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EVALUATION OF THE BENEFITS TO SUSTAINABLE MANAGEMENT OF SEASONAL CLOSURE OF THE GREENCASTLE CODLING (*GADUS MORHUA*) FISHERY

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ABSTRACT

The project examined whether the seasonal closure of the traditional cod fishing grounds off Greencastle, Co. Donegal, could be an effective alternative management measure. The project was instigated by the local fishing industry and operated in co-operation between industry, the Marine Institute and Bord Iascaigh Mhara. The main objectives of the project were to demonstrate the change in yield likely to result from seasonal closure, and, to determine the pattern of movement of cod from the Greencastle fishery. Each winter from 2003 to 2005 the fishery was closed by Statutory Instrument. This was achieved with the voluntary commitment of the local industry. During this period over 13,000 cod were tagged and released by Marine Institute and BIM staff working aboard chartered fishing vessels. The closure itself provided a significant conservation benefit. During 2000-2002 50% of the Irish catch weight of cod in Division VIa (> 60% by number) was taken in the winter. The closure will therefore have markedly reduced the fishing mortality on cod that would otherwise have occurred from 2003 to 2005. As the Greencastle codling fishery is a mixed whitefish fishery, any benefits flowing from the closure are likely to have extended to other whitefish stocks. Growth was extremely variable but averaged around 17 cm per annum for cod at liberty for extended periods. During the winter tagging surveys the repeated recapture of recently tagged cod on the grounds indicated the retention of cod on the grounds during winter. Tagged cod at liberty for extended periods were subsequently recaptured on, or near the Cape grounds. This strong fidelity towards the Cape grounds during winter coupled with high growth rates may mean that a short winter fishing season, with a delayed opening, may yield a similar total weight of codling than the traditional fishery but with the catch of a reduced number of cod. Such schemes may reduce current fishing mortality rates. However, the stock status of Division VIa cod is so poor that a complete closure of the fishery is warranted. It is recommended that continuation of the project be considered as a mechanism for maintaining a closure of most of the Irish fishery, whilst simultaneously improving the quality of data available for stock assessment.

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INTRODUCTION

In 2001 recovery measures were introduced for cod to the west of Scotland (ICES Division VIa). An assessment of the importance of various areas for juveniles and adults provided the basis for these measures. Identification of these areas would allow Technical Conservation Measures such as seasonal closure to be implemented as part of a suite of management tools intended to improve sustainability. One of the areas of prime importance to juvenile cod is that around Greencastle. The area falls within Ireland's six nautical mile jurisdiction, giving Ireland the ability to implement an experimental seasonal closure of the fishery.

The History of Fishing on the Cape

The fishing ground known as The Cape (Béal Locha is the old Irish name), north of Greencastle, Co. Donegal is located northwest of the fishing port of Greencastle (Figure 1). It is a relatively small area of clean ground of 40-80 meters depth. The Cape has held a traditional winter fishery for generations of Inis Owen fishermen, from long-lining in the open Drontheim to trawling modern full shelter deck steel trawlers. The geographical location of the Cape has traditionally made it an ideal ground for a winter fishery. Lying in the lee of the prevailing southwest winds allowed the local boats to fish at times when other fishermen around the coasts were harbour bound. This also extended the fishing time for the smaller vessels and often allowed them get a better return on their fish as they could sell fresh fish when it may have been in short supply elsewhere. The location of the ground also makes it an ideal place to fish on the return trip from the more distant northern grounds with many vessels getting a tow in on the Cape before returning to the port of Greencastle. For generations local fishermen have noted that codling come onto the Cape in late autumn (September / October), and remain on the ground for the winter until they depart in late January-early February. This led to an intensive winter codling fishery prosecuted by the local fleet of Inis Owen.

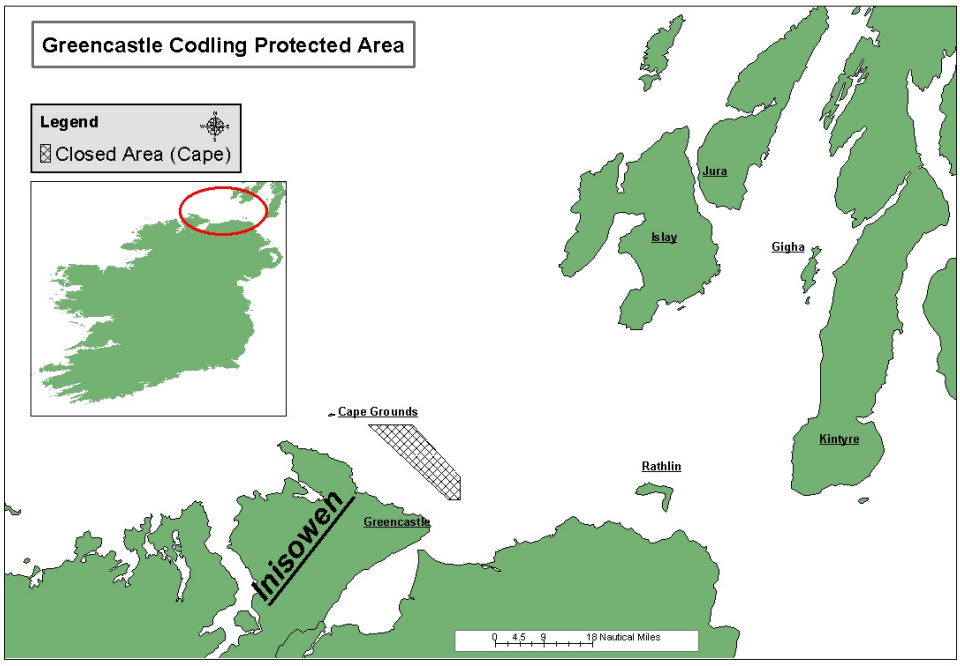

Figure 1. Location of the Cape fishing grounds. Inset: location of the Cape in relation to Ireland.

Length-at-age analyses indicate that this fishery directly targets a winter nursery ground for cod. Catches from the fishery are dominated by 1 and 2-year old cod (55% and 44% respectively). A comparison of the age structure of the Cape catch and that of the VIa landings (Figure 2), highlights the dependence of the Cape fishery on young cod.

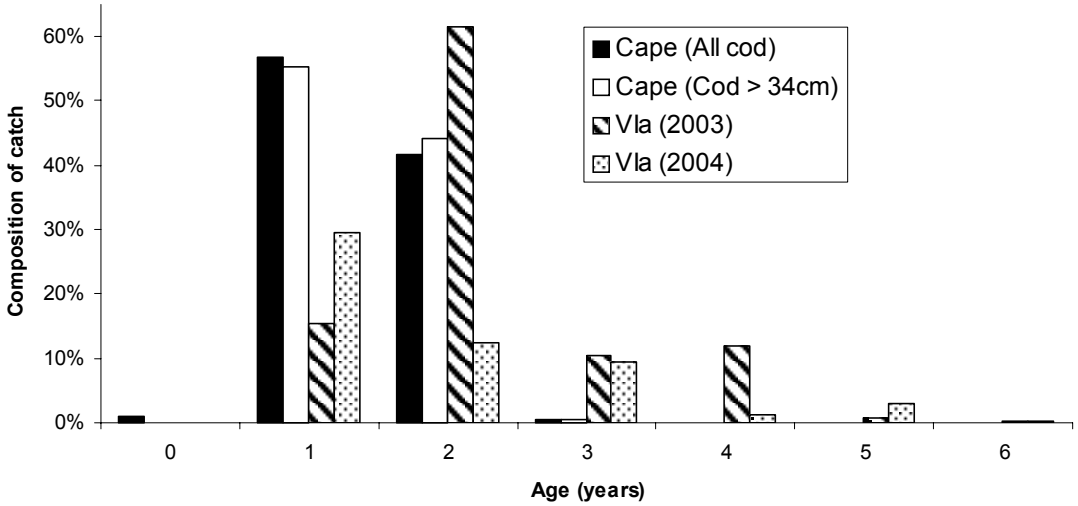

Figure 2. Age compositions of cod caught on the Cape during Greencastle Codling Project Surveys and of the commercial landings of all fleets operating in ICES Division VIa (VIa data from ICES, 2005).

As cod in Division VIa are only 50% mature at age one (Figure 3) the fishery removes cod from the stock before many have had a chance to reproduce and contribute to local and more distant recruitment. The fishery also removes cod at a body weight at which they contribute much less than the maximum possible yield.

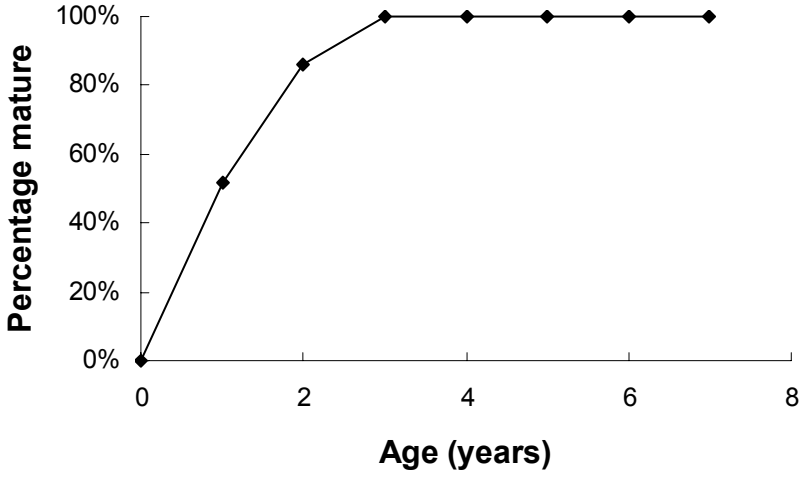

Figure 3. Maturity ogive of cod in ICES Division VIa (Source: ICES, 2004).

Importance of the Cape to the Irish fleet

Analysis of the cod landings data from Irish boats fishing demersal trawl gear shows the importance of the Cape (represented by ICES statistical reporting rectangles 39E2 and 39E3) to the Irish cod fishery in Area VIa. In the fourth quarter the Cape returns as much cod as the rest of Division VIa combined (Figure 4). Whilst these statistics may not account for the fact that many of the Irish vessels fishing in Division VIa at that time may be on the Cape consideration of the landings data in conjunction with the effort data shows the true value of the Cape.

The effort data shows that the Cape yields approximately the same yield as the rest of VIa with a fraction of the effort (Figure 5). It is the aggregation of the cod on the Cape that makes this fishery so important for the Irish fleet in Division VIa. This aggregation allows for efficient fishing close to the homeport and the market.

In 2000 the landings reported by the Irish fleet operating within Division VIa showed a marked increase. In 2000 landings and effort on the Cape Grounds was at its highest in recent years. These increases coincided with the entry of several new, highly efficient vessels to the Irish fleet. Stock assessments also indicate that the 1999 year-class of cod (which would have been a principal component of the 2000 fishery) was about double the strength of the recruiting year-classes observed in 1999 and since 2000 (ICES, 2005).

Landings and effort statistics for 2005 were not available at the time of publication.

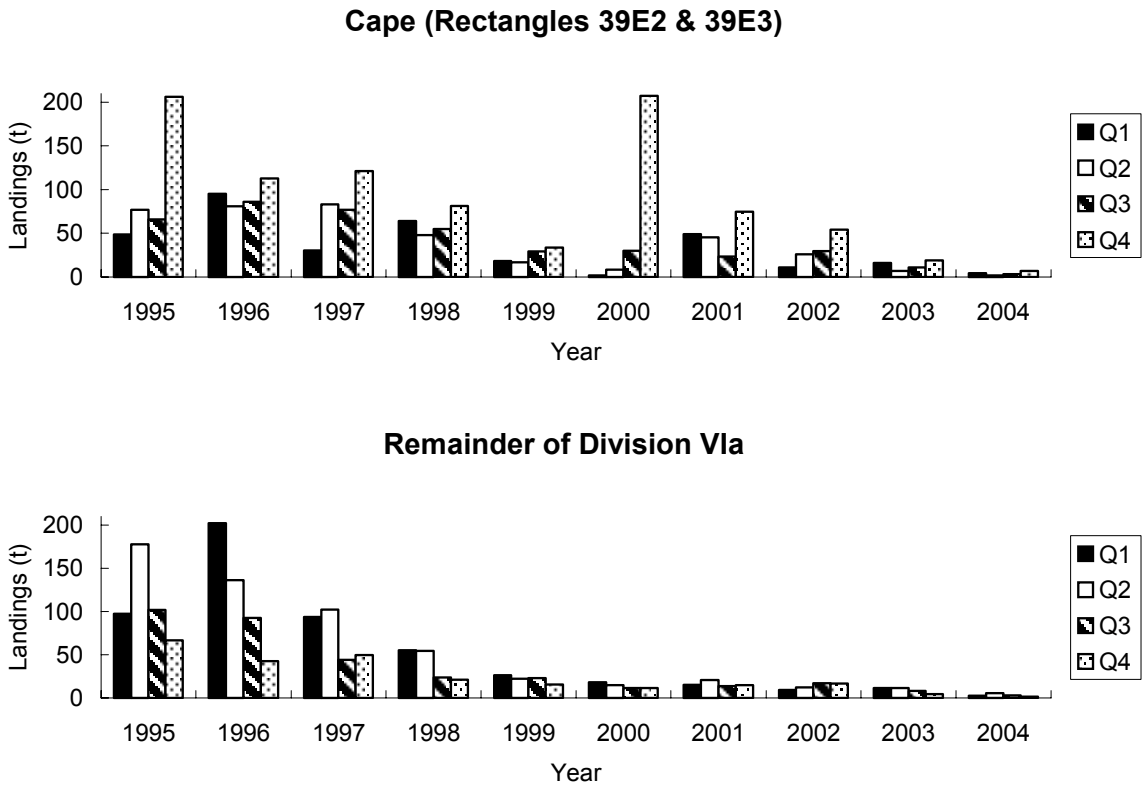

Figure 4. Landings of cod by Irish otter trawlers on the Cape and in the rest of ICES Division VIa (Source: DoCMNR logbook data).

