areas designated by the then congested district board and the land acts of the late 19th and early 20th century. At the time when purchasing land adjoining the coast, the land folio normally made mention of entitlements of the landowner to cut the seaweed in that area of shoreline for their own use. It is thought this was originally implemented due to the importance of seaweed as a land fertilizer, and as a source of ash for glass making. Since then the importance of these rights has see-sawed according to the economic benefit to be gained from seaweed and in practice to the behavior of the parties involved.

When Arramara Teoranta started purchasing *A. nodosum* for the alginate industry in the early 1960s, the question of seaweed cutting rights once again came to the fore with people defending their patch, even those who did not and do not harvest the seaweed. Much feuding has resulted from this state of affairs. This is especially true for the Connemara region, although some areas in Mayo and Donegal have also resisted any attempts at harvesting. In the long term, these rights would be an obstacle to any company hoping to use extended stretches of a coastline for mechanical harvesting. However, recent clarifications on the legal status of traditional seaweed rights by the office of the Attorney General have shown such seaweed rights to be largely insubstantiated. (Nation Seaweed Forum Report, 2000) This very recent clarification of existing foreshore legislation shows that the Government, through the Department of Marine and Natural Resources has the necessary authority to grant foreshore licences for the purpose of gathering seaweed regardless of individual claims of entitlement, baring a very small number of exceptions. This finding should in time remove doubt over any perceived obstacles to harvesting as much as the growing irrelevance of seaweed rights in the first place to a younger generation pursuing other careers.

Quality

The quality of the mechanically harvested seaweed in both areas was of concern. It was thought that the *in situ* washing during mechanical harvesting should eliminate the need for washing the seaweed at the factory. After a vigorous inspection of chopped weed in both areas impurities were observed in the seaweed. The small amount of seaweed harvested in Connemara was littered with periwinkles and parts of periwinkle shells as well as being contaminated with other seaweeds (e.g., *Ulva* sp., *Fucus* sp., and *Enteromorpha* sp.). The seaweed harvested in Mayo was less contaminated with other species, however, it contained a larger amount of sand and mud and other inorganic debris, that would require additional washing before processing. Generally it was thought that the hydraulic arm may have been maneuvered too close to the substratum rising all manner of silt etc. and obscuring further the visibility necessary for keeping proper cutting height above the bottom.

As with all intertidal endeavours the tidal cycle determines the length of harvesting time for both hand and mechanical harvesting. This factor was minimized for the mechanical harvester by anchoring offshore and using a long mechanical arm. In Connemara, the hydraulic arm was much shorter than that used in Clew Bay and this was clearly a factor in the resulting poor harvest. It is considered that the longer hydraulic arm was easier to manipulate and took in a wider range of shore without requiring movement of the harvesting craft. In stark contrast to the uneven boulder shore of Connemara the gently sloping shore of

Clew Bay facilitated unhindered access to the shore for the flat-bottomed modified salmon barge. However, a shallow sill at the entrance of the narrow Bay delayed entrance of the harvesting craft in the first place and effectively shortened the available work window. Once in the area, the boat could move closer to shore with less risk of being grounded. As a general principal it is recommended for harvesting practices to retain the essential characteristics of the habitat.

Overall, the bare economics of the trial make for sober reading. For the trial each mechanically-harvested ton of seaweed cost in the region of IR£850!. Bearing in mind that the current price paid for a fresh tonne of Asco is £21 (Arramara Teoranta *pers comm*. 2001) this represents a massive 4000% increase in cost. Obviously this figure is hugely distorted due to the small tonnage that was harvested, the high costs incurred in the rental of the boat and harvesting equipment and the economic effort in specially fitting out the harvester for the trial. It is clear that further trials and development of mechanical harvesting capability is necessary. Realistic harvesting economies will become known when harvesting is carried out on a regular basis using a specifically designed vessel. If a hand harvester can harvest on average 3 wet tonnes during one low tide then as a minimum requirement a mechanical harvester should ideally be able to harvest 8-10 times that amount in the same time.

(See also Appendix IV **for additional discussion on the relevance of mechanical harvesting)**

4.2 Special Areas of Conservation (SAC's)

Postscript on recent developments concerning cSAC's during 2000-2001 ***Jim Morrissey***

Note: The following comments on SAC issues are provided in good faith without prejudice from recent dealings, official documents, and personal communications with Dúchas and we the authors do not take any responsibility for any potential misunderstandings arising from these comments.

Since the inception of this project in 1997 the situation regarding SAC's has changed considerably in the four intervening years to 2001. Primarily, speculation about the long-awaited introduction of Marine cSACs has changed since May 2000, with the considerably overdue publication by Dúchas, of the locations of the initial 32 Marine cSAC's (candidate Special Areas of Conservation). It is not known at present how many additional marine sites will be designated in the forthcoming 4th round of cSAC designations but it is clear that the EU are strongly pushing Ireland for considerably more designated marine conservation areas. A full list of the existing 32 marine cSAC areas designated by Dúchas as of May 2000 are included in **Appendix V**. Candidate (cSAC) sites are known as such on being designated until such time as a full management plans are put in place for each area, in which case they will be referred to as full marine SAC's, however notifiable actions still apply while the designation is classed as candidate.

