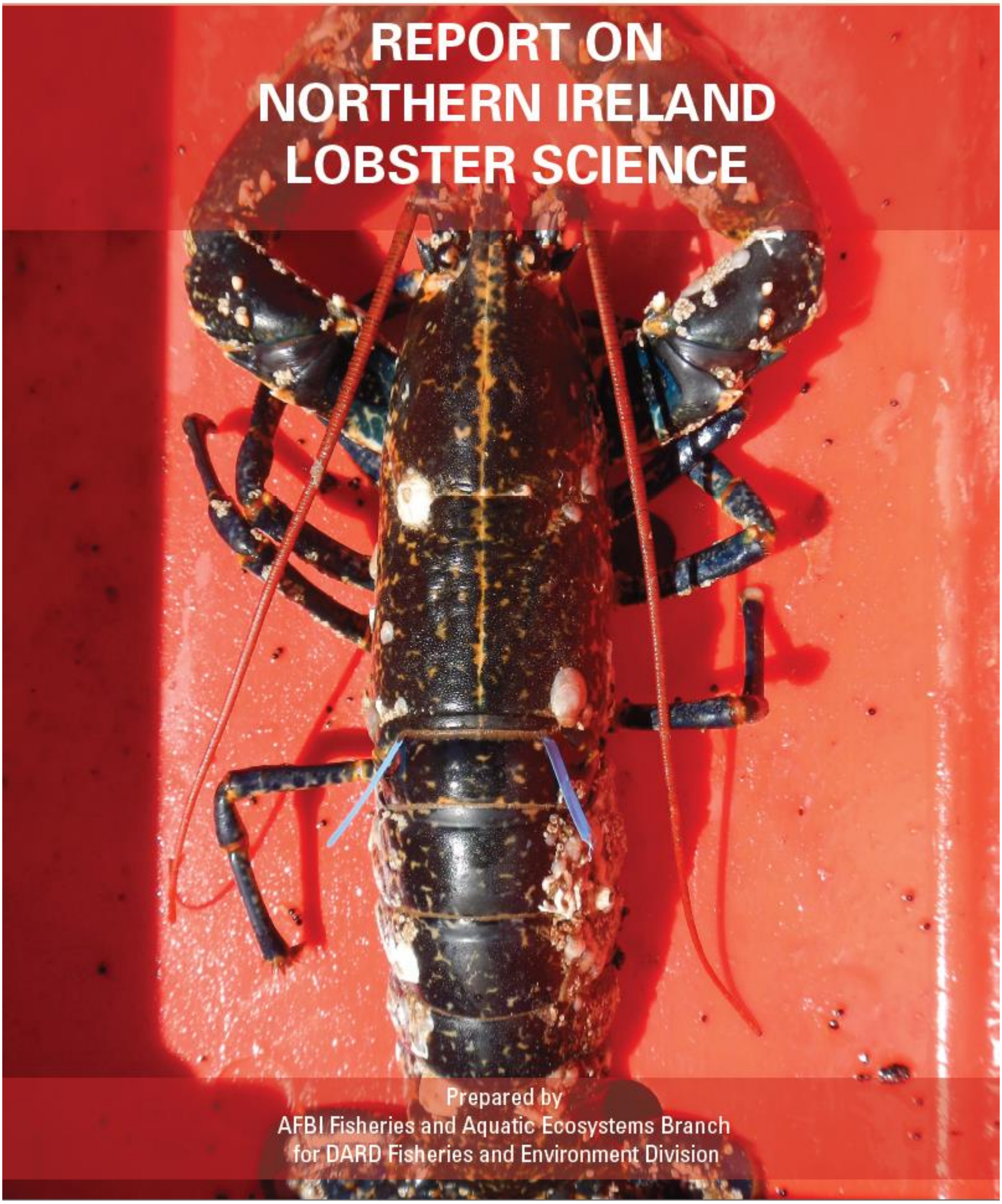
Agri-Food and Biosciences Institute

Queen's University Belfast

European Fisheries Fund

REPORT ON NORTHERN IRELAND LOBSTER SCIENCE



Prepared by
AFBI Fisheries and Aquatic Ecosystems Branch
for DARD Fisheries and Environment Division