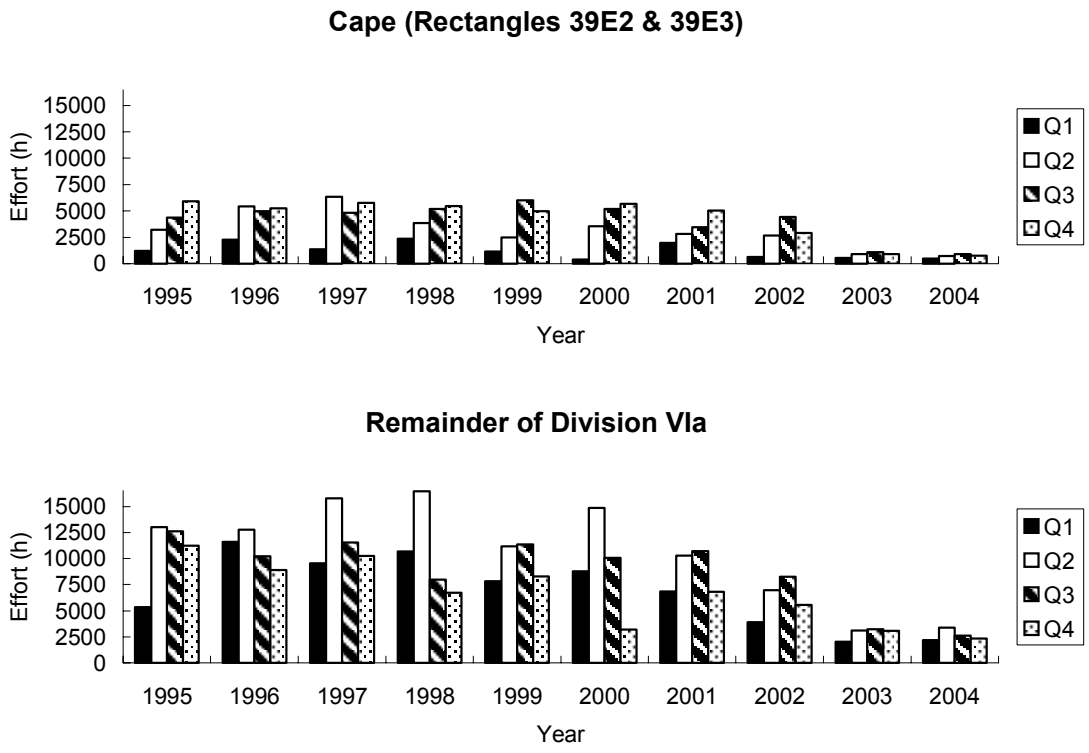

Figure 5. Effort of Irish otter trawlers on the Cape and in the rest of ICES Division VIa (Source: DoCMNR logbook data).

Need for the Project

Heightened awareness of the decline of cod stocks in the North-east Atlantic has raised the concern of fishermen and scientists of the effects that localised fishing may have on stocks. The fishermen of Inis Owen have raised concerns about the effect that the Cape fishery may have on the cod stock in Division VIa. As catch-rates of cod have declined in Division VIa the fishermen have seen an increased need to protect the Cape fishery and investigate new alternative methods of management to protect the cod.

The Greencastle Codling Project was established by the local fishermen, in association with the Marine Institute and BIM, to examine whether the seasonal closure of the juvenile nursery ground could be an effective alternative management measure for cod in Division VIa. Partners for the project are the Marine Institute, BIM, Foyle Fishermen's Co-operative, Killybegs Fishermen's Organisation, Greencastle Fishermen's Co-operative, and Greencastle Fish Exports.

Objectives

The project had two main objectives:

1. To demonstrate the change in yield likely to result from seasonal closure, and,
2. To determine the pattern of movement of cod from the Cape fishery.

Implementation of a closure to the fishery, accompanied by a comprehensive tag and release program was seen as the most effective way of achieving these objectives.The recapture of tagged, released cod provides information on migration, mortality and growth. These data were considered necessary to evaluate the possible increase in yield that would result from allowing the Cape cod population to grow through the period of closure. These benefits need to be weighed against the loss of fish from the fishery due to natural mortality and migration.

The original project specification outlined a substantial amount of work devoted towards understanding the population structure of the cod stock in Greencastle and Division VIa, how these change over time, and also the effects of the closure on other demersal fish species. Insufficient resources were subsequently granted to achieve all aspects of these programs. Data collection on population structure and other species was therefore limited to that which could be gathered during the tagging program.

MATERIALS AND METHODS: FIELDWORK PROGRAM

Implementation of the closed area

At a meeting in Greencastle on the 17th July 2003 attended by local fishermen, representatives from the Co-operatives, the Producers' organisations, BIM and Marine Institute staff it was decided the close the fishing ground known as the Cape (Figure 1) to all fishing during the period of the traditional codling fishery. The fishermen requested that the area be closed by Statutory Instrument (SI) from mid-September 2003 to mid-February 2004 (SI No. 431 of 2003, See also Appendix 1: Statutory Instrument used to implement closure of the fishery). The fishermen undertook to seek an extension to the closed area outlined in the SI should too many tagged cod be recaptured on the edge of the closed area.

In early December 2003 the fishermen requested that the closed area be extended along its eastern edge. This decision followed an expression of concern on the part of fishermen regarding the recapture of tagged cod and indications that cod were mainly being recaptured just outside the eastern perimeter of the closed area. In December 2003 the closed area was extended along its eastern edge by amendment to the Statutory Instrument (enacted in SI No. 664 of 2003).

With the impending expiry of the SI a meeting was convened in Greencastle in early February 2004 to discuss the previous survey season and future of the closed area. The fishermen decided that the SI should be allowed to expire to ensure that the area could be once again open to all fishing methods. However, the trawler-men decided that they would impose a voluntary exclusion to trawling within the boundaries of the closed area as described in SI 664 of 2003. This would protect any tagged cod within the box whilst allowing the whelk fishermen to deploy their gear for the up-coming season. It was felt that closing the area to all fishing methods could potentially antagonise sectors of the fishing industry and consequently undermine the effectiveness of the project. Arising from this meeting the local fishermen submitted signed declarations effectively banning trawling on the Cape from February 15th to July 1st 2004.

At a meeting in October 2004 fishermen once again called for another official closure of the Cape grounds for the 2004-2005 season. SI No. 670 of 2004 reinstated the closure of the Cape to all fishing methods from 1st November 2004 until 14th February 2005. During each closed season official derogations were sought and received from the Department of Communication, Marine and Natural Resources to allow chartered survey vessels to operate in the closed area whilst participating in tagging surveys (See Appendix 2: Derogation allowing research work by the Marine Institute (and chartered vessels) during the Project). In late 2005, and by agreement with BIM, the project was extended until 28th February 2006. At a stakeholder meeting in October 2005 another official closure of the Cape grounds for the 2005-2006 season was agreed. A new Statutory Instrument (SI No. 700 of 2005) re-instated the closure of the Cape to all fishing methods from 14th November 2005 until 14th February 2006. Another period of tagging and recapture of cod on the Cape Grounds was undertaken in December 2005 – January 2006.

Chartering of Vessels
At a well attended meeting in Greencastle in September 2003 an outline of the proposed survey was presented to the fishermen. Invitations were sought from vessels to participate in the upcoming survey (Part A). A deadline for submission of application forms and tax clearance certificates was set at 10th October 2003.

At the progress report meeting in early December 2003 a second call for tenders was sought for Part B of the survey (due to commence in January 2004). The deadline for submission of application forms and tax clearance certificates for Part B was the 16th December 2003. Absence from port when fishing increases the propensity for skippers to miss deadlines for submissions of tenders. The two calls for tenders issued by the Marine Institute for the 2003-2004 season were intended to overcome this: making the project as inclusive as possible, and involving as many suitable vessels as possible in the tagging program. A total of 10 local vessels were chartered to carry out the tagging during the 2003-2004 season. All vessels that expressed an interest were evaluated according to criteria of vessel suitability and knowledge of the fishing grounds. Historical knowledge provided by the local fishermen ensured that tagging periods were planned to coincide with the period of peak abundance of cod on the ground. The intensity of the tagging surveys ensured that maximum effort was applied during this period of peak abundance.

Additional funding was secured to carry out more tagging in the winters of 2004 and 2005. The administrative arrangements for these charters were organised by BIM as the extra funding for vessel charter was provided directly by BIM.

Sampling Equipment
Following extensive research of methods of capture of cod for tagging purposes it was decided to trial three methods: (1) Long-lines, (2) Fish traps, and (3) Demersal otter-board trawling, in order to identify methods of capture that would minimise damage to the cod.

Long-lines
The long-line consisted of a 8mm polyethylene four-strand main line with 50 hooks at 4m intervals, each interval being marked with “nylon stoppers”. These “stoppers” each 4cm apart were designed to stop the snap with snood and hook from slipping along the mainline, ensuring all the hooks were always 4m apart. Each stainless steel snap included a swivel to which a 50cm monofilament snood and a No.6 Mustard hook were attached. Each long-line was anchored with a 14kg four-prong anchor at each end with a line to the marker buoy. The first and last hook was placed 20m from each anchor to facilitate shooting and hauling.

Fish Traps
The fish traps tested were of two types:

Circular Portuguese Fish Trap
The circular Portuguese Type consisted of a steel cylinder with a diameter of 1.2m and a height of 90cm fabricated using 8mm mild steel reinforcing bar. The structure was then covered using 1mm gauge wire mesh with a mesh size of 40mm. The swan-neck entrance was fabricated of the same material. The trap was fitted with a trap-door for

easy access and an anode to prevent erosion. The trap was also fitted with a bait-bag to facilitate easy baiting.

Rectangular Alaskan Fish Trap

The rectangular Alaskan type trap was based on the type of traps employed in the Alaskan trap fishery. The trap consisted of a steel rectangle measuring approximately 1.2m by 0.9m by 0.6m fabricated from 8mm mild steel reinforcing bar. The metal structure was covered using 80mm mesh size netting with a thickness of 8mm braided twine. The entrance to the trap was the commercially produced 7" by 22" Neptune Trigger Entrance, a proven product in fish trap fisheries all over the world. The Alaskan trap was also fitted with a trap-door, bait-bag and anode.

Deployment of Static Gear

In an effort to achieve the best possible operating conditions for the static gear an open deck trawler, the MFV *Silver Bell* was chartered for the first week of the survey program. The open deck allowed for more workspace and an easier hauling position for the gear. All the static gear was deployed on grounds that the skipper considered from his experience to be the part of the ground that would yield the highest cod catches. This was later confirmed in demersal tows of these same areas.

The long-line was baited with fresh queen scallop (*Chlamys opercularis*), proven bait for cod that was also available locally. The long-line was set an hour before the slack tide and hauled an hour after the slack giving a soak time of two hours. On shooting the baited hooks were attached to the mainline using the stainless steel snaps. This allowed the long-line to be deployed safely and efficiently. To haul back the long-line the mainline was drawn through a snatch block fitted above the gunwale and wound onto the spare net drum, the snoods with hooks being unsnapped as they came aboard and fixed to the holding tray. The bait bags in the fish traps were also baited with queen scallop prior to deployment. Set of the fish traps was a simple operation of dropping them over the side and noting their positions. Hauling back of the fish traps was done by placing the main line in the snatch block and using the capstan to haul it back. This procedure facilitated the lifting of the trap over the gunwale and minimised any dangers in lifting of the trap. Each fish trap was set for 24 hours before hauling.

Success of the Static gear

While the design of the long-line allowed for safe deployment and hauling of the gear the labour and time involved made it a slow procedure. No cod were caught in the two deployments of the long-lines carried out. Catch rates of other fish from the long-line were also very low with the catches comprised mainly of dogfish and haddock. While the fish caught were in good condition the low catch rates of cod and the considerable time involved in working the gear made it an impractical method for cod tagging purposes.