In addition, during 2000 several constructive meetings relating to SAC issues took place between representatives of the seaweed industry and Dúchas, including a briefing with the National Seaweed Forum. These meetings have helped clarify certain matters and a working relationship has been developed between the various parties.

History of *candidate* Special Areas of Conservation (cSACs)

The EU habitats Directive (92/43/EEC) of 21st May 1992 obliged all EU member states to protect a certain suite of habitats which were identified as being of European importance. This network of conservation sites is made up of Special Protection Areas (SPA's) established under the Birds Directive, and Special Areas of Conservation, (SAC's) established under the Habitats Directive. The Network is collectively known in the EU as *Natura 2000* and Ireland's contribution to this network is being created under the European Communities (Natural Habitats) Regulations, 1997 (S.I.94/97). Ireland has identified about 16 such habitat types in total covering both land and marine areas, for example *grasslands, bog-land, woodland, estuary, sand dunes, salt marsh, islands,* etc, which are known as priority habitats in a European context, and which the Government are obliged by EU law (Directive 92/43/EEC) to protect. Marine habitats recognised as being of prime conservation value have been assigned an identity number and are listed in Table 20 below.

Basis for selection of cSAC sites.

- The findings of the BioMar project/survey carried out in the mid 1990s were used as the main scientific criteria for choosing the candidate SAC sites and for choosing particular species deemed to be under threat and which should be afforded protection.

- The BioMar survey was an extensive landmark survey carried out mainly by Environmental Sciences Unit, TCD, and Ecoserve Ltd. in collaboration with the Dept. of Botany, NUI, Galway over 3 years (1993-1996). The aim of the survey was to provide descriptions of the littoral and sublittoral habitats and associated communities of the Republic of Ireland. Dúchas assessments of the resultant data for biological interest and nature conservation importance were used as a basis for designation of conservation areas. Hence, the findings of the BIOMAR survey have provided most of the foundation for current national and EU related conservation designations.

Table 20. List of marine habitat types classified under existing SAC legislation.

(Marine) Habitat no.	Habitat Description
1.1	*Open marine waters, inlets and bays, tidal rivers and estuarine channels, marine caves, reefs, submerged sandbank*
1.2	*Mudflats and sandflats, sandy coastal beaches, shingle beaches, boulder beaches, bedrock shores, marine caves.*
1.3	*Saltmarsh.*
1.4	*Sand dunes and machair*
1.5	*Brackish lakes, lagoons*
1.6	*Rocky sea cliffs, clay sea-cliffs, sea stacks and islets (stacks, holms and skerries)*

Each cSAC habitat type/number has an accompanying list of notifiable actions some of which are shared and others which are specific to that particular habitat. For example, '*The cutting or harvesting of growing seaweed'* is a notifiable activity in habitats 1.1 and 1.2. Following on from difficulties experienced with the designation of initial land SAC's Dúchas have been directed by the Minister of Arts, Heritage, Gaeltacht and the Islands to involve themselves in better consultation processes with local interests groups / organisations, etc. to avoid similar pitfalls, and ease local worries about the continuation of 'traditional activities' in the Marine cSAC areas. 'Traditional activities' that includes seaweed harvesting by hand. Communication has taken place between ISIO member companies and Dúchas on several occasions during 2000-2001

The interpretation of the existing SAC regulations regarding the status of activities within a conservation area is that one may continue to carry out existing activities in a traditional manner (providing they are not damaging to the environment) and that any new activity cannot take place without the approval of the minister, and in certain cases where additional permission is required, consent from another statutory body, i.e. county council.

All the newly announced marine cSAC areas except for one in Lough Swilly, include habitat 1.1 (open marine waters, inlets and bays), among other habitats, which states that within these areas *cutting or harvesting growing algae is a notifiable action requiring consent*. This does not mean that seaweed cutting is disallowed but that it requires some form of written consent from the Minister for Arts, Heritage, Gaeltacht and the Islands. The explanatory note in Dúchas's official SAC announcement continues with the statement:

"In most cases the Minister's objective of sustainable use is met by a continuation of the current practices and after the consultation period, the user will continue as s/he always has".

"*In some cases an intensification of exploitation will not be environmentally sustainable or a use will be environmentally damaging and it will not be acceptable to the Minister. In these cases the activity must be discontinued and a compensation system will be invoked".*

What does this mean for existing seaweed harvesting activities within designated cSAC areas?