Suggested citation: McMinn, C., Clements, A., Service, M., Prodohl, P., Bailie. D. (2015) Report on Northern Ireland Lobster Science. A report prepared for the Department of Agriculture and Rural Affairs, funded through the European and Fisheries Fund. 113pp

Further information

Agri-Food and Bioscience Institute (AFBI)

Fisheries & Aquatic Ecosystems Branch

Coastal Zone Science Group

Newforge Lane

Belfast

BT9 5PX

Tel: 028-90255472

Acknowledgements

Firstly, acknowledgment should go to the Department of Agriculture, Northern Ireland who approved this project for funding through the European Fisheries Fund, without which this project would not have gone ahead. Also thank you to DARD for supplying AFBI with the landings figures used throughout this report.

Thank you to Jonathon Beattie (AFBI) for carrying out many of the observer trips and for helping throughout the project.

Finally, a massive thank you goes to all the fishermen who helped out on this work and allowed AFBI staff to carry out observer trips onboard their vessels. Not only does this provide us with vital information on lobsters but discussions with the sector provide a useful insight into the fishery by those that have spent their life fishing it. Whilst it was an absolute pleasure to work with all the fishermen, a special mention has to be made to Colin Nelson, Director of the North East Lobster Co-Op, who has had the enthusiasm and vision to contemplate the use of modern DNA technologies to assist the v-notching scheme and Bob McMullan and David Galbraith of the North Coast Lobster Fisherman's Association who provided a constant source of information on the two v-notching schemes currently running in Northern Ireland. Dr Deborah Bailie and Professor Paulo Prodöhl were also supported by the Beaufort Marine Research Award in Fish Population Genetics funded by the Irish Government under the Sea Change Programme.

1. Summary

- The European lobster, Homarus gammarus, is a solitary, aggressive, shelter seeking animal common around coastal waters of Britain and Ireland. Lobsters are traditionally fished using pots or creels. Worth an estimated first sale value of £1 million in 2014, the Northern Ireland lobster fishery is valuable to both those that target it and the greater Northern Ireland economy.
- Lobsters represent the highest proportion of pot landings for both the North Coast and Antrim Coast. Indeed, while the total weight of landed lobsters is greatest along the County Down coast, the catch per unit effort (CPUE) tends to be higher along the North Coast were a small number of vessels fish a small number of pots.
- Observor trips were carried out on board commercial fishing vessels targeting lobsters. These trips supported the landings figure showing the greatest CPUE along the North Coast. They also showed that the greatest CPUE occurs between the months of July and September.
- Lobsters from Strangford Lough had a larger average carapace length (CL) compared to the other areas surveyed. Growth studies from tag recaptures also showed that whilst the average growth at moult for lobsters for Strangford Lough was 12.1mm, elsewhere the growth was lower at an average of 10.6mm for males and 9.7mm for females. This increased size in Strangford Lough means that there is a higher percentage of landable sized lobsters in the catch, for example 48% of lobsters caught in Strangford Lough were greater than the minimum landing size (MLS) whilst in County Down only 20% of lobsters were 87mm or greater.
- From the observer trips, between 6.1% and 13.3% of all female lobsters caught were v-notched. In the NELCO region, 47% of all berried females were v-notched. Across the area surveyed, the CL length of berried females ranged from 70mm to 159mm.
- Over the duration of the project 4,034 lobsters were tagged using plastic streamer tags that are retained throughout moulting. There was a reported recapture of 8.8%. This is a known underestimate as they were reports that the details of some recaptured tagged lobsters were not returned plus there was an issue with the fading of the writing on the tags which meant that recapture details could not be returned.
- The number of days between initial tagging and recapture ranged from 9 days to 1,001 days. The distance moved ranged from 9m to 105km, averaging at 2.4km. An examination of the direction of movement showed that while there was no migration of lobsters between inshore and offshore as reported for the American lobsters, a

small number of lobsters did move offshore, particularly from along the County Down coast.