While some live cod were caught in the fish traps, with one pot yielding two lively cod, the time involved in working the traps and the low capture rate also made it an impractical method for cod tagging purposes. The limitation of daylight hauling only for the fish traps also contributed to the decision not to carry on using the fish traps.

Due to the limited success of the static gears and their labour-intensive nature, a decision was quickly made to abandon the use of static gear in favour of the more efficient short tows with the demersal trawl.

Demersal otter trawl
For logistical reasons the demersal otter trawl of the vessel chartered was used while that particular vessel was sampling. This resulted in the use of ten different demersal trawls, each of a different size depending on the size of vessel. The size of the doors employed to spread the net also was boat dependant. All vessels employed a codend mesh size of 80mm.

Short tows were carried out by the chartered vessel on towlines within the closed box that the fishermen regarded as the areas that would achieve the highest catches. Each tow was kept as short as possible to achieve the highest number of live tag-able cod from the tow. This resulted in the tow duration varying depending on the vessel and general conditions of the day. Tow duration was calculated as the interval between the trawl doors hitting the water and the start of the haul back. Tow duration ranged from 10 to 90 minutes, with an average duration of 35 minutes.

On completion of a tow the net was hauled back slowly, with the vessel speed reduced to minimise the drag on the codend. This allowed the cod some time to adjust to the reduction in pressure, associated with a reduction in water depth. The effects of decompression are potentially a major cause of mortality (Hislop & Hemmings, 1971) and cod must therefore be brought slowly to the surface to avoid swim bladder damage. Rapid pressure reduction causes the expansion of the gas contained in the swim bladder possibly leading to rupture of the bladder and compression of internal organs. Whilst cod can overcome this by absorbing the gas in order to remain neutrally buoyant, the compensatory mechanisms are rather slow (Harden Jones & Scholes, 1985). During the survey each codend was fitted with a 5-10kg weight of chain. This helped to slow the ascent of the codend, thus minimising decompression injuries that would be caused to the fish by rapid surfacing of the codend.

On board handling of the catch
Once aboard the codend was opened from a minimal height (Figure 7) and all cod were quickly and carefully transferred to a holding tank, the rest of the catch being boxed for later analysis. At all times fish were handled using gloves in order to minimise mucus and scale loss, and "burns" from warm, ungloved hands. Two types of holding tanks were used, each of fibreglass construction with a capacity of $1m^3$, one of cylindrical shape and the other rectangular. The use of either tank was dictated by the available space aboard the chartered vessels, both tanks being used when two vessels were tagging simultaneously. Each tank had an outlet pipe attached to the side that regulated the water level within the tank. The water level was always kept at the maximum depth possible without creating an over-spill. Whilst hauling the net the tank was filled with the vessel deck hose at its maximum flow rate, ensuring that the fresh seawater in the tank was well aerated.

The deck hose was then securely fastened to allow a continuous flow of fresh seawater into the tank with the outlet pipe facilitating the over flow. The flow of water from the hose was regulated to maintain the maximum possible flow deemed not to adversely affect the cod. Once tagging was completed for a haul the outlet pipe was lowered to empty the tank before the next haul. Seawater in the holding tank was kept fresh and well aerated to satisfy the elevated oxygen demand of cod stressed during capture and handling.

Once in the holding tank strong healthy cod would swim straight to the bottom of the tank. Unhealthy cod with distended swim bladders would float to the top of the tank and were immediately removed (Figures 7 and 8). Removing all the cod but the healthy cod swimming at the bottom of the tank ensured that only the best cod were used for tagging. The policy adopted for the survey by both fishermen and scientists was that it was better to carry out more tows per day than to waste time tagging unhealthy cod.

Figure 7. Opening the cod-end.

Figure 8. Cod in holding tank. Healthy cod swimming on the bottom, cod with distended swim bladders floating at the water surface.

Tagging

Each vessel carried one trained scientist (a Marine Institute or BIM staff member) who carried out the tagging work with the close co-operation of the crew. For tagging one cod at a time was removed from the holding tank, using a lifting net, and placed in a tagging cradle. The cod was then quickly measured, tagged and data recorded before being returned to a keep basket within the holding tank. The tag was inserted posterior of the first dorsal spine in the flesh just below the dorsal fin using an Avery Denison Tagfast III tag applicator (Figure 9 and 10) using Hallprint T-bar anchor tags. Each tag was printed with a unique-number and the letters:

REWARD MARINE INST. IRL. TEL. 353 91 730400

High-reward tags deployed during the winter 2005 survey were printed with a unique-number and the following text:

€100 REWARD MAR. INST. IRL. Ph. 353 91 730400

The time spent by the cod in the holding tank was always kept to a minimum. This sometimes resulted in several tagged cod being released before all the cod from that haul were released. On completion of tagging the tagged cod were gently released over the side of the boat. All the tows were carried out within the area of the closed box and most of the tagged cod were released within the boundaries of the box. The latitude and longitude of release was recorded. Seabirds took some unhealthy cod released on the first day of the survey. Strong, healthy cod quickly swam straight down from the surface upon release. A strict policy of keeping only the best cod for tagging was introduced in order to ensure that seabirds took no further tagged cod on release.

The target in the initial tagging survey of winter 2003 was to successfully release 3,000 tagged cod. In the winter 2004 and 2005 tagging surveys the targets were to successfully release over 3,500 tagged cod each survey.

Figure 9. Avery Denison Tagfast III tag applicator and tags.

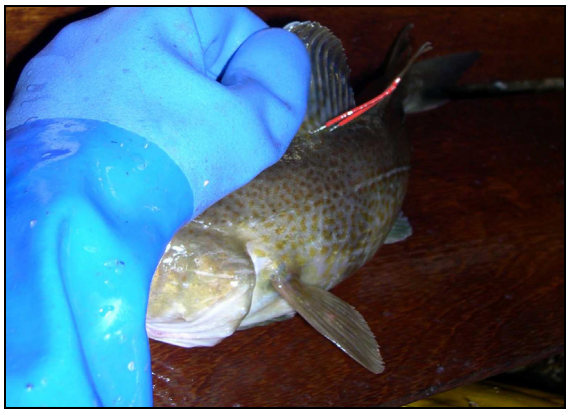

Figure 10. Tags were inserted posterior of the first dorsal spine. This cod is double-tagged.

Measured only fish

All commercial fish that were caught in each tow were measured to the nearest whole centimetre below. Cod that were unfit for tagging were also measured and recorded. Any tagged cod, released on previous survey days, which were re-caught were recorded and re-released if deemed fit enough to go back. The tag number of recaptured cod not fit enough to be returned to the sea was noted and their length was recorded as part of the measured only component of the catch.

Methods used to boost tag reporting rates

Advertisements were placed in the Irish Skipper, Marine Times and the Fishing News in order to increase industry awareness of the project within Ireland and in the UK. Regular information articles giving the latest update of the project were also published in the trade press allowing increased exposure without the associated costs of re-advertisement. Radio interviews were conducted on both local and national radio stations, including a prime-time interview on RTE Radio One – Morning Ireland (estimated listenership of 400,000). Information leaflets were distributed to the fishing community through the staff of the Marine Institute/BIM, the Fishermen's Co-operatives, producer organisations and at trade shows (Fish Ireland and Inshore Ireland). The media campaign was intended to keep the Greencastle Codling Project a high profile project and help to ensure that all tagged cod caught were spotted, recorded and reported.

Handling of recaptured tagged cod

In order to maximise reporting rates an active media campaign was initiated with the commencement of the tagging programme and maintained throughout the project. Persons reporting recaptured tagged cod were rewarded for the provision of information on the date of recapture, the location of the recapture and the total length of the cod.

A local system for tag return was set up for the boats in Greencastle. Datasheets for recording information were distributed to the local fishermen for them to complete when tagged cod were recaptured. Recaptured cod were then put on ice ungutted in a separate box for landing to the Foyle Fishermen's Co-operative. Once landed the staff of the Co-operative transferred the fish to McCormick's fish processing plant where the fish were kept in cold storage for collection by Marine Institute staff. This proved to be an efficient system allowing for the automatic collection of data from recaptured cod. The system also ensured that fish not reported by the fishing vessel were not lost as on spotting the fish the Co-operative staff would transfer them to McCormick's.

Tag returns from ports outside Ireland were handled in a different manner. On recapture of a tagged cod the skipper of the fishing vessel contacted the Marine Institute by phoning the telephone number on the tag or by directly contacting Macdara Ó Cuaig as advertised in the trade press posters. On contacting the Marine Institute the fisherman relayed the relevant data i.e., tag number, length, date and position of capture. Where possible the fish with tag attached was picked up by regional Marine Institute technicians who took length/weight data and otoliths for ageing. In the Scottish, UK and Northern Irish ports the capture of a tagged fish was often reported firstly to the local fishery officer who then relayed the information to the Marine Institute. The fishery officers also received the fish, took length/weight data and removed the otoliths.

Some tagged fish that were missed by the fishermen were spotted in the processing plant by the factory workers were then reported to the Marine Institute by the plant managers. These fish were usually recorded with only tag number and length data and required a follow up to ascertain the fishing vessel of capture, landed port, date of capture and possible fishing ground. No positional data were recorded for these fish.

On receipt of information relating to the recapture of a tagged cod the data was entered into the database and a response pack was sent within a week. The response pack contained a personal letter to the returnee with a brief history of the fish returned, an up-to-date map showing distribution of recaptures, a reward cheque and some leaflets for the returnee to distribute to his/her colleagues.

Additional Survey Work

The Marine Institute in association with the Geological Survey of Ireland (GSI) has started to map the seabed of the Cape fishing ground. Preliminary data is presented in Appendix 3. It is hoped that these data coupled with underwater TV footage and the biological data collected during this Greencastle Codling Project will be amalgamated to produce a habitat map of the Cape. This work will be incorporated into the Mapping European Seabed Habitats (M.E.S.H) project of which the Marine Institute is an active partner. A report on the mapping project will be published in due course.

MATERIALS AND METHODS: ANALYTICAL METHODS

Survey CPUE

The survey Catch Per Unit Effort (CPUE) was standardised as the number of cod captured per Kwh and then increased to the number of cod captured per 300Kwh. 300 Kwh was used as the standard for presentation as it allows easy conversion to the Kw power of the local vessels fishing in the area, and hence facilitates interpretation. Consideration of the CPUE of all boats combined ignores boat specific differences that will contribute to differences in catch rates. It was not possible to properly standardise the CPUE of all vessels. Therefore consideration of the CPUE of individual vessels used throughout the period of the project provides another means of avoiding boat specific differences in catch rates. As the *Paul Stephen* was used in the surveys of all three winters it was deemed the most useful boat from which to present a boat-specific CPUE. The *Paul Stephen* used the same net, for all tagging trips without any gear modifications.

Movement

Information on the release and recapture positions for each cod was used to deduce movement. All the cod released during the Greencastle Codling Survey were released on the Cape grounds giving a release site corresponding to the closed area. Recapture positions were plotted using ARC GIS mapping software. Rates of movement were not calculated as this information is of little utility. The passage taken by cod between their points of release and recapture is unknown and will fundamentally impact upon calculations of movement speed.

Data base design

An Access database was designed to hold the haul metadata and the associated catch details. All lengths of all species pertaining to each haul were entered into this database and extracted as needed for analysis. A separate database was created for the tagged cod data. This database was designed to allow continuous updating when new information on recaptured fish was received. This database was also designed with query facilities for extraction and analysis.

Growth Estimation

The length increments measured from recaptured, tagged fish were used to estimate growth using a non-linear regression of the Fabens (1965) re-parameterisation of the von Bertalanffy growth function:

$$\Delta L_i = (L_\infty - L_i)(1 - e^{-Kti}) \qquad \textbf{Equation 1}$$

where ΔL_i is the growth increment, L_∞ is asymptotic or average maximum length, L_i the release length, K the coefficient of growth and t_i the time at liberty of individual cod.

The periods for which recaptured cod were at liberty varied considerably. It was therefore necessary to standardise the observed growth increments to represent annual length increments.

Measurements from cod that had negative or zero length increments were excluded from growth increment analyses. Whilst preliminary analyses of the data suggested that inclusion of these growth increments would have little impact on the values of growth parameters derived from the analysis, these growth increments were excluded because they do not make sense biologically for cod in the size range tagged. Negative increments generally appeared to be the result of measurement error (94 % of negative increments represented length reductions of 2cm or less). Fish exhibited outlying growth rates were excluded from the analysis. Only the growth increments within the lower 5th and upper 95th percentiles were included in the analysis.

Estimation of tag loss

Cod were double-tagged in order to estimate the rate of tag loss. The second tag was physically identical to the first and inserted posterior to the first tag. Estimation of the rate of tag loss is required in order to rescale the number of tagged fish recovered to account for tag loss. In the tagging seasons of winter 2003 and 2004 it was intended that 15% of the tagged cod released would be double-tagged (10% of fish assigned to high-reward tags were to be double-tagged). The assignment of cod to be single- or double-tagged was randomised so as to distribute any effects due to double-tagging randomly across hauls and tagging locations. In winter 2005 it was intended that all tagged cod released would be double-tagged. However, some cod that were considered too small to carry two tags were released single-tagged. Estimation of the rate of tag loss assumes rates of mortality, migrations, non-reporting, etc. apply equally to all cod irrespective of the number of tags attached to the fish.