- *Seaweed harvesting by hand, as it stands, passes as a traditional activity so will be allowed to continue as normal within cSAC areas.*

- *Seeking to substantially increase the biomass of weed harvested within a conservation area would require the consent of the Minister.*

- *Any plan to introduce mechanisation of seaweed harvesting in SAC areas would definitely be questioned. Prior to this mechanisation of harvesting has been largely untried so what was involved was unknown apart from second hand information from France, Norway, Canada and Iceland, all of which have tried or use regularly mechanised harvesting. Any attempt to introduce mechanisation of seaweed harvesting into a SAC areas would have to be adjudicated on.*

- *Seaweed aquaculture of indigenous species is permitted and subject to the usual licencing considerations. Introduction of foreign species of seaweed for cultivation would be questioned.*

- *By law, the Department of Marine & Natural Resources has to consult with Dúchas if aquaculture licence applications are within a conservation area. The Department has been doing this up to now in any case but the agreement was less formal.*

- *Notification publication of the cSAC sites is accompanied by a list of notifiable activities which states activities which will require consent in which habitats. This allows individuals, businesses to engage in self-diagnosis of their operations for compliance with the SAC restrictions.* (see Appendix 5)

- In the case of Dúchas refusing to allow an activity within an area an appeal can only be based on scientific grounds and in such circumstances an appellant would be entitled to receive such information from Dúchas regarding the initial scientific criteria/ basis on which the cSAC designation was based upon.

- Once the Marine cSACs have been identified *conservation plans for each site will be drawn up by Dúchas over the following two years.* Following the publication of these management plans locals can form marine liaison groups for their marine SAC, with representation from individuals involved in activities within the designated area.

Comment
For the vast majority of seaweed harvesters who harvest in a cSAC area, its a case of ‘business as usual’. Basically, a foreshore licence is required for all seaweed harvesting on state shore (which is 99% of the coast) and the DoMNR must by law consult with Dúchas if the foreshore application is within a cSAC area. So if one is in possession of a valid foreshore licence for an area within a cSAC one theoretically has by default, permission of Dúchas. Exceptions may be with licences in cSAC areas not renewed since the introduction of the conservation areas in May 2000. For queries contact DoMNR (coastal zone division) or Dúchas at 01-6473000. Dúchas also have a SAC hotline at **1800 405000.**

4.3. Sampling sites

The site at Connemara, Co. Galway consisted of predominantly bedrock and boulders (84%) with only a small amount of gravel, sand and mud. This contrasts with the site in Clew Bay Co. Mayo, which consisted of predominantly mud and sand (47%) with more or less even amounts of gravel, cobbles, pebbles and bedrock (see Fig. 7). The two sampling sites showed communities with a higher species richness at Connemara (97species) than Clew Bay (84 species). The larger number of microhabitats and increased shading from boulders and bedrock at Connemara probably accounts for the different species and higher richness (especially of red algae) present at the Connemara shore. Variation in substratum within the sites will contribute to variation in species abundance and cover during the surveys. The site at Clew Bay was more susceptible to anthropogenic activity than the site at Connemara, which was more secluded. A large trestle-type oyster farm (approximately 500bags) was situated beside the Clew Bay site and there were occasional intrusions from domestic agricultural animals.

4.4 *Ascophyllum nodosum* coverage, growth and regeneration

There was a significant reduction in cover of *Ascophyllum nodosum* from 70-100% to less than 30% at both sites after hand-cutting. Cover, but not biomass was restored to 70% within 11 months in Clew Bay, and 14 months in Connemara. Mechanical harvesting removed less *Ascophyllum* biomass than hand harvesting, due to several factors effecting the effectiveness of the mechanical harvester. After hand harvesting the length of the plants left on the shore was around 20 cm while the mechanical harvester left plants with a length around 50 cm.
One of the problems encountered during this study was the disappearance of plants or tags, or plants had broken away leaving a small stump. To measure re-growth and overcome these problems it is recommended that laboratory trials be performed or the marking of a larger number of plants (at least 50 sample plants per zone and shore level) in the field.

Biomass of *A. nodosum* ranged in Clew Bay from 0.2 -37 kg m^{-2}. Low biomass values at the Clew Bay site were caused by the patchy distribution of *A. nodosum*. This is directly related to the substratum in Clew Bay with fewer rocks and pebbles to serve as an attachment point (Fig. 7). The site in Connemara consisted predominantly of rocks and boulders and similar high biomass values were found as in Clew Bay but no low values resulting in a homogenous biomass in Connemara. Plant densities were also substantial larger at Connemara compared to Clew Bay. The rate of broken and or lost plants was higher in the Connemara site most probably due to more severe weather conditions. Exposure to weather conditions might also explain the longer average length, more plants were over 1 m, and amount of laterals at the Clew Bay site compared to the Connemara site, however, the amount of base shoots was higher at the Connemara site, a possible indicator of a larger biomass and more exposed conditions. The age distribution measured by the number of bladders in the primary shoot showed that the *A. nodosum* bed at Clew Bay was slightly older, which might be another explanation of the larger plants found at this site.