- In terms of habitat type, the majority of strings which had more than 10 lobsters per string were captured within 4km of the coast and in depths of 20m or shallower. The biggest proportion of lobsters 48% were caught on bedrock and boulders.
- Between 2003-2014 NELCO v-notched almost 27,000 berried lobsters. A comparison of the genetic make-up of the samples collected suggests that the samples comprise a good representation of the local stocks and that the v-notching scheme is not affecting the genetic make-up of the local stock.
- The offspring of lobsters v-notched in 2003/04 began appearing in the fishery as berried lobsters in small numbers in 2007. Numbers increased to a peak in 2009. In practical terms, based on the figures, this means that between 2007 and 2013 9-33% of all lobster landings by NELCO originated from the v-notching scheme. It is estimated that in 2013 almost 26,000 lobsters recruited into the fishery are resulting from the v-notching scheme.
- A number of v-notched lobsters were caught over several years indicating that many of the v-notched lobsters can contribute to the stock for 10-15 years.
- 81% of lobsters caught in County Down were assigned to females caught in the same area in 2003/04 showing that most recruitment appears to be local. However, only 24% of lobsters caught in the Outer Ards area assigned to mothers from that area. For individuals assigning to other areas, results suggest a biased movement North. Indeed, 9% of the lobsters caught by the NCLFA from the Antrim Coast and North Coast can be traced back to the NELCO v-notching scheme.

2. Introduction

2.1 Biology

Homarus gammarus (L. 1758), also known as the common lobster or European lobster, is common around coastal waters of Britain and Ireland and to depths of about 50m (although they can be found in deeper waters). Elsewhere, the species has a broader distribution ranging from the Lofoten Islands to western Baltic, North Sea, English Channel, Atlantic and Mediterranean coasts of Europe, south to North-West Africa and east to the Black Sea (Gibson *et al*. 2001, Prodöhl *et al.* 2006). European lobsters are solitary and sedentary animals and aggressive competition for shelter on rocky substrates is a common behaviour. Habitat availably, in addition to smaller clutch sizes (i.e. lower fecundity), are thought to be the major factors accounting for this species lower abundance in comparison to American lobsters *Homarus americanus* (H. Milne Edwards, 1837), their closely associated species and the only other representative of the genus *Homarus*.

Whilst much of the life history of *Homarus* species has been extensively studied, many ecological details are still lacking. Thus, despite their economic importance, much remains to be understood in order to properly managed and ensure long-term sustainability of exploited stocks (Cobb and Castro 2006). *Homarus* species are shelter seeking animals and tend to inhabit areas with stones and boulders on top of sand where they can use the rocks as shelter and the soft bottom allows them to dig hollows into the bed (Dybern *et al.* 1967). In a study of the American lobster, Sheehy (1976) introduced artificial concrete “shelters” in a normally uninhabited sandy area and found that within 1 week 60% of shelters were inhabited.

H. gammarus are variable in length with larger specimens reaching 500mm (total length). The carapace of these animals is generally granular but lacking spines or ridges. The dorsal is dark blue-black often with paler yellow or orange spots ventrally. The claws on the first pair of legs are large and powerful, with the right claw being larger than the left and used for crushing whilst the left claw is much sharper and used for slicing. The main predators of lobsters are teleost fish, sharks, rays, skate and octopus (Phillips *et al*, 1980). While lobsters are primarily nocturnal animals, leaving their shelter at nighttime to forage for food, if water visibility is poor, they may leave their shelter during the daytime to forage (Cooper and Uzmann, 1980). The diet of the European lobster has been found to include crabs, gastropods, polychaetes, mussels and starfish (Cooper and Uzmann, 1980). Adult lobsters as well as postlarval juveniles are also able to feed on suspended particles (Loo *et al*. 1993).