The project applied the methodology published by the CATAG project (Thorsteinssen, 2002) to estimate rates of tag loss:

The probability of a tag having come off by time t, will be a function of time, say p_t. Hence the probability of the tag not coming off is $(1- p_t)$. In this project identical tags were used to tag all double-tagged cod. Hence the probability of detachment of either tag should be the same:

N_0 = no. recaptured with no tags; Probability,	$P = p_t^2$	**Equation 2**
N_1 = no. recaptured with 1 tag; Probability,	$P = 2\,p_t\,(1- p_t)$	**Equation 3**
N_2 = no. recaptured with 2 tags; Probability,	$P = (1-p_t)^2$	**Equation 4**
Then,	$N_1 / N_2 = 2\,p_t / (1- p_t)$	**Equation 5**
or,	$N_1 / (N_1 + N_2) = 2\,p_t / (1+ p_t)$	**Equation 6**

Microsoft Excel Solver was used to calculate the value of p_t at which both sides of Equation 5 and Equation 6 were equal. Estimates of tag loss from cod tagged with standard red tags were compared with the estimates from cod tagged with high-reward yellow tags. To allow accurate comparison of both yellow and red tags only fish released on, or before 10th of December 2003 were considered for this analysis. 10th of December 2003 was the last date on which yellow tags were released. An estimate of tag loss was also calculated for red tags recaptured over the entire period of the study. It was not possible to calculate rates of tag loss for the cod tagged in the final winter 2005 survey. Insufficient time had elapsed at the time of writing to generate an adequate number of tag recaptures for such an analysis.

Estimation of tag return rate

The number of tagged cod reported as recaptured will be a function of the number released, their probability of being recaptured with retained tags and the rate at which their recapture is reported. The expected number of tagged cod recaptured (E) was therefore calculated as follows:

$$E_i = r\,N\,P \qquad \textbf{Equation 7}$$

where i is the number of tags retained by recaptured cod (1 or 2), r is the reporting rate, N is the number of tagged fish released, and P is the probability of recapture. For cod originally released double-tagged the probability of recapture with one or two tags is given by Equation 3 and Equation 4 above, respectively.

Microsoft Excel Solver was used to calculate the value of reporting rate at which the expected number of tagged cod recaptured equalled the observed number recaptured. Estimates of reporting rate of cod tagged with standard red tags were compared with the estimates from cod tagged with high-reward yellow tags using the same intervals as described above. An estimate of reporting rate was also calculated for red tags recaptured over the entire period of the study.

Estimation of tag reporting rate

In order to estimate the tag reporting rate two types of tags were used (standard red tags and high-reward tags). Both tag types were physically identical, with the colour being the only distinguishing feature between both tags. However, return of the standard tags was eligible for a reward of €10, whereas return of high-reward tags was eligible for a reward of €100. Accurate estimation of a tag-reporting rate is contingent on the reward level being high enough that there is a 100% return rate for the high-reward tags. The standard tag-reporting rate can then be estimated as the relative recovery rate of standard tags to the recovery rate of high-reward tags (Pollock *et al.,* 2001).

For the first 35 survey days of the 2003-2004 tagging season 5% of the tagged cod released were tagged with high-reward yellow tags. In the final tagging survey of winter 2005 25% of the tagged cod released were tagged with high-reward yellow, pink or blue tags (9%, 8% and 7% respectively). The assignment of cod to be standard- or high-reward-tagged was randomised so as to distribute any effects due to tag colour randomly across hauls and tagging locations. In 2005 several colours of high-reward tags were used in order to examine whether rates of tag loss and recapture were significantly influenced by tag colour.

The use of both standard and high-reward tags makes estimation of the tag reporting rate possible. Assuming that the reward level is high enough to produce a 100% reporting rate for high-reward tags, the standard tag return rate can be estimated using the ratio of the recovery rate of standard tags to the recovery rate of high-reward tags (Pollock *et al*., 2002). Considering only recaptures from one cohort, the reporting rate ($\hat{Y}$) can be estimated as:

$$\hat{Y} = (R_s / N_s) / (R_h / N_h) = R_s N_h / R_h N_s \qquad \textbf{Equation 8}$$

where R_s is the number of standard tags returned, N_s is the number of standard tags released, R_h is the number of high-reward tags returned, and N_h is the number of high-reward tags released.

Estimation of Rates of Mortality

The experimental design used in this study was structured to provide data that would support a multi-year tagging model that enables total mortality estimates to be partitioned into fishing and natural mortality components. The rationale of using multi-year tagging studies to estimate total mortality is as follows: two cohorts of tagged fish are released one year apart; the proportion of the tags recaptured in any subsequent year should be the same for the two cohorts except that one cohort has been at liberty for an extra year and thus had its abundance decreased by an additional year of mortality. This difference in tag-recapture rates allows for the estimation of total mortality.

The exploitation rate (a function of fishing and natural mortality) can then be estimated as follows: the proportion of tags recaptured in a year is equal to the number of tags present at the start of the year times the exploitation rate times the tag-reporting rate. Hence, if the tag-reporting rate can be estimated, then the exploitation rate can also be estimated. Use of a multi-year tagging model to estimate mortality in this way requires at least two tagging seasons, and at least two recovery seasons, Frusher & Hoeing, (2001), (the first recovery season being coincident with the second tagging season and the second recovery season occurring one year later). In this study tagging has been conducted over three consecutive years but the second recovery season has yet to be completed at the time of writing. It is therefore not yet possible to use a multi-year tagging model to estimate mortality.

Alternative estimates of total mortality were calculated in the absence of direct estimates of mortality from a multi-year tagging model. Instantaneous total mortality (Z) was estimated by catch curve analysis: the number of cod in each age class ($\log_e(x+1)$ transformed) was plotted against age. The slope of the regression line fitted to those age classes that are fully represented in the sample is equal to the instantaneous rate of total mortality (Z) of that population (with the sign of the slope changed). This is strictly correct only in a population with stable age structure (constant rates of recruitment through time) and constant age-specific mortality rates.

Pauly (1990) proposed that the regression line be fitted to those points to the right of the highest point (P_{max}) on the catch curve; P_{max} should be excluded because of incomplete recruitment effects. This procedure was adopted unless P_{max} lay above the leftward projection of the regression line that did not include P_{max} because this indicates that recruitment is complete (Pauly, 1990).

Yield estimation

To assess the potential effect on yield of changing the rate of exploitation, yield-per-recruit (YPR) analyses were conducted at different levels of fishing mortality (F). The data required for the YPR analyses are estimates of fishing mortality and natural mortality (M), and the mean weight at age. Estimates of F were calculated from the estimates of total mortality (Z) given by the catch curve analyses ($F = Z - M$). Natural mortality was assumed to be 0.2 for all ages and years, consistent with the assumed natural mortality for cod in the study area (ICES, 2005).

RESULTS

Effort

Ten commercial fishing vessels were chartered for the Greencastle Codling Project. A total of 141 days fishing were carried out during which 1086 tows were made. A breakdown of the Catch Per Unit Effort (CPUE) is presented as the number of cod caught per 300Kwh (Figure 11). This shows a high CPUE for the first week of the 2003 survey. This week was the first week of fishing on the Cape following the closure to all fishing methods on September 15th. The subsequent weeks show a relatively steady rate for the rest of November with a drop at the start of December. The last week of the winter 2003 survey shows an increase again to a CPUE comparable to the fourth week of the survey. Results from the fishing trip carried out during the voluntary trawling ban in June 2004 show a low CPUE as expected. Local knowledge had predicted that there would not be many cod on the Cape at this time of year but a trip was deemed necessary to confirm this fact.

As the Cape was not closed until November 1st in 2004 the 2004 survey followed a period of intensive fishing by the local boats during October. The first two weeks of the 2004 survey show an increase in the CPUE followed by a steady decline. The period of the 2004 survey was shorter than the 2003 survey due to financial constraints associated with problems in securing extra funding. The 2005 survey commenced a month later than the 2003 and 2004 surveys. The 2005 survey followed a period of commercial fishing activity on the Cape grounds during which very low catch rates were reported. Catch rates on the winter 2005 survey were the lowest recorded during the entire project.

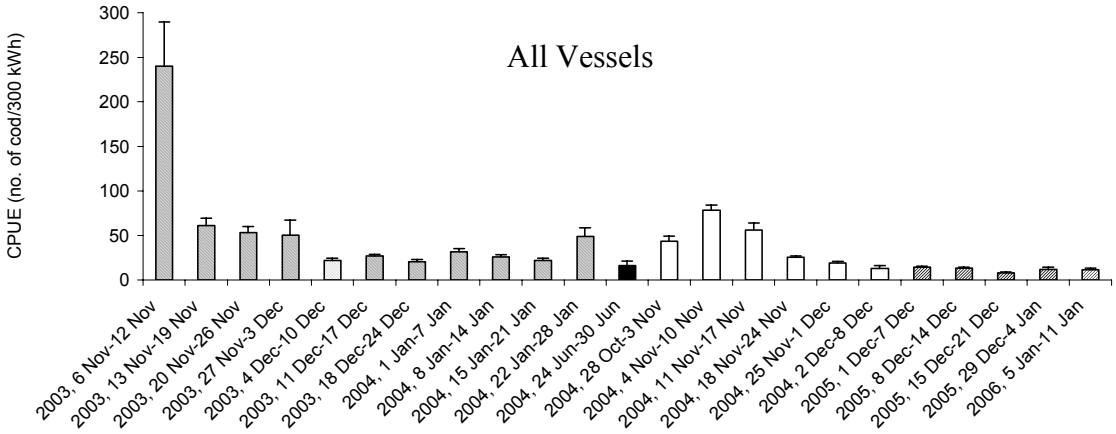

Figure 11. Average CPUE of all vessels used on the Greencastle Codling Project (no. of cod / 300 KWh ± 1 standard error).

The catch rates of the *Paul Stephen* were highest and most variable during the winter 2003 survey (Figure 12). Catch rates on the 2004 survey were slightly lower. Whilst the catch rates recorded during the winter 2005 survey were about one-third of those previously recorded, the 2005 tagging was conducted one month later than the 2003 and 2004 surveys.

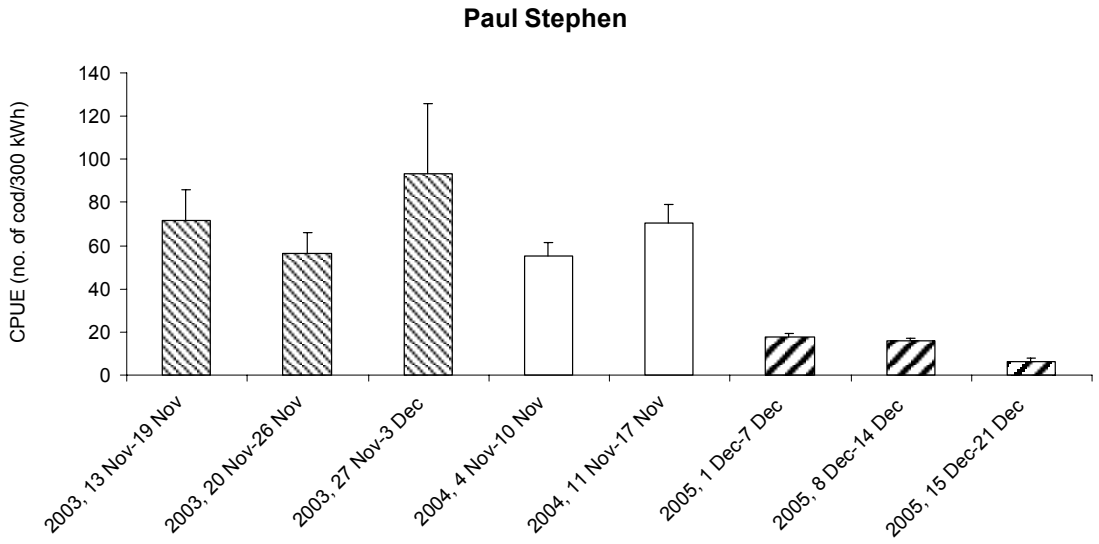

Figure 12. Average CPUE of the *Paul Stephen* during the Greencastle Codling Project (no. of cod / 300 KWh ± 1 standard error).

Tagging

Length Frequency Distributions

Length frequency distributions for tagged cod are available for the 2003 and 2004 surveys. The data collected on the 2005 survey are yet to be computerised. Very similar length frequency distributions were found for all cod caught on the 2003 and 2004 surveys (Figure 13). A slightly greater proportion of larger cod were caught on the 2003 survey whereas a greater proportion of small cod were caught on the 2004 survey. The length frequency distributions of cod tagged on the 2003 and 2004 surveys were almost identical to the distributions for all cod. However, most of the smaller cod caught in 2004 were not subsequently tagged.