4.5. Impacts of harvesting on biodiversity

Significant differences in number of species occurred in the control section over time at both sites (Figs. 10 and 11). Differences may reflect a seasonal trend with higher numbers in summer and lower numbers in winter. This seasonal trend is more apparent at Connemara maybe due to more severe exposure to weather conditions. No changes in number of species were attributable to harvesting.
Harvesting did not have an impact on red algae cover at Clew Bay although there was evidence of a possible reduction after harvesting at Connemara with subsequent recovery. At Clew Bay percentage cover of red algae was low and variable. Significant differences on the upper zone were due to the higher abundance of red algae in the mechanical harvested section

at Clew Bay even before harvesting and high variability in percentage cover at Connemara even in the control sections which showed significant differences over time on the upper zone. There is a slight seasonal trend to higher cover during the summer months.

It was predicted that harvesting would lead to temporary increases in ephemeral algae (Boaden & Dring, 1980). Increase in ephemeral alga cover in the middle zone after harvesting may have been facilitated by removal of the *Ascophyllum* canopy. However, harvesting did not have a significant impact on ephemeral algae over time at either Connemara or Clew Bay. Percentage cover was very variable at both sites even within the control. There was evidence of a seasonal pattern with higher cover during summer months, although this was patchy and variable across the shore.

An increase in *Fucus vesiculosus* was expected after harvesting (Boaden & Dring, 1980; Jenkins *et al.*, 1999). Harvesting however did not have an impact on *Fucus vesiculosus* at Clew Bay. However, at Connemara there was a significant ($P<0.03$) increase in percentage cover of *Fucus vesiculosus* 11 months after harvesting in the hand-cut section. There was also significant variation in cover of *Fucus vesiculosus* in the control section at both sites. Harvesting did not have a significant impact on *Fucus serratus* at either Connemara or Clew Bay.

Harvesting caused a reduction in abundance of *Littorina obtusata* (Black & Miller, 1991). This is in agreement with the results of this study were harvesting caused a significant ($P<0.05$) decrease in abundance of *Littorina obtusata* during the winter months on the middle and upper zones at both sites. However, there was a simultaneous increase in abundance at the control sites after harvesting. It is possible that periwinkles may have redistributed themselves to the control and machine-cut areas during the winter months where there was more shelter available. Mechanical harvesting damaged more than half of the periwinkles present in cut weed. Smaller winkles were found in harvested sections (Boaden & Dring, 1980). However, the study found that harvesting did not have an impact on the size distribution of *Littorina obtusata* where this was studied at Clew Bay (Fig. 16).

Harvesting did not have a significant impact on herbivorous gastropods at either Connemara or Clew Bay except for the lower zone at Connemara with evidence of a reduction here in the hand-cut section a month after harvesting with a gradual recovery thereafter. Numbers were very variable over space and time although there is evidence of a seasonal pattern with lower numbers present during winter and spring especially at Connemara.

A decrease was predicted in encrusting species such as sponges and bryozoans following harvesting (Boaden & Dring, 1980). There is evidence of a reduction in sessile fauna after hand-cutting at both sites (and to a lesser extent after mechanical harvesting at Clew Bay) particularly 10-12 months post-harvesting and this was significant at both sites in the hand-cut section.

Black & Miller (1991) found no evidence for adverse effects on fish following harvesting of *Ascophyllum nodosum*. In the present study harvesting did not have a significant impact on mobile epifauna and fish at either Clew Bay or Connemara where abundance was extremely variable throughout. The return of weed cover within 1-year is likely to restore the habitat needs of young fish. The effects of *Ascophyllum* biomass recovery are more likely to affect epifauna and epiflora through effects on temperature and desiccation at low tide, and light transmission through the weed canopy at high tide.

Harvesting did not have a significant impact on overall diversity although it did have an impact on certain species. Hand harvesting led to increases in *Fucus vesiculosus* and ephemeral algae with no significant impact on other flora. Hand harvesting resulted in decreases in littorinid numbers during the winter months and a reduction in total encrusting sessile fauna. Further studies are recommended to examine the longer-term impacts of harvesting and especially at re-harvesting on associate biodiversity and on the use of mechanical harvesting and the numbers of herbivorous gastropods.

5. CONCLUSIONS & RECOMMENDATIONS

The observations of mechanical harvesting in terms of efficiency and economics are mostly negative towards the success of the trial. However, the trial is the first of its kind to be carried out in Ireland at an exploratory level and the knowledge of its capability at an unrefined level proves that mechanical harvesting in Ireland is a distinct possibility. It is recommended to develop further and optimize mechanical harvesting techniques together with detailed field trials.

The results from the clew Bay site are encouraging to Arramara Teoranta, especially as this is one of the least exploited seaweed regions of Ireland. In the present economic climate it must be remembered that Arramara Teoranta is a semi-state body that provides vital part-time employment to many seaweed harvesters on the west coast. Perhaps it is only if the number of cutters declines that the company will embark on mechanical harvesting means of supply of raw materials, and if it does the project will have determined the crucial focal points.