The sex of a lobster is determined by its first pair of swimmers (Figure 1). In males these are hard and grooved to pass sperm cells into the body whilst those of a female are soft and feathery (Taylor, 1975). On average lobsters mature around 5-8 years with females being around 75-80mm in carapace length (CL) and males slightly smaller. Size and age at maturity are dependent on water temperature and vary substantially across the distribution range of the species (Cobb and Castro, 2006). For example, in the American lobster, a steep latitudinal temperature gradient was observed in CL size with females in southern New England maturing at 70-80mm CL whilst those in the colder Bay of Fundy (about 300km away) do not mature until approximately 100mm CL (Wahle *et al.* 2013). In Ireland, Tully (2001) reported on significant regional differences between size of maturation (CL) for females.

Lobsters grow by moulting, which decreases in frequency during the juvenile stages until becoming an annual part of the mating, spawning and egg hatching cycle (Factor, 1995). Individuals moult their shell (ecdysis) in summer or early autumn. Temperature and food are the most important factors in moulting. During moulting, water is absorbed by the body tissues, and this causes the lobster to swell and rupture its exoskeleton, which allows further swelling to occur and the new exoskeleton to begin to harden. The lobster eats its old exoskeleton which provides some of the calcium needed for the new shell. The size increase between moulting events has been estimated to be around 10-15% of CL from studies involving lobsters reared in laboratory conditions, tagging-recapture, and caging experiments in the field (Table 1).