The length frequency distributions of cod unfit for tagging are available for all three surveys. The 2005 length frequency distribution is distinctly bi-modal and substantially different to the distributions collected on the 2003 and 2004 surveys.

Tagging summary

During the winter 2003 survey 60 charter days were carried out during which 7,822 cod were tagged and released. 5% percent of those tagged were tagged with a high-reward yellow tag and the rest were tagged with standard red tags. Of the cod released during the winter 2003 survey with red tags, 16% were double-tagged. 10 % of the 413 cod released with yellow tags were double-tagged. Due to budgetary constraints no cod were tagged with the high-reward yellow tags during the winter 2004 survey. In the 41 charter days of the survey 3,740 cod were tagged and released with red tags. 14% of these were double-tagged.

At the time of writing 1,206 (10%) of the 11,563 cod tagged and released on the 2003 and 2004 surveys have been recaptured (Table 1). As expected returns of fish that were originally double-tagged are higher then those tagged with a single tag accounting for tag loss.

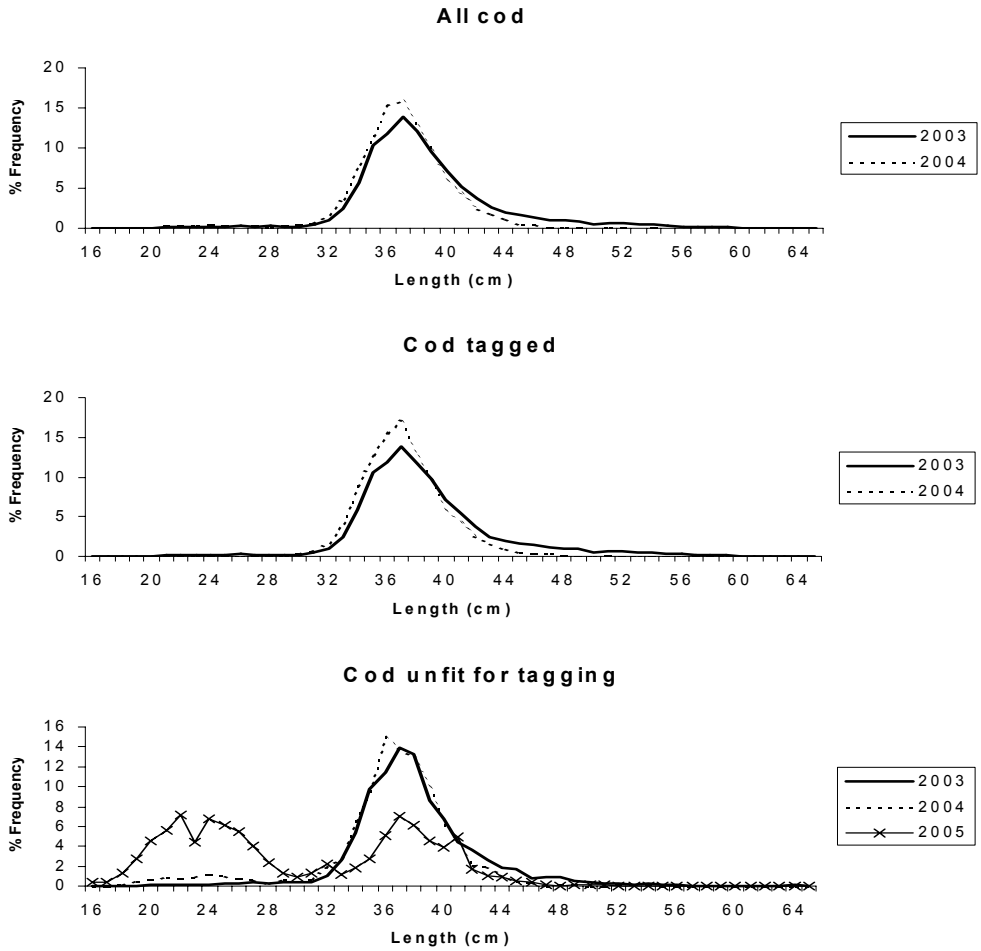

Figure 13. Length frequency distributions of cod caught on the tagging surveys.

Table 1. Total number of tagged cod released on the winter 2003 and 2004 surveys, and those subsequently recaptured.

Tag type:	Double- or Single-tagged:	Number released:	Number recaptured:	Tagging period:
Yellow	Double	41	10	6 Nov 2003 - 10 Dec 2003
Red	Double	1771	222	6 Nov 2003 - 2 Dec 2004
Yellow	Single	372	44	6 Nov 2003 - 10 Dec 2003
Red	Single	9379	930	6 Nov 2003 - 2 Dec 2004
Yellow	Both	413	54	6 Nov 2003 - 2 Dec 2004
Red	Both	11150	1152	6 Nov 2003 - 2 Dec 2004
Both colours	Both	11563	1206	6 Nov 2003 - 2 Dec 2004

A further 31 charter days were conducted on the winter 2005 survey during which 1,594 cod were tagged and released. 76% of these cod were tagged with standard red tags. The remainder were tagged with high-reward tags (9% yellow, 9% pink and 7% blue). It was intended that all tagged cod released on the winter 2005 survey would be double-tagged but some fish were considered too small to carry a second tag. Consequently 3% of the standard red-tagged cod were released single-tagged, and 1% of the high-reward tagged cod were released single-tagged.

Tag loss

Due to the short time interval between the conclusion of the 2005 survey and the time of writing tag loss could not be calculated from recaptures of the cod tagged in winter 2005. The following results therefore relate only to the cod tagged in the winters of 2003 and 2004. Of the 41 cod that were double-tagged with yellow tags 10 were recaptured. Of these 10 recaptured double-tagged cod, five had lost one tag (Table 2). The associated probabilities of losing one or both yellow tags were calculated as 0.33 and 0.11, respectively. For red tags tag loss was calculated over three intervals. The first interval (to 10/12/2003) corresponded to the period over which yellow tags were released and was chosen to allow direct comparison of rates of tag loss between yellow and red tags. The second interval included the entire study period, while the third period only included double-tagged cod released after 10/12/2003. Of the 830 cod that were double-tagged with red tags prior to 10/12/2003 135 were recaptured. Of these 135 recaptured double-tagged cod, 42 had lost one tag (Table 2). The associated probabilities of losing one or both red tags were calculated as 0.18 and 0.03, respectively. Of the 1771 cod that were double-tagged with red tags prior to 18/2/2005 222 were recaptured. Of these 222 recaptured double-tagged cod, 54 had lost one tag (Table 2). The associated probabilities of losing one or both red tags were calculated as 0.14 and 0.02, respectively. Of the 941 cod that were double-tagged with red tags after 10/12/2003 87 were recaptured. Of these 87 recaptured double-tagged cod, 12 had lost one tag (Table 2). The associated probabilities of losing one or both red tags were calculated as 0.07 and 0.01, respectively.

Table 2. Summary of recaptures of double-tagged cod, probabilities of tag loss and reporting rate.

Tag type	Calculation interval includes cod released:	No. released:	No. recaptured with:		Probability of tag loss:		% of recaptured cod retaining:		Estimated return rate:
			1 tag	2 tags	1 tag	2 tags	1 tag	2 tags	
Yellow	up to 10/12/2003	41	5	5	0.33	0.11	11%	44%	27%
Red	up to 10/12/2003	830	42	93	0.18	0.03	30%	67%	17%
Red	up to 18/02/2005	1771	54	168	0.14	0.02	24%	74%	13%
Red	after 10/12/2003	941	12	75	0.07	0.01	14%	86%	9%

Tag reporting rate

Due to the short time interval between the conclusion of the 2005 survey and the time of writing tag reporting rate could not be calculated from recaptures of the cod tagged in winter 2005. The following results therefore relate only to the cod tagged in the winters of 2003 and 2004. The reporting rate for standard red tags was estimated as the recovery rate of standard tags relative to the assumed 100% recovery rate of high-reward tags. These calculations indicated a marked decline in reporting rate from the first to the second year of the project from 67% to 38% (Table 3).

Table 3. Estimated reporting rates for standard red tags deployed during the winter surveys of 2003 and 2004. The 100% reporting rate for yellow, high-reward tags is an assumption of the calculations.

Tag type	Calculation interval includes cod released:	Reporting rate:
Yellow	up to 10/12/2003	100%
Red	up to 10/12/2003	67%
Red	up to 18/02/2005	51%
Red	after 10/12/2003	38%

Migration

Recapture positions are presented with all the recapture sites plotted, and as for recapture information for cod recaptured after varying numbers of days at liberty. The number of fish recaptured at each site may vary. Results from the recapture information received from the tagged cod show a wide distribution of tagged cod released on the Cape. To date information on recaptured cod has been received from fishermen from Ireland, Northern Ireland, Scotland, England, Isle of Man and France. While the majority of the cod released were caught in close proximity to the release site the data shows that the Cape cod can be found all around the coast (Figure 14). The cod that were recaptured by fishing vessels were mainly caught east of the closed area with survey vessels accounting for most of the recaptures within the box. Many of the cod that were recaptured by the chartered vessel were in a fit healthy state and were re-released.

Most of the recaptured cod have been caught in Area VIa, mainly in ICES rectangle 39E3 (i.e. on the Cape Grounds). The remainder in Area VIa, have been recaptured in the North Channel, around Islay, the Stanton Bank and the Clyde. Eleven of the cod recaptured to date have been returned from the Irish Sea (Division VIIa) representing 0.9% of the recaptures. This however does not include the further 16 fish returned from Fleetwood. The Fleetwood fish were returned by local fish processors, some of the fish had came in over-land consignments from Kilkeel while the rest were caught by local boats fishing the North Irish Sea and the North Channel. As we are not certain of the capture positions we have left the recapture site for these fish as Fleetwood. Two cod from the Cape have made it to the south of the country to be caught in Division VIIj, one in East Dingle Bay and the other South of the Mizen. One cod released on the Cape has been recaptured on the shelf edge off the North West coast by a French fishing vessel.

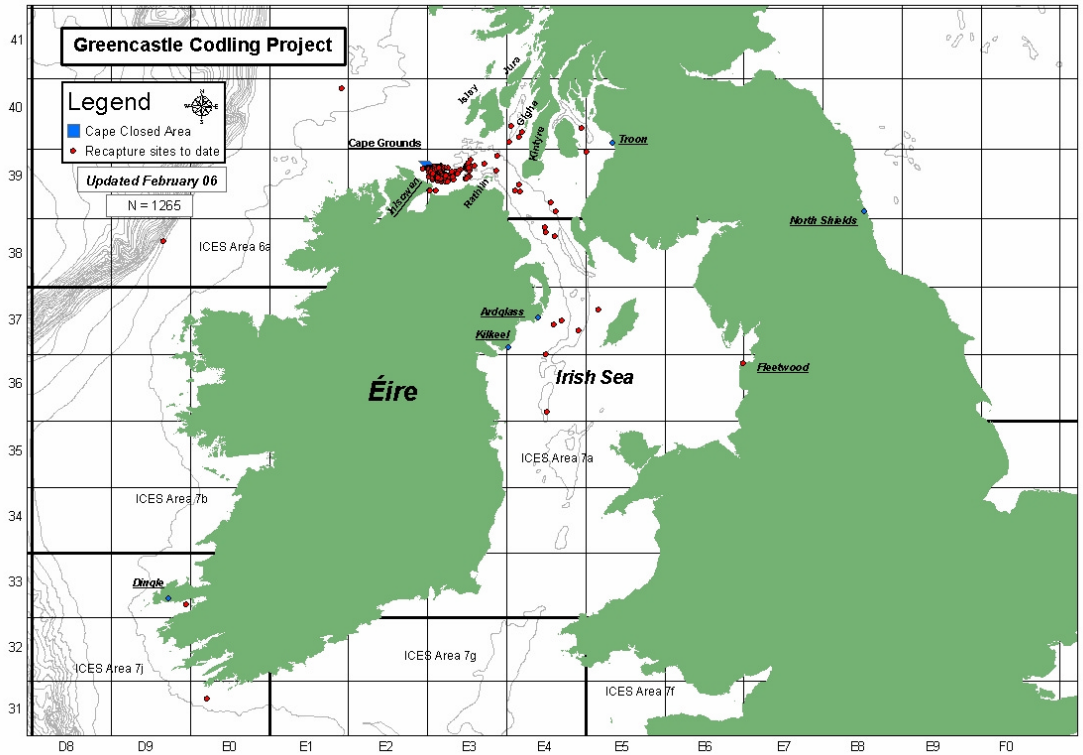

Figure 14. Recapture sites of tagged cod released on the Cape grounds.

Figure 15 shows the recapture sites for cod released on the Cape and recaptured after being at liberty for one to 15 days. A total of 408, tagged cod were recaptured within this time period.