- ♦ Harvesting of *Ascophyllum nodosum* had no impact on overall biodiversity although it did have an impact on a small number of individual species.
- ♦ Harvesting led to effective removal of percentage cover of *Ascophyllum nodosum* but cover showed recovery in percentage cover at two contrasting sites over the course of one year. Mechanical harvesting was less effective than hand-cutting in removal of *Ascophyllum nodosum*.
- ♦ In Connemara, harvesting of *Ascophyllum* significantly increased cover of *Fucus vesiculosus* over 11 months after harvesting. Harvesting did not have an impact on *Fucus vesiculosus* at Clew Bay.
- ♦ Harvesting of *Ascophyllum* did not have a significant impact on *Fucus serratus*, red algae or ephemeral algae.
- ♦ A reduction in numbers of *Littorina obtusata* during winter months with a corresponding increase in the control section at both sites may result from hand-harvesting. Harvesting did not have an impact on other gastropods except for an immediate reduction in the lower zone at Connemara.
- ♦ Harvesting lead to a significant reduction in sessile animal such as sponges and bryozoans at both sites.
- ♦ Harvesting of *Ascophyllum* did not have any significant impact on fish and large mobile epifauna.
- ♦ It is recommended that the study of the two sites should continue to monitor longer-term impacts.
- ♦ This study dealt with impacts at two sites. The results indicate mechanical harvesting will have less of an environmental impact than hand harvesting at a local scale. Neither method of harvesting had long-term effects on biodiversity and no species were lost from any of the harvested sites.
- ♦ This study did not address the impacts of harvesting at a regional scale. It is recommended that appropriately scaled geo-referenced electronic maps of the seashores in the region are compiled in a Geographical Information System (GIS). The biomass of *Ascophyllum* and date of last harvest should be recorded on the maps to provide statistics on the resource, rate of harvesting and areas impacted by harvesting.

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7. APPENDICES

Appendix 1

Number of occurrences of different taxa at each site (taxa only found once are included in other species). Total number of samples in each zone for Clew Bay = 72, for Connemara = 56.

	Clew Bay			Connemara			
Species	**U**	**M**	**L**	**U**	**M**	**L**	
FLORA							
Ceramium sp.	-	-	1	-	-	56	red algae
Chondrus crispus	-	1	13	14	36	45	
Corallina officinalis	2	1	6	-	-	3	
Corallinaceae indet.	-	-	-	8	14	25	
Furcellaria lumbricalis	-	-	-	-	6	21	
Gelidium pusillum	1	1	3	3	9	6	
Gelidium sp.	9	9	13	20	23	30	
Hildenbrandia rubra	15	4	5	22	28	21	
Lomentaria articulata	-	-	-	-	2	9	
Mastocarpus stellatus	-	-	1	2	1	7	
Membranoptera alata	-	-	-	-	1	10	
Osmundea hybrida	-	-	3	-	-	2	
Rhodophyllis divaricata	-	1	-	1	5	6	
Rhodothamniella floridula.	6	2	4	17	24	24	
Cladophora rupestris	8	-	-	32	32	40	ephemeral algae
Ectocarpus sp.	1	12	8	2	8	12	
Enteromorpha sp.	19	28	31	17	31	33	
Pilayella sp.	1	5	15	1	3	9	
Ulva sp.	1	9	13	3	9	20	
Ascophyllum nodosum	71	71	72	56	56	56	other algae
Chorda filum	-	-	-	-	-	2	
Fucus ceranoides	6	1	-	-	-	-	
Fucus serratus	2	2	31	1	10	37	
Fucus spiralis	29	6	3	13	1	1	
Fucus vesiculosus	33	47	45	26	28	18	
Pelvetia canaliculata	7	2	-	-	-	-	
Polysiphonia lanosa	33	51	6	29	34	32	
Verrucaria mucosa	1	-	2	6	1	2	
Other flora	1	-	-	1	2	3	
Total Flora	**19**	**18**	**20**	**21**	**23**	**30**	

FAUNA							
Gibbula cineraria	-	5	6	1	5	14	Herbivorous gastropods
Gibbula umbilicalis	-	-	-	17	24	18	
Littorina littorea	27	11	32	37	32	46	
Littorina obtusata/mariae	68	65	67	54	55	55	
Littorina saxatilis	21	7	4	12	3	-	
Rissoa parva-interrupta	54	38	24	18	17	14	
Alcyonidium gelatinosum	-	-	10	2	1	5	sessile fauna (% cover species)
Appendix 1 continued							
Alcyonidium sp.	-	2	4	-	-	-	
Ascidiella aspersa	-	-	2	-	-	-	