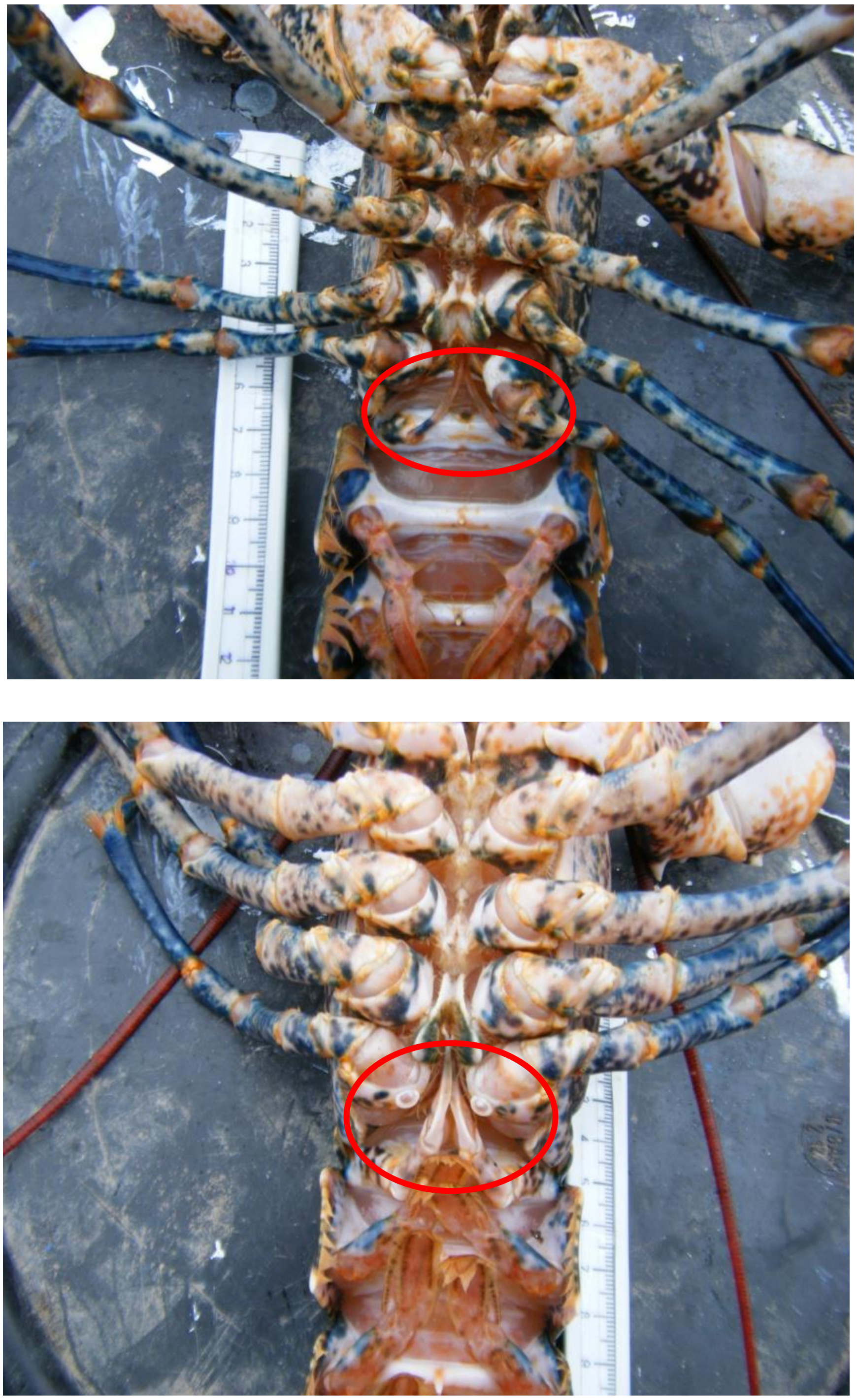


Figure 1: Female (top) and Male (bottom) lobster

Table 1: Summary of size increment from studies examining growth patterns at moult of the European lobster

Source	Location of work	Increment (mm)	
		Male	Female
Hepper (1967)	Yorkshire and Cornwall	9.8	8.4
Hepper (1970)	Menai Straits	12.4	12.3
Hepper (1972)	Menai Straits	12.3	10.3
Gibson (1967)	Ireland	8.5	7.5-7.6
Simpson (1961)	North Wales	10.1	10.7
Thomas (1958)	Scotland	12.3	10.1
Agnalt *et al*. (2007)	Norway		7.1
Agnalt *et al.* (2009)	Stefjord, Norway	5.6	4.0
Agnalt *et al.* (2009)	Morsvikfjord, Norway	8.3	

The rate of moulting decreases with age (Gibson, 1967; Taylor, 1975; Richards and Wickens, 1979; Comeau and Savoie, 2001). For the American lobster, moulting and spawning take place in every second year for females less than 120mm CL (Waddy *et al*. 1995). Water temperature and age, however, can influence this cycle with small females inhabiting warmest waters moulting and spawning during the same summer. Growth has been found to be impacted by maturity, with the onset of maturity reducing growth increment particularly in females (Hepper, 1978; Phillips *et al*. 1980; Schmalenbach *et al*. 2011; Wahle *et al.* 2013). In addition, the time between moults is also longer for mature females compared to similar sized males, probably due to the egg brood hindering moult (Wahle *et al.* 2013). This explains why larger animals can be more encrusted with barnacles etc. than smaller animals which "retain" their shells for shorter periods. Also disease, the recovery from an injury or the regeneration of a limb will transfer energy towards recovery and away from growth (Richards and Wickens, 1979). Cheng and Chang (1993) reported that autotomy in the American lobster can reduce moult increment by 30-40%. No terminal moult has been reported for any lobster species.

Moulting of males and females tends to be staggered with males moulting earlier in the year than females (Welby, 2014). Reproduction takes place during the summertime and is linked with the moulting cycle (Atema, 1986). It is during moulting that the soft bodied female mates with a hard bodied male. Inter-moult mating, however, has been documented for both European and American lobsters (Skog, 2009). After extrusion the eggs are held on the pleopods for approximately another year until hatching the following summer. Lobsters are iteroparous (i.e. multiple reproductive cycles over the course of its lifetime) and, thus can breed from maturity throughout the rest of their life with the egg mass and number (i.e. fecundity) increasing with the size and age of the lobster. The female can retain the male sperm for up to a year, until needed to fertilise the eggs. The eggs are extruded from the base of the second pair of walking legs along with a sticky substance which cements the eggs in place under her tail. At this stage the female is referred to as being ‘berried’ (Figure 2). A female lobster, depending on its size, may produce from 6 up to 15 thousand eggs. Tully *et al.* 2001 reported that in Ireland the number of eggs carried by a female varied with the carapace length as the power function clutch size = 0.0044 x $CL^{3.16}$, which would translate to a clutch size of around 9,200 for a lobster of 100mm carapace length. The eggs are carried by the female for 9-12 months during which they go through different phases. Initially, the eggs are dark green then black. As they ripen, they will turn reddy-brown before turning paler with an ‘eyed’ appearance. Once the eggs are matured the female will release them in bursts each night. The larvae remain planktonic for 5-10 weeks and go through three moults before moving to the seabed to begin their life as bottom dwellers. Little is known about these post-settlement early juveniles and the habitat type they inhabit.