The chartered vessels working within the closed area recaptured most of these cod with over half, 271 cod, being recaptured, re-recorded and re-released by the chartered vessels. During the start of the 2003 tagging season many tagged cod were also recaptured by commercial fishing vessels working along the eastern edge of the original closed area, described in SI No. 431 of 2003, prompting a call by the fishermen to increase the area of the closed box by extending it to the east. This request resulted in the enlarged box as described in SI No. 664 of 2003. Local Greencastle boats fishing outside the extended closed area reported the recaptures from the eastern side of 39E3.

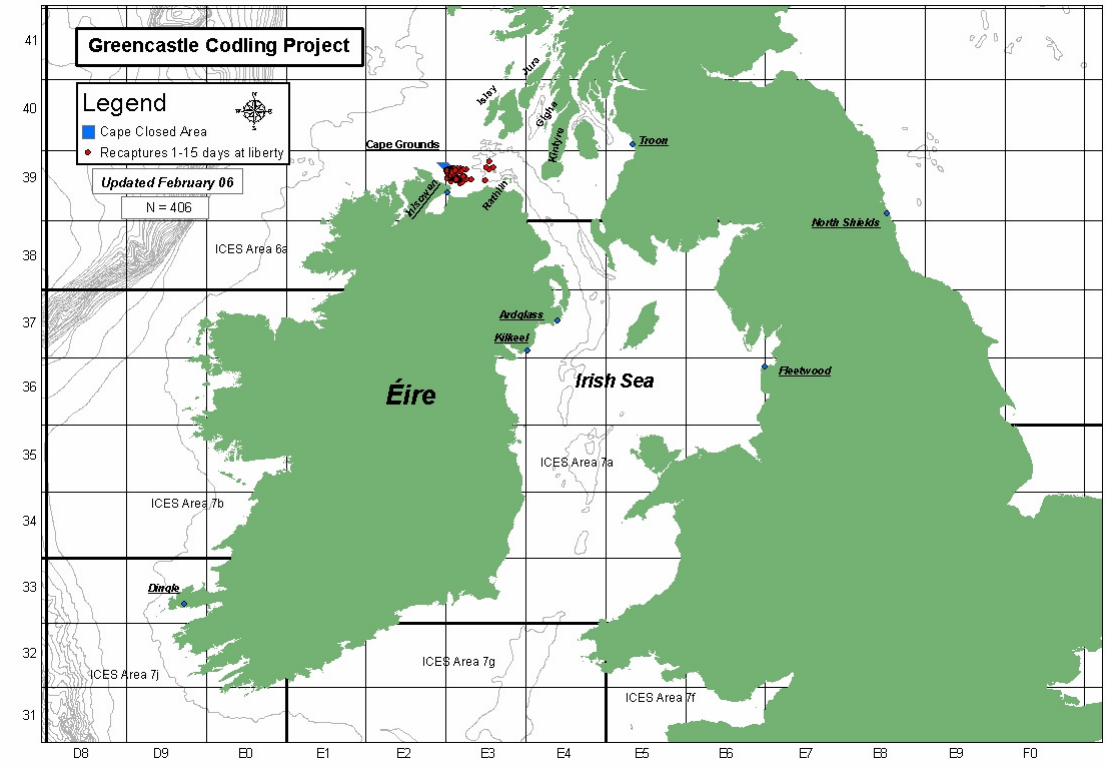

Figure 15. Recapture sites for cod 1 to 15 days at liberty.

Most of the fish caught within the "15-90 days at liberty" time period (Figure 16) were caught by either the chartered vessel fishing within the closed area or local vessels fishing to the east of the Cape. The recaptures from ICES Rectangle 40E4 were recorded by Scottish vessels. In early March 2004 one vessel recaptured 26 tagged-cod in the space of three days whilst fishing the clean grounds off Gigha. These fish are interesting as they were caught together over the three days, with many of the recaptures having been tagged and released within days of each other the previous winter on the Cape. Two of the fish recaptured in one tow by the Scottish vessel were originally captured, tagged and released from a single tow on the Cape in mid November 2003. Reported recaptures for this time period may have been affected by effort regulations pertaining to the Irish Sea Cod Recovery Plan. As part of the Recovery Plan an area of the North West Irish Sea is closed from 14 February – 30th April to protect spawning cod. While carrying out a survey within this area, during the closed period, the Northern Irish research vessel recorded the recapture from Rectangle 37E4 represented here. This suggests that some of the cod released on the Cape may actually reside within the Irish Sea Cod Box closed area during this closed period and evade capture due to the reduced effort.

Local fish processors returned the fish with recaptures recorded from Fleetwood. Some of the fish had arrived in over-land consignments from Kilkeel while local boats fishing the North Irish Sea and the North Channel caught the rest. As we are not certain of the capture positions we have left the recapture site for these fish as Fleetwood.

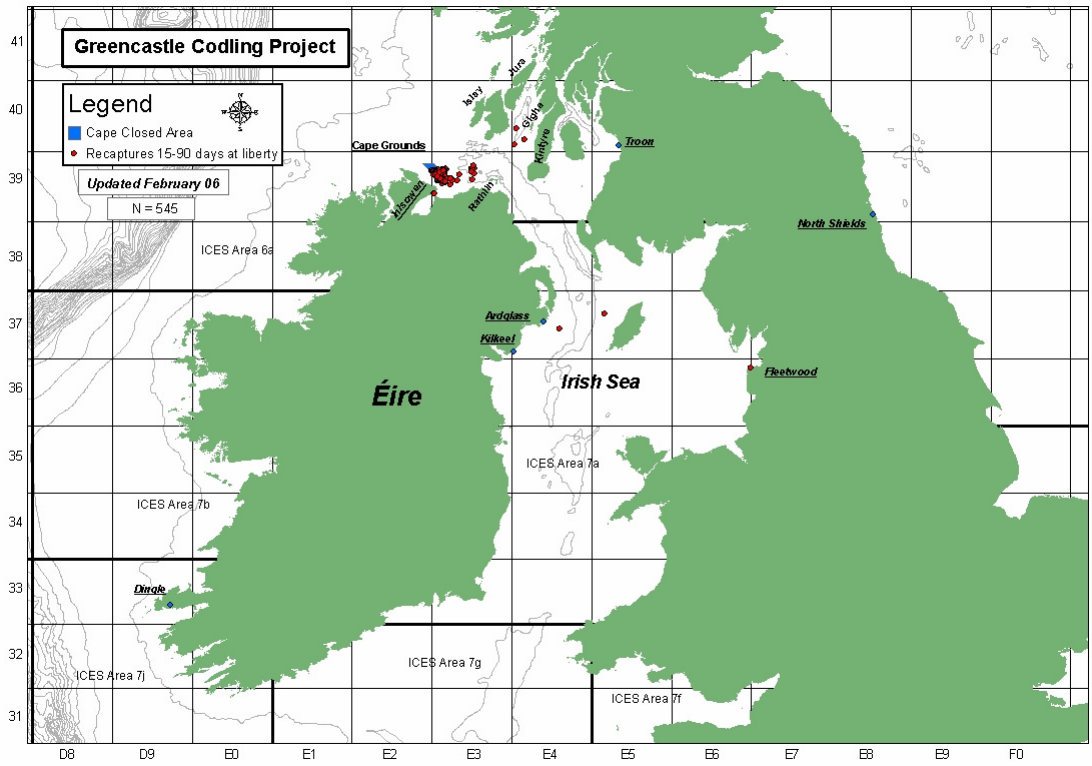

Figure 16. Recapture sites for cod 15 to 90 days at liberty.

The results presented below (Figure 17) from the recapture sites of cod "90-180 days at liberty" highlight the reduction in effort in rectangle 39E3 by Irish fishing vessels during the spring and early summer. Most of the local Greencastle fleet re-direct their fishing efforts to the "Spring fishing" in the Celtic Sea where they target whiting, haddock and other demersal species. The remainder of the local fleet go North to Stanton or the Barra grounds as weather permits with only limited fishing effort remaining on the grounds local to the Cape.

A total of thirty two cod were recaptured for this period. Two cod released on the Cape were recaptured in ICES Area VIIj. One fish was recaptured in Dingle bay in April 2004 after 146 days at liberty and the other was recaptured south of the Mizen in June 2004 after 167 days at liberty. Unfortunately our low-tech tags do not inform us as to the path taken by these fish on their journey south– West Coast or East Coast?

The recapture in Rectangle 39E5 represents the first recapture from the Clyde. The skipper returning this fish and others along the coast of Scotland reported that the tagged fish were "running with" spawning cod, even though they were not mature enough to spawn themselves. The recapture in Rectangle 40E1 represents one fish caught on the southwest corner of Stanton by a local Greencastle boat and to date represents the fish with the highest latitude of recapture. As for Figure 16 fish recorded from Fleetwood processors with no definitive recapture co-ordinates are assigned "Fleetwood" as their recapture site.

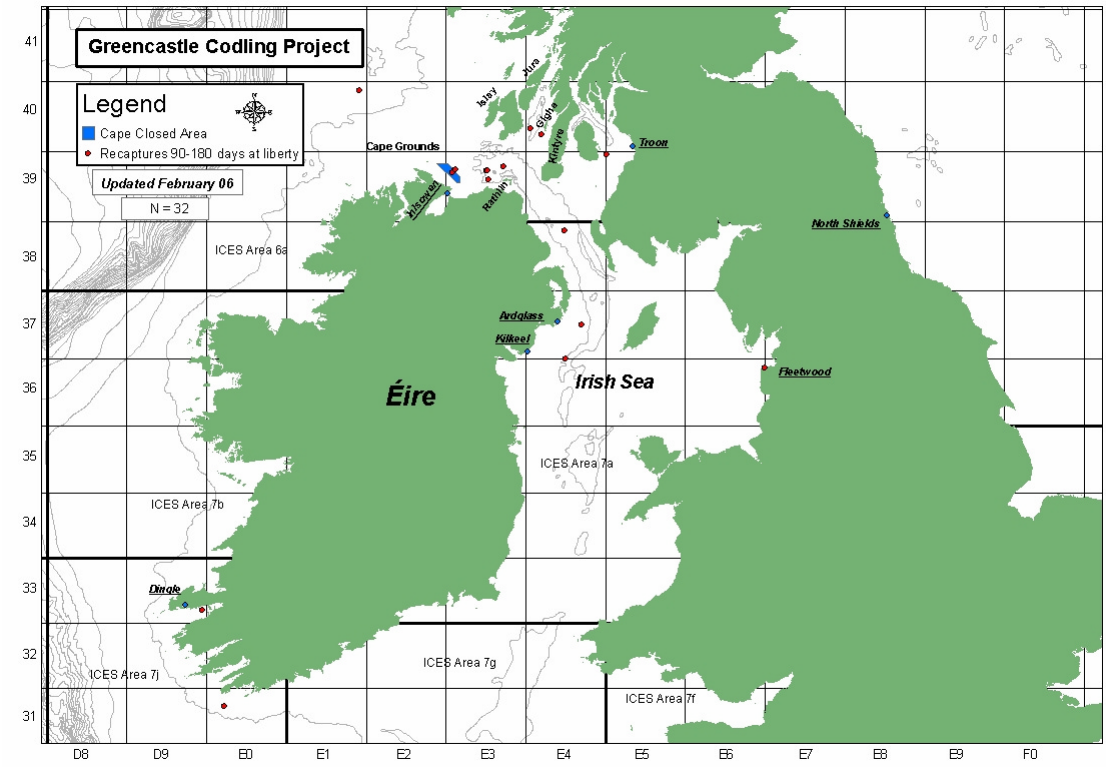

Figure 17. Recapture sites for cod 90 to 180 days at liberty.

The majority of the fish recaptured in the period "180 – 270 days at liberty" (Figure 18) were recaptured by the Northern Irish fleet fishing both the North Channel and the Irish Sea. The recapture site in Rectangle 39E2 represented below is located and rough ground on the western edge of the Cape. A local angling boat recaptured this fish on ground that is inaccessible to bottom trawl gear. The fish was recaptured 219 days after its release.