Botryllus schlosseri	-	2	7	1	1	12	
Bowerbankia imbricata	5	17	25	1	4	11	
Bryozoa crust indet.	-	-	4	-	-	-	
Dendrodoa grossularia	-	3	12	2	17	32	
Didemnidae indet.	-	-	5	-	-	-	
Dynamena pumila	-	11	49	7	-	10	
Flustrellidra hispida	-	-	3	2	12	21	
Grantia compressa	-	-	8	-	3	1	
Halichondria panicea	-	-	4	-	1	3	
Halisarca dujardini	-	1	22	1	4	15	
Hymeniacidon perleve	-	3	12	1	8	12	
Leucosolenia complicata	-	-	5	-	5	8	
Obelia sp.	-	4	15	-	-	1	
Schizoporella unicornis	-	-	2	-	4	12	
Actinia equina	1	-	2	5	4	1	Other fauna
Anemonia viridis	-	-	-	-	2	16	
Archidoris pseudoargus	-	-	3	-	-	1	
Buccinum undatum	-	-	-	-	-	2	
Carcinus maenas	20	9	16	12	16	14	
Cerastoderma edule	-	2	1	-	-	-	
Chthalamus montagui	4	-	-	16	2	-	
Elminius modestus	32	16	24	-	-	-	
Gammaridae	34	9	13	15	6	4	
Idotea neglecta	1	1	-	1	1	2	
Lanice conchilega	-	-	-	-	-	3	
Leptochiton asellus	1	-	2	1	-	1	
Mytilus edulis	2	6	8	3	-	2	
Nucella lapillus	5	4	8	12	21	11	
Pagurus bernhardus	-	-	-	-	-	8	
Patella spp.	-	3	16	11	3	6	
Polychaeta indet.	2	1	-	-	1	1	
Pomatoceros triqueter	-	1	7	-	-	2	
Semibalanus balanoides	11	11	16	1	4	5	
Spirorbidae indet.	31	34	50	29	39	45	
Terebellidae	-	1	1	-	-	2	
Turbellaria	-	-	-	-	1	2	
Turritella communis	-	-	-	-	-	2	
Venerupis senegalensis	-	-	2	-	-	-	
Other fauna	4	3	5	2	7	10	
Total fauna	**23**	**30**	**43**	**27**	**36**	**48**	
Total flora & fauna	**40**	**48**	**63**	**48**	**59**	**78**	

U = upper zone, M = middle zone, L = lower zone.

Appendix 2

- Snorkelling Survey

Maximum and median abundance of taxa found during snorkelling surveys.

- = none found; Med = median; Max = maximum.

	Clew Bay											
	09-Jul-98						28-Jul-99					
	Hand		Machine		Control		Hand		Machine		Control	
species	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max
Pollachius pollachius	-	-	-	-	-	-	2	2	1	1	2	2
Carcinus maenas	12	12	12	12	11	19	2	15	2	13	8	15
Chelon labrosus	1	1	-	-	-	-	-	-	-	-	-	-
Unidentified fish	1	1	-	-	2	2	-	-	-	-	-	-
Crenilabrus melops	-	-	-	-	-	-	-	-	-	-	-	-
Gobiusculus flavescens	-	-	-	-	4	6	-	-	-	-	-	-
Palaemonetes varians	-	-	-	-	2	2	1	1	1	1	1	1
Mysidacea	-	-	-	-	-	-	-	-	2	2	-	2
Pagurus bernhardus	-	-	-	-	-	-	-	-	-	-	-	-
Spinachia spinachia	1	1	-	-	-	-	-	-	1	1	1	1
Ctenolabrus rupestris	-	-	-	-	-	-	-	-	-	-	-	-
Comb jelly	1	1	-	-	1	1	-	-	1	1	-	1
Scophthalmus maxima	-	-	-	-	-	-	-	-	-	-	-	-
Gobius niger	-	-	-	-	-	-	-	-	-	-	-	-
Liocarcinus puber	-	-	-	-	-	-	-	-	-	-	-	-
Nerophis lumbriciformis	-	-	-	-	-	-	-	-	-	-	-	-
Nudibranchia	-	-	-	-	-	-	-	-	-	-	-	-
Callionymus lyra	-	-	-	-	-	-	-	-	-	-	-	-
Anguilla anguilla	-	-	-	-	-	-	-	-	-	-	-	-
Pollachius virens	-	-	-	-	-	-	-	-	-	-	-	-
Pholis gunnellus	-	-	-	-	-	-	-	-	-	-	-	-
Total no. species	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**
Total no. individuals	**16**	**16**	**12**	**12**	**19**	**30**	**5**	**18**	**8**	**19**	**11**	**22**