Determining age in lobsters in particularly difficult because all hard parts are shed at each moult. Thus, the use of methodologies that are useful in other marine species are not suited for lobsters. Lipofuscin, the “age-pigment” that is known to accumulate over time in the brain or eyestalk neural tissue has been considered as a potential useful approach to age decapods. However, initial studies have indicated considerable variation in age estimates for the European lobster (Sheehy *et al*. 1996). Thus, further refining would be required before this technique could be routinely used (Wahle *et al.* 2013). More recently, a new technique, based on the number of annual growth rings on the gastric mill has been proposed for the American lobster. This new technique was developed in parallel to research which developed an aging technique for crabs and shrimp by counting the annual growth rings on the eyestalk. Kilada *et al.* (2012) successfully used this technique to estimate age at length relationships for the American lobster, snow crab (*Chionoecetes opilio*), sculptured shrimp (*Sclerocrangon boreas*) and northern shrimp (*Pandalus borealis*). In 2015 the list of species aged using this technique extended to include the red squat lobster (*Pleuroncodes monodon*) yellow squat lobster (*Cervimunida johni*) and the nylon shrimp (*Heterocarpus reedi*) (Kilada and Acuńa, 2015). Its potential use for the European lobster, has yet to be determined.

Figure 2: Berried female lobster

2.2 Fishery

Lobsters along with crabs are traditionally fished using pots or creels. The main types of pot used to catch lobsters are inkwell pots and parlour pots. Inkwell pots are the traditional style of pots. Lobsters climb into the pot to feed on the bait through the entrance at the top. However, the animal can get back out with relative ease, and therefore these pots have to be checked regularly to prevent loss of catch. Unlike inkwell pots, parlour pots have two chambers which makes it much more difficult for the animal to get back out. These pots are traditionally used in areas were weather can prevent fishermen getting out to the check the pot regularly.

A large number of pots may be attached to a single string, which is marked by a buoy at each end. The pots are baited and placed on the seabed to soak for a number of days before being hauled. Once hauled, given their very aggressive behaviour, any lobsters which are caught have their claws banded to prevent damaging by fighting. For baiting, while a wide range of different types will successfully work for brown crab, only very oily or salted bait tends to be effective when fishing lobsters (Lawrence *et al*. 2015).

Watson *et al*. (2009) suggested that the probability of a lobster entering a pot and being captured is a function of: a) its ability to detect the bait in the pot; b) its motivation to locate, approach and enter the pot; c) the interaction with other animals either already in the pot or in its vicinity; and d) the chances of escaping from the pot before it is hauled.

Addison (1995) investigated how potential behavioural interactions in the pot could affect the catch of a pot. After observing that most frequently only one lobster is caught in a given pot, he tested the hypothesis that the presence of a lobster in a pot deters other lobsters from entering it. Pre-stocking pots with a lobster of 82-83mm CL was shown to significantly reduce the catch rate of additional lobsters, as well as the catch of crabs. There was no difference between pre-stocking the pot with a male or a female lobster. Also, based on lobster fishermen's belief that the presence of high numbers of soft crab reduces lobster catches, pots were baited with dead or damaged soft crab, which is known to deter other soft crab from entering the pot. These pots were found to catch significantly more lobsters compared to those baited with fish. The use of escape gaps, which allow undersized animals to leave the pots, may therefore enable more legal sized animals to enter the pot. Fishermen who use escape gaps report a reduction in sorting time and therefore overall fishing time and fuel consumption, along with a reduction in the bait used (Pers. Comm.).