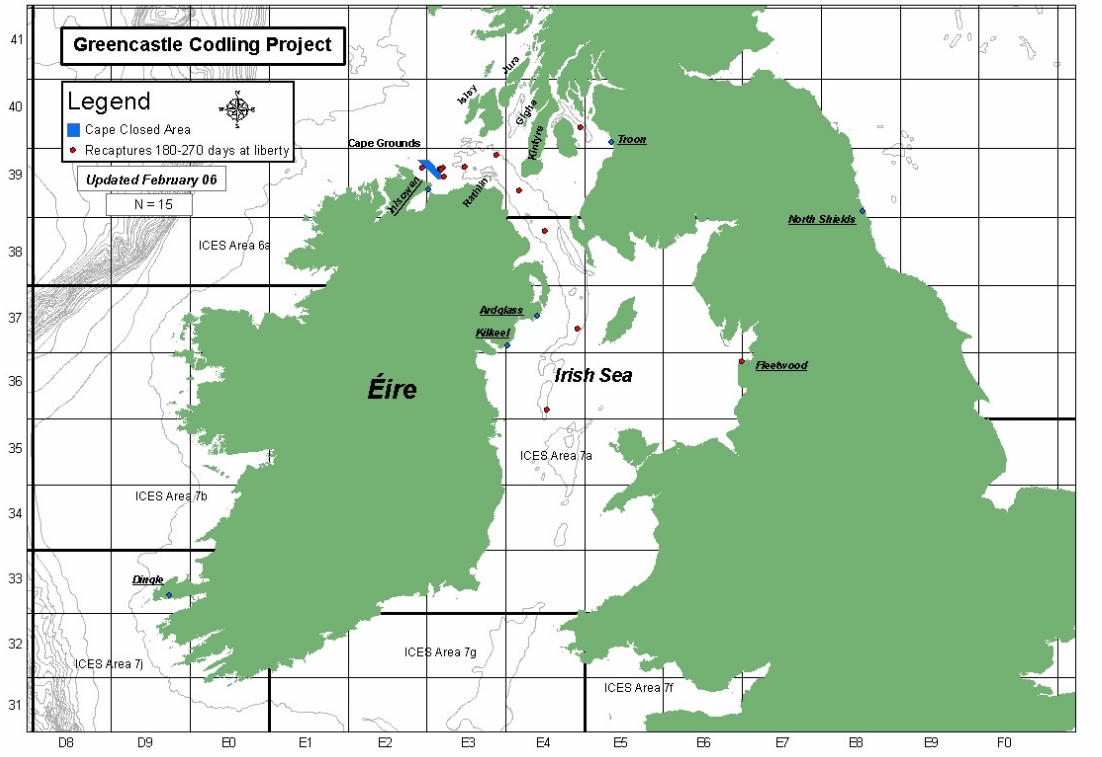

Figure 18. Recapture sites for cod 180 to 270 days at liberty.

The majority of the recaptures for a period at liberty "greater than 270 days" were recorded in the vicinity of the Cape, in ICES Rectangle 39E3 (Figure 19). Most of these fish were recaptured when the local fleet return to the area in the autumn the year after the first tagging season to fish the Cape prior to the seasonal closure. The chartered vessels also recaptured many of these fish, during the second and third tagging season.

The higher recapture rates in 39E3 after 270 days at liberty is a result of a combination of higher effort in the area and also the possible return to the Cape by some fish. While the type of tags used in this project do not allow us to retrace fish movements between the time of release and recapture the results presented here show some fidelity to the Cape by a component of the stock. This association with the ground is either a result of the fish staying on the ground during the period at liberty and evading capture or returning to the ground after an extended period elsewhere. The results may also be a combination of both scenarios.

To date a total of 61 cod have been recaptured with periods at liberty of more than 270 days. Whilst carrying out the tagging survey the chartered vessels recaptured six of these fish that were fit enough to be re-released. These six fish were at liberty for periods ranging from 302 to 359 days, prior to their re-release and some of them may hopefully be recaptured again in the future. The recapture site represented in 38D9 records a fish recaptured by a French fishing vessel from Concarneau. This recapture is the deepest to date at a depth of 250m and was recaptured by the French vessel 349 days after its release on the Cape. The fish recorded with the longest period at liberty to date is that from the recapture site in 38E4 with a period at liberty of 777 days. This fish recorded an increase of 33cm during it period at liberty, reaching a size of 71 cm at time of capture.

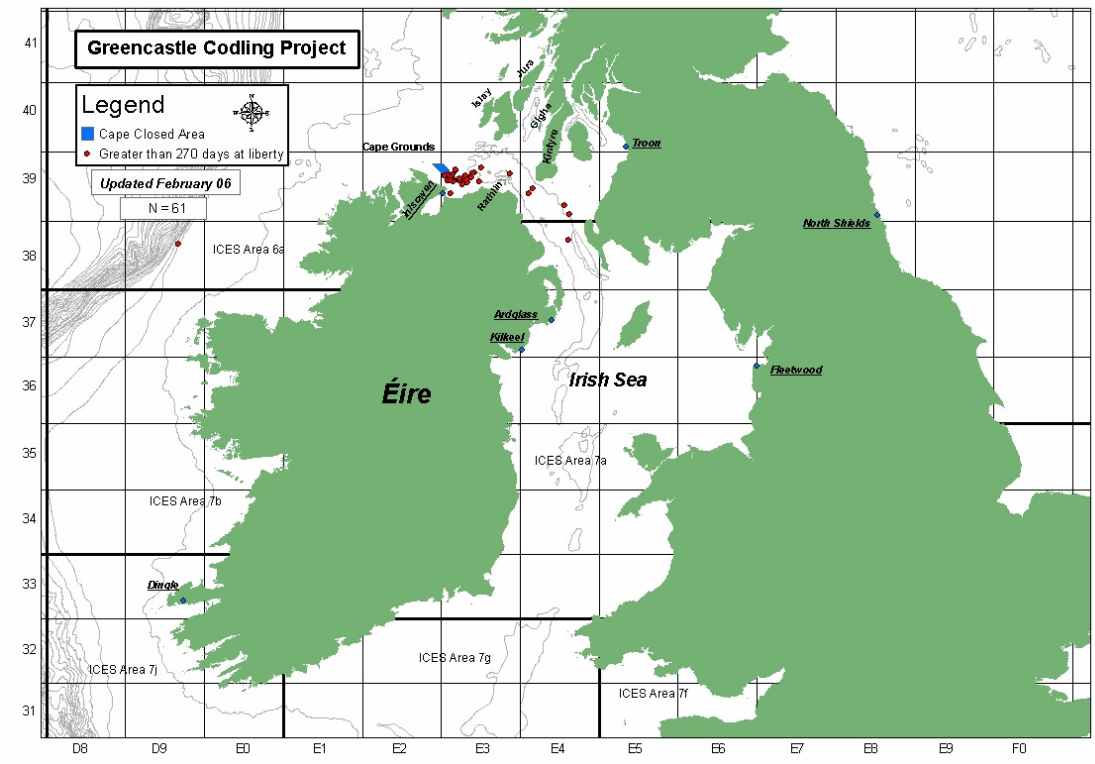

Figure 19. Recapture sites for cod greater than 270 days at liberty.

Growth

Lengths at recapture were available from 535 individuals. 181 were excluded from the growth analysis as their length increment of zero cm was considered to be biologically unfeasible. A further 17 fish with anomalous growth rates were excluded from the analysis (growth rates < the 5th or > the 95th percentiles (5.8 and 98.3 cm/year, respectively)). Growth observed in the remaining 318 recaptured cod averaged 20.6 cm per annum but was highly variable (CV: 71.6%). Many of these recaptured cod were recaptured during the survey periods themselves when the period at liberty was less than two months. Resulting growth rate estimates tended to be either unrealistically low or high due to length being measured only to the nearest centimetre below. Analyses of growth rates were therefore conducted for several groups of recaptured cod with successively greater periods at liberty.

Table 4. Growth rates of tagged cod recaptured after various periods at liberty.

Period at liberty (days)	Average growth rate (cm/yr)	Standard deviation	Coefficient of Variation	n
>= 1	20.6	14.7	71.6	318
>= 14	17.5	11.0	62.6	283
>= 90	16.4	5.8	35.2	91
>= 180	16.9	5.4	31.7	66
>= 270	16.8	4.9	29.4	54

The growth increments observed in recaptured cod were highly variable. Furthermore, most cod recaptured were tagged at a very similar size and there was very little data at the extremes of the range of initial tagging lengths. The fit of these length increment data to the Faben's re-parameterisation of the Von Bertalanffy growth function was consequently very poor (Figure 20).

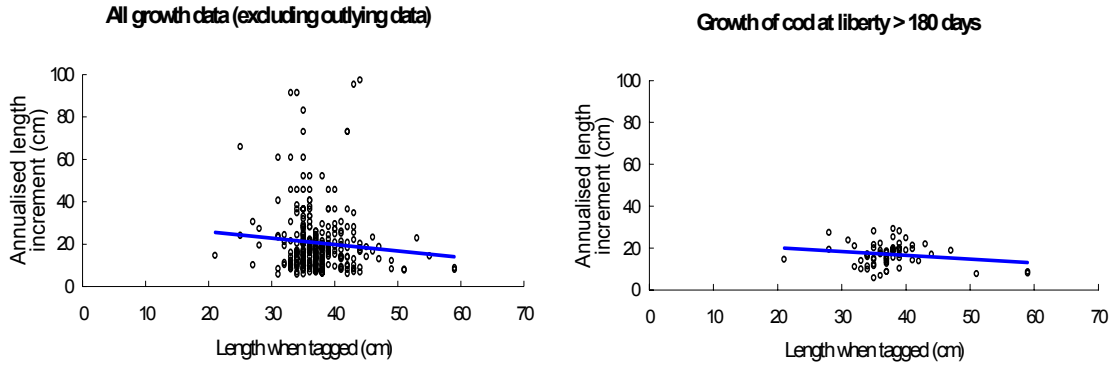

Figure 20. Growth increments observed in recaptured cod. Solid lines indicate the fit of the Faben's re-parameterisation of the Von Bertalanffy growth function to these data.

Mortality

Length frequency distributions for tagged cod collected on the 2005 survey are yet to be computerised. It was therefore not possible to apply an age-length key to these data to calculate an age distribution. The 2005 age distribution was therefore calculated using the length distribution of cod unfit for tagging on the winter 2005 survey. Catch curve analyses suggest a much higher rate of total mortality (Z) for cod caught on the Cape compared to the rest of the Division VIa cod population (Figure 21).

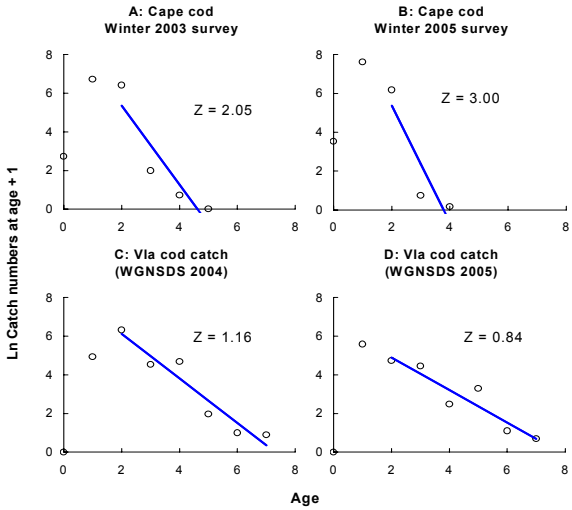

Figure 21. Catch curve estimates of total mortality for cod caught on the Cape grounds in winter 2004 (A) and 2005 (B) and in the all of Division VIa in 2003 (C) and 2004 (D).

Yield

Yield per recruit analyses were calculated using estimates of fishing mortality derived from the catch curve analysis. At the time of writing it was not yet possible to calculate an independent estimate of mortality from the tag-recapture data. Simple yield per recruit analyses indicate that the cod in Division VIa are fished at levels of exploitation far exceeding the point at which yield is maximised (Figure 22). This is particularly true for cod on the Cape grounds.

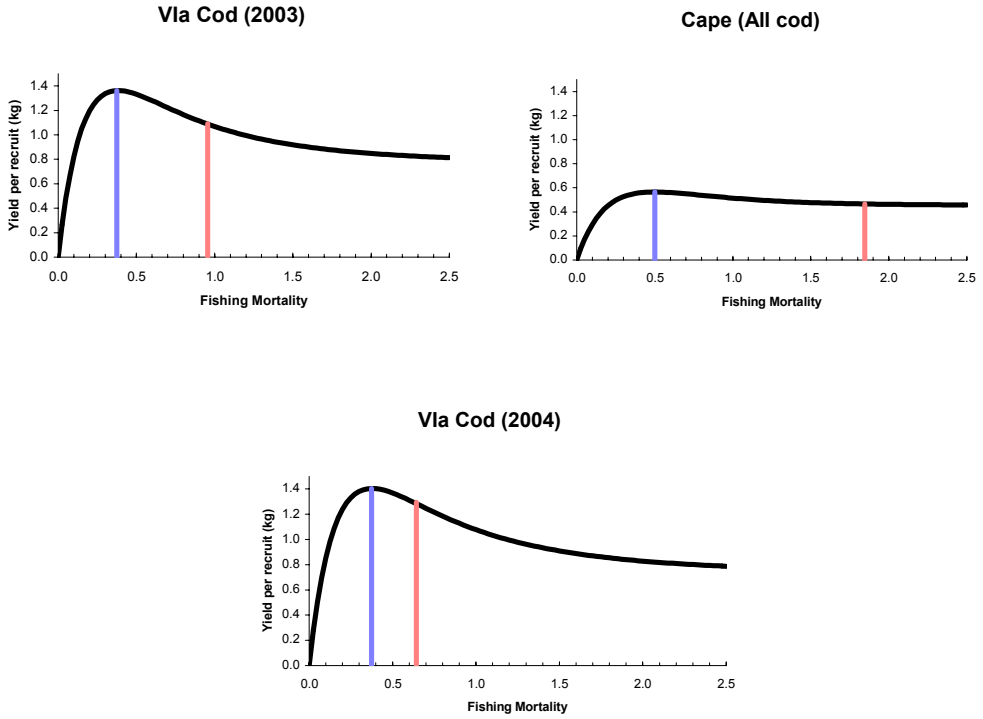

Figure 22. Yield per recruit curves for cod caught on the cape grounds and in all of Division Via in 2003 & 2004. Red lines indicate current estimates of fishing mortality, blue lines indicate the fishing mortality at which yield is maximised.