Appendix 2 continued

	Connemara															
	21-May-98				**27-May-98**				**22-Jun-98**				**29-Jul-99**			
	Hand		**Control**		**Hand**		**Control**		**Hand**		**Control**		**Hand**		**Control**	
species	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**	**Med**	**Max**
Pollachius pollachius	70	89	79	89	84	89	6	13	1	25	16	30	2	2	26	50
Carcinus maenas	28	73	51	73	62	73	13	17	12	77	9	37	1	3	3	7
Chelon labrosus	-	-	-	-	-	-	-	-	1	1	-	-	26	200	50	50
Unidentified fish	2	2	-	2	2	2	100	100	3	3	2	2	2	2	2	6
Crenilabrus melops	26	26	26	26	-	26	-	-	30	30	15	15	3	3	-	-
Gobiusculus flavescens	-	-	-	-	-	-	2	2	3	4	2	2	3	127	6	39
Palaemonetes varians	-	-	-	-	-	-	-	-	9	17	10	10	2	2	1	1
Mysidacea	-	-	-	-	-	-	-	-	17	17	7	7	-	-	-	-
Pagurus bernhardus	6	6	-	6	-	6	-	-	-	-	-	-	2	2	-	-
Spinachia spinachia	-	-	-	-	-	-	-	-	2	3	1	1	-	-	-	-
Ctenolabrus rupestris	-	-	-	-	-	-	-	-	3	3	3	3	-	-	-	-
Comb jelly	-	-	-	-	-	-	-	-	1	1	-	-	1	1	-	-
Scophthalmus maxima	2	2	-	2	-	2	-	-	-	-	-	-	-	-	-	-
Gobius niger	-	-	-	-	-	-	-	-	-	-	-	-	2	2	1	1
Liocarcinus puber	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-
Nerophis lumbriciformis	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-
Nudibranchia	-	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-
Callionymus lyra	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
Anguilla anguilla	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
Pollachius virens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Pholis gunnellus	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Total no. species	**8**	**7**	**5**	**8**	**7**	**8**	**5**	**4**	**13**	**9**	**9**	**6**	**11**	**7**	**9**	**8**
Total no. individuals	**136**	**200**	**158**	**200**	**148**	**200**	**122**	**133**	**85**	**184**	**64**	**107**	**45**	**345**	**91**	**156**

Appendix 3

Quadrat code/number **Date** **Name of recorder**

Feature	Parameter	Unit	Plant number											
			1	2	3	1	2	3	1	2	3	1	2	3
individuals		no.												
colour of weed														
epiphytes present	name	1												
		2												
		3												
		4												
stump size	length	cm												
	Breadth	cm												
base shoots		no.												
lateral shoots		no.												
main frond	length	cm												
	bladders	no.												
	> bladder	cm												
	< bladder	cm												
*growth		cm												
Longest Frond Lth.														
Bladders														
Lateral shoots														

*** note:** This refers to the growth of the individual, from where it has been marked with the cat gut at time of first sampling record the distance from the base of the stump to cat gut mark.
> bladder =largest bladder
< bladder = smalles$_{t}$ bladder

Appendix 4 (postscript)

Relevance of mechanical harvesting to the Irish Seaweed Industry

Arramara Teoranta is by far the largest seaweed company in Ireland providing over 70% of employment within the seaweed sector (currently* numbering over 250 mixed part-time and full-time seaweed harvesters) and generating less than half of the current turnover. To date all of there harvesting is carried out by hand. As the main supplier of bulk meal with access to the majority of harvesters, they supply seaweed meal as raw material to several other Irish companies, notably Kerry Algae. Consequently, ensuring the continuity of their business is widely recognised as being pivotal to the survival and prosperity of the wider Irish seaweed industry. At the height of the industry in the 1960s there were 12 factories drying seaweed on the west coast but now the two* remaining factories operated by Arramara Teoranta are the only remaining primary source of bulk quantities of Irish seaweed meal.

It is accepted by Arramara Teoranta and another larger Irish company, Kerry Algae, that the development of a mechanical harvesting capacity for the harvesting of bulk quantities of seaweed (*Ascophyllum nodosum*) is not only inevitable but is critical to the long-term survival of the Irish seaweed industry. The problem lies not so much with the traditional methods of hand harvesting being unable to satisfy current requirements, but is more to do with looking ahead at the forecasted shortage of labour over the next 5-10 years, and the inevitable negative consequences for this labour-intensive activity. An examination of the existing age profile of seaweed harvesters in the Connemara district (1998 figures) shows the high age profile of existing harvesters and worryingly shows an almost total lack of recruitment of younger people into the industry. Out of a total of 130 harvesters more than 80% of them are over 41 years old with only three harvesters under thirty years recorded.

This situation is closely mirrored nationally in other areas of manual work including fishing, aquaculture and farm labouring. Some of these industries have actively recruited manual labour from abroad. It is no surprise that young Irish people are turning their backs on traditional manual labour in rural areas in preference for higher paid jobs in manufacturing, building and services centered in urban areas.

The lack of a reliable supply of raw material has been identified as a major barrier to expansion by all companies, particularly Kerry Algae. If these current trends are ignored, the overall supply situation will get worse as more harvesters retire and based on current age profiles this could become critical within the next 5-10 years. An annual harvest of about 30,000 tonnes of *A. nodosum* is needed to satisfy existing demands. It seems important therefore that mechanical harvesting be thoroughly investigated at this stage for operational feasibility in tandem with environmental compliance. Appropriate mechanical harvesting technologies could help to guarantee the future supply of seaweed in a manner acceptable to national and EU conservation obligations.