DISCUSSION

Effective tagging programs require concentrated effort on two phases of the program: 1. The initial tagging and release of the fish, and, 2. tag recovery. We operated the Greencastle Codling Project with the intention of achieving the maximum return possible for both phases.

An intensive media campaign coupled with the central involvement of local fishermen in the project helped to boost the reporting of recaptured tagged cod. Historical knowledge provided by the local fishermen ensured that the tagging period was planned to coincide with the period of peak abundance of cod on the ground. The intensity of the tagging survey ensured that maximum effort was applied during this period of peak abundance. The care and attention of the fishing crews and scientists ensured that the healthiest cod were tagged and released in the best possible condition.

The interest of industry is regarded as the single most important element in the tag recovery phase. The Greencastle Codling Project had an advantage here in that it was based on a firm foundation of close co-operation with the fishermen from the start. This support, coupled with an effective media campaign to publicise the project, ensured that fishermen all around the coast were looking out for the tagged cod. A policy of prompt response to tag return information received ensured that returnees felt a part of the project and resulted in multiple returns from the same vessels.

Despite these efforts we noticed a halving in the reporting rate of standard red tags from the first to the second year of the projects. The accuracy of our estimation of tag-reporting rates is contingent on the reward level being high enough that there is a 100% return rate for high-reward tags (Pollock *et al.,* 2001). Our calculations also assume that the high-reward tagging does not alter the reporting rate of standard tags. These assumptions are unlikely to be fully satisfied in our tagging program and we therefore consider that our estimates of the standard tag reporting rate will be positively biased, and that the absolute level of reporting is uncertain. However, it is unlikely that violation of these assumptions will have affected the scale of the differences in reporting rate observed during the project.

There are many potential explanations for the decline in reporting rate observed during the project. The most important of these appears to be the successive decline in effort exerted on research surveys during the life of the project. By the end of 2004 there was a marked decline in the effort exerted in areas where recaptures were most probable. In 2003 9 vessels undertook 59 charter days within the closed area. This declined to 45 charter days on 6 vessels in 2004, and fell further to 31 days on 3 vessels in 2005. Most of the recaptures of tagged cod observed in the first two years of the project were recovered during the survey periods. Effort also decreased throughout the life of the project due to the relocation of larger fishing vessels from Division VIa to the south-east coast and due to the decommissioning of several vessels in late 2005.

The greater probability of tag loss observed in 2003 for yellow tags than for standard tags was a cause of great concern. Inexperience in the tagging technique cannot explain the difference observed between tag colours. It is more likely that the colour of the yellow tags made them more susceptible to be pecked of by other fish. Whilst it is interesting to speculate on the cause of this result our primary concern was the diminished number of tag returns that would result from a decreased rate of tag retention for yellow tags. Our ability to accurately estimate tag retention, relative reporting rates, and subsequently, mortality rely upon a substantial rate of recovery of high-reward tags. Remedial action was taken for the winter 2005 survey in order to boost tag return rates. The effect of tag colour of rates of tag-loss was addressed by using several colours for high-reward tags in winter 2005. The proportion of fish tagged with high-reward tags was also increased to 25% of the total number tagged. We also sought to obtain more robust estimates of tag loss by double-tagging almost every fish released on the winter 2005 survey. Unfortunately it is too soon to determine whether these measures have been successful.

Insufficient time has also elapsed for the calculation of mortality estimates directly from the tag-recapture data. Our discussions of potential management strategies are therefore limited to what we can glean from our observations of the population structure, growth rates, and movement patterns of cod in this fishery.

The length frequency distributions of cod caught in winter 2005 suggests that a relatively strong recruiting year-class is entering the fishery in 2005. It is difficult, however, to discern the relative strength of this year-class from the length frequency distribution alone. Catch rates on the 2005 survey were exceptionally low. This led to more extensive searching of the grounds than had been the case on previous surveys. The northern-end of the grounds was worked more extensively in winter 2005 than in the previous two surveys. It is known locally that the Northern-end of the grounds ordinarily contains a greater relative proportion of smaller codling than the rest of the grounds. The length frequency of the cod tagged in winter 2005 was not available at the time of writing. It is unlikely than the same proportion of smaller codling will be represented in the length distribution of tagged cod. Smaller cod were not as hardy as bigger fish and were therefore more likely to be rejected as unfit for tagging. Nevertheless, a far greater proportion of tagged fish released in winter 2005 were smaller cod.

The distinct lack of older age-classes of cod on the Cape Grounds is noticeable in all years. The fishery has traditionally operating on young cod and it is therefore not reliable to consider the age structure of cod on the Cape grounds as representative of the wider population. We therefore consider the mortality estimates derived from catch curves for the Cape grounds to over estimate rates of mortality in the wider population. However, the rates of total mortality calculated for the wider population from more representative data indicate that current rates of mortality are grossly in excess of those at which yield is optimised. The growth rates observed in the project support this conclusion. Growth was extremely variable between individuals but averaged around 17 cm per annum for cod at liberty for extended periods. Cod at the modal size of about 37cm weigh about 600 gram. If allowed to grow for one additional year at the average growth rate they would attain about 54 cm and triple their weight to about 1.8 kg.

Unfortunately it was not possible to use the spatial distribution of fishing effort to standardise the spatial distribution of tag-recaptures. Whilst the spatial distribution of effort was available for Irish vessels effort data were not available for the fleets of other Nations. Any standardisation of recapture distributions using the spatial distribution of just the Irish fleet would be an incomplete and probably unrepresentative analysis.

Strong fidelity towards the Cape grounds was exhibited over two time scales. During the winter tagging surveys the repeated recapture of recently tagged cod on the grounds indicated a retention of cod on the grounds during each winter. Tagged cod at liberty for extended periods were subsequently recaptured on, or near the Cape grounds. This behaviour has important implications for the potential management of the Cape grounds fishery. The fidelity of cod to the grounds during the winter season coupled with high growth rates during the season may mean that a short winter fishing season, with a delayed opening, may yield a similar total weight of codling than the traditional fishery but with the catch of a reduced number of cod. Such schemes may reduce current fishing mortality rates. However, all indications are that current levels of mortality (both natural and fishing) being exerted on cod are grossly excessive. Advice for no directed cod fishery is the only advice that is consistent with the current status and needs of the stock. Scientists have proposed such advice for many years for several northern European cod fisheries. However this advice has not been adopted or implemented by fishery managers because it does not properly consider the economic and social consequences of a fishery closure.

The continuation of projects such as the Greencastle codling project have great potential in alleviating this conflict. The local industry were centrally involved in this project, worthwhile project objectives were agreed upon and, critically, industry vessels were used to conduct the research program. As a result the main Irish fishery for cod in Division VIa has remained closed since 2003, whilst scientific objectives for improved data on the stock were achieved simultaneously.

Acknowledgements
We wish to thank the skipper and crew of each vessel chartered. Their knowledge, skill and interest in the project proved invaluable, ensuring the maximum number of cod were both caught and kept in prime condition for tagging and release.

Thank you also to all the fishermen and processors of Ireland, Northern Ireland, Scotland, England and France, who spotted and returned tagged cod with all the information. Your co-operation has helped us gain a valuable insight into the lives of cod from the Cape.

This project was instigated by the cod fishermen of Greencastle and has enjoyed the support of every one involved and interested in cod. It is important to remember that tagged Cape cod still swim in our seas. If reported upon recapture these cod can add more to our knowledge and understanding of cod in the waters around Ireland.

The photographs used in this report were taken by Emmet Jackson (BIM) and Macdara Ó Cuaig (MI).

This project was funded under the National Development Plan (NDP) with additional funding provided by the Marine Institute and Bord Iascaigh Mhara (BIM).

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APPENDICES

Appendix 1: Statutory Instrument used to implement closure of the fishery

SI No 431 o f 2003

Cod (Fisheries Management and Conservation) (No 14) Order, 2003.

I, Dermot Ahern, Minister for Communications, Marine and Natural Resources, in exercise of the powers conferred on me by section 223A (inserted by section 9 of the Fisher ies (Amendment) Act, 1978 (No. 18 of 1978), and amended by section 4 of the Fisheries (Amendment) Act, 1983 (No. 27 of 1983)) of the Fisheries (Consolidation) Act, 1959 (No. 14 of 1959), and the Fisheries (Transfer of Departmental Administration and Minist erial Functions) Order, 1977 (S.I. No. 30 of 1977) ((as adapted by the Marine and Natural Resources (Alteration of name of Department and Title of Minister) Order, 2002 (S.I. No 307 of 2002)), hereby order as follows:

1. This Order may be cited as the Cod (F isheries Management and Conservation) (No 14) Order, 2003 and shall come into operation on the 22 nd day of September 2003 and shall cease to have effect on the 15 th day of February 2004.

2. (1) In this Order: -

"the specified area" means that part of ICE S Sub -area VIa in the box bounded by the following co - ordinates:

Point no	Latitude	Longitude
1	55 o 25'N	07 o 07'W
2	55 o 25'N	07 o 00'W
3	55 o 18'N	06 o 50'W
4	55 o 17'N	06 o 50'W
5	55 o 17'N	06 o 52'W
6	55 o 25'N	07 o 07'W

"the fishing gears" means demersal and pelagic trawls, seines and similar towed gears, beam trawls, static demersal nets including gill nets, trammel nets and tangle nets, hook and line including demersal longlines and jigging, fish and shellfish traps includ ing lobster and crab creels.

"Irish sea -fishing boat" means a fishing boat included on the Irish Register of Fishing Boats.

(2) In this Article: -

"the Communication" means the Communication (85/C347/05) from the Commission of the European Communitie s on the description of the ICES sub -areas and divisions used for the purpose of fishing statistics and regulations in the North East Atlantic ([1]);

"ICES" means the International Council for the Exploration of the Sea.

([1]) O.J. C.347/14 of 31/12/85

(3) In any proceedings in which a contravention of this Order is alleged prima facie evidence of the Communication may be given by the production of a copy of the Official Journal purporting to contain the Communication.

3. Neither an Irish sea-fishing boat nor a person on board an Irish sea-fishing boat shall deploy the fishing gears in the specified area and the master of an Irish sea-fishing boat shall not cause or permit the boat or any person on board to deploy the fishing gears in the specified area.

GIVEN under my Official Seal,
this 19th day of September, 2003.

LS

Dermot Ahern
Minister for Communications, Marine
and Natural Resources

EXPLANATORY NOTE

(This note is not part of the instrument and does not purport to be a legal interpretation).

This Order prohibits for a five-month period the deployment of a wide range of fishing gears including demersal, pelagic and shellfish fishing gears in an area bounded by the following co-ordinates off the Greencastle coast in County Donegal:

Point no	Latitude	Longitude
1	55°.25'N	07°.07'W
2	55°.25'N	07°.00'W
3	55°.18'N	06°.50'W
4	55°.17'N	06°.50'W
5	55°.17'N	06°.52'W
6	55°.25'N	07°.07'W

This Order comes into effect from the 22nd day of September , 2003.

(PRN 944) (Price € 0.76)
Published by the Stationery Office, Dublin.

Appendix 2: Derogation allowing research work by the Marine Institute (and chartered vessels) during the Project

An Roinn Cumarsáide,
Mara agus Acmhainní Nádúrtha,
Baile Átha Cliath 2.

Department of Communications,
Marine and Natural Resources,
Dublin 2.

Seafood Control Division

4th November 2003

Mr Macdara Ó Cuaig,
Fisheries Science Services,
The Marine Institute,
Galway Technology Park,
Galway.

Dear Macdara:

Please note that the Department of Communications, Marine and Natural Resources is prepared to agree to your request for a derogation to carry out survey work on the Greencastle Codling Project. The derogation form compliance with Statutory Instrument 431 of 2003 (Cod (Fisheries Management and Conservation) (No 14) Order, 2003) is specific in that it only permits the fishing vessels listed below to take cod under the terms you have outlined in your correspondence with Ms Roisín Laverty.

These conditions include that a maximum of two fishing vessels will be on the grounds at the one time, that the landing of cod for commercial purposes will be kept to a minimum and confined to cod of legal length and are unfit for tagging. The derogated vessels should retain a copy of this letter while at sea conducting the survey work. The derogation is limited to the following fishing vessels:

Áine Íde G 180, Foyle Warrior SO 274, Marliona D 59, Paul Stephan SO 746, Silver Bell C 240 and Summer Star SO 497.

Sincerely,

Andrew Kinneen.
Sea Fisheries Control Manager.

Appendix 3: Seabed mapping swathes conducted by the Marine Institute during the Project