At the same time while Arramara Teoranta would like to have the capacity for mechanised harvesting, their company policy may delay introduction of this technology until such time, with the retirement of its older harvesters, as the supply of hand harvested weed looked to be droping towards a level to cause concern. Such a scenario may not be long coming as even since the start of this project in 1997 the national employment situation has changed, reaching near full capacity and leading to labour shortages across many labour-intensive industries. The provision of employment in the peripheral coastal areas is of great importance to Arramara since its foundation in the late 1940s and their decision ultimately to utilise mechanical harvesting would be balanced against this consideration. Concerns over seaweed harvesting rights and resistance to the concept of mechanised harvesting (due to fear of losing seaweed harvesting jobs), most vociferous among older harvesters, may well fade away as older harvesters retire, and if a younger generation continue to seek employment elsewhere.

*** Postscript: Announcement in July 2001 by Dept. of Marine and Natural Resources to close Arramara's Mweenmore plant in Co. Donegal and shift production to Kilkieran plant in Co. Galway. It is unknown at time of publication if any type of seaweed processing will continue in Donegal)**

APPENDIX 5: LIST OF INITIAL CANDIDATE SPECIAL AREA's OF CONSERVATION (cSACs) MARINE HABITATS AS DESIGNATED BY DUCHÁS, JUNE 2000

COUNTY	cSAC AREA'S	NOTIFIABLE ACTIONS UNDER MARINE HABITAT SECTION	SITE CODE NO.
CLARE	***KILKEE REEFS***	1.1 1.2 1.6	**002264**
CORK	***LOUGH HYNE NATURE RESERVE***	1.1 1.2 1.3	**000097**
CORK	***ROARING WATER BAY AND ISLANDS***	1.1 1.2 1.3 1.5 1.6	**000101**
DONEGAL	***DONEGAL (MURVAGH) BAY***	1.1 1.2 1.3 1.4 1.6	**000133**
DONEGAL	***INISHTRAUHULL***	1.1 1.2 1.6	**000154**
DONEGAL	***RATHLIN O'BIRNE ISLAND***	1.1 1.2 1.6	**000181**
DONEGAL	***MULROY BAY***	1.1 1.2 1.3 1.6	**002159**
DONEGAL	***RUTLAND ISLAND AND SOUND***	1.1 1.2 1.3 1.4 1.5 1.6	**002283**
DONEGAL	***LOUGH SWILLY***	1.5	**002287**
DUBLIN	***LAMBAY ISLAND***	1.1 1.2 1.6	**000204**
GALWAY	***INISHBOFIN, INISHARK***	1.1 1.2 1.3 1.4 1.5 1.6	**000278**
GALWAY	***SLYNE HEAD***	1.1 1.2 1.3 1.6	**000328**
GALWAY	***KILKIERAN BAY & ISLANDS***	1.1 1.2 1.3 1.4 1.5 1.6	**002111**
GALWAY	***KINGSTOWN BAY***	1.1 1.2 1.6	**002265**
KERRY	***BALLINSKELLIGS BAY AND INNY ESTUARY***	1.1 1.2 1.3 1.6	**000335**
KERRY	***BLASKET ISLANDS***	1.1 1.2 1.6	**002172**
KERRY	***MAGHAREE ISLAND***	1.1 1.2 1.6	**002261**
KERRY	***VALENCIA HARBOUR***	1.1 1.2 1.3 1.6	**001501**
KERRY	***KERRY HEAD SHOAL***	1.1 1.2	**002263**
KERRY/ CORK	***KENNMARE RIVER***	1.1 1.2 1.3 1.4 1.6	**002158**
LOUTH	***DUNDALK BAY***	1.1 1.2 1.3 1.5 1.6	**000455**
LOUTH	***BOYNE COAST & ISLANDS***	1.1 1.2 1.431.4	**001957**
MAYO	***BROADHAVEN BAY***	1.1 1.2 1.3 1.4	**000472**
MAYO	***ERRIS HEAD***	1.1 1.2 1.6	**001501**
MAYO	***CLEW BAY COMPLEX***	1.1 1.2 1.3 1.4 1.5 1.6	**001482**
MAYO	***ACHILL HEAD***	1.1 1.2 1.6	**002268**
WEXFORD	***SALTEES ISLANDS***	1.1 1.2 1.6	**000707**
WEXFORD	***HOOK HEAD***	1.1 1.2 1.6	**000764**
WEXFORD	***LONG BANK***	1.1	**002161**
WEXFORD	***CARNSORE POINT***	1.1 1.2 1.6	**002269**
WICKLOW	***WICKLOW REEF***	1.1 1.2	**002274**
WATERFORD	***WATERFORD HARBOUR***	1.1 1.2 1.3 1.6	**000787**