Bennett and Brown (1979) carried out a review of studies which examined how the pot immersion time affected catch. This review reported that there is little difference in catch with extended immersion time. For example, Mason (1965) reported little differences in catches of brown crab between pots immersed for 1, 2 or 3 consecutive days. In Wales Bennett and Lovewell (1977) reported that the catch per pot hauled was constant for immersion periods of up to 5 days. With only 2% of the annual potting effort at that time having immersion times exceeding 5 days, the authors concluded that CPUE (weight of lobsters caught per 100 pots) was an adequate index of abundance (Bennett and Brown, 1979). Bannister and Addison (1995) also found no significant difference in lobster catch relating to soak time in a study carried on the east coast of England.

The trap design can influence the impact of immersion time on catches. For example, larger pots can be immersed longer before becoming saturated with catch. Also, the efficiency of the bait will reduce with increased immersion time therefore reducing the draw of the pot to the animals. Competition between animals will limit the effect of immersion time on catches.

If a lobster enters the pot first, it's territorial behaviour will limit catches of additional lobsters and also of other species (pers. comm.).

Whilst mobile gear such as dredges and trawls can damage the seabed, pot fishing is seen as a relatively benign form of fishing having little impact on the environment (Kinnear *et* al. 1996; Holt *et al*. 1998; Eno *et al*. 2001; Adey *et al*. 2006; OSPAR Commission, 2009). Indeed, in areas where other forms of fishing have been prohibited, the use of static gear has been allowed to continue. Mortality of bycatch by pot fishing is also low in comparison to other fishing gear (Welby, 2014)

One issue that can arise from pots is ghost fishing. This is when a pot is lost after bad weather or being snagged accidently by another vessel. Lost gear may continue to fish. While it is unknown how long the gear will continue to fish, it is thought that gear that has been dragged by other vessels such as dredgers and trawlers will be more likely to be damaged and tangled to such an extent that it will fish less effectively (Jennings et *al*. 2001).

2.3 Management throughout the UK and Ireland

Anyone fishing for shellfish on a commercial scale must have a license (which registers the vessel as a fishing vessel under the Merchant Shipping Act 1995), with a shellfish entitlement. This entitlement has been granted by the 2003 UK Restrictive Shellfish Licensing Scheme, which was set up to cap levels of crab and lobster fishing. Through this scheme a fisherman was granted a shellfish entitlement based on track record (if they had landed or sold more than 200kg lobsters or 750kg crabs during any 12-month consecutive period between 1 January 1998 and 31 December 2002). Anyone who now wants a shellfish entitlement can only do so by transferring the license from a fisherman who is leaving the sector or by buying a vessel which has a shellfish entitlement.

Fishing for lobster, similar to crab, is not subject to European total allowable catch regulations and there are no national quotas. The primary means of managing stocks is through a minimum landing size (MLS), which is the minimum size at which it is legal to keep or land an animal. This is thought to be an effective way of managing the reproductive population as it protects a proportion of the females carrying eggs from the fishery. Whilst a minimum landing size may not be as effective for fish species, which are usually dead when returned, for shellfish a minimum landing size is an effective tool as most shellfish usually survive when returned and can re-enter the population where they can reproduce until they have reached the MLS and can be landed.

The current European MLS for lobsters is 87mm CL. However, around the UK and Ireland national legislation and byelaws have been regionally instated to increase the MLS. In Cornwall the Inshore Fisheries and Conservation Authority (IFCA) has increased the MLS of lobster to 90mm CL for their district. This is also the case in the district of the Isles of Scilly and Devon and Severn IFCA's. Some of the IFCA's also protect the lobster stock by byelaws banning the landing of berried lobsters or through the protection of v-notched lobsters (see below for details).

The English IFCA's have set a number of additional byelaws for the management of the pot fishery. In some areas pot limits have been introduced to control the effort placed on the fishery. In some cases, a limit has been decided directly by the IFCA. For example, Sussex IFCA set a standard pot limit at 100 pots per crew, up to a maximum of 300 pots per vessel. Other IFCA's have set a pot limit by putting it out to consultation with the fishermen and letting them decide on the maximum number of pots allowed. While there is some grievance from a few fishermen who currently fish over the limit, fishermen with a large number of pots tend to have larger vessels capable of going further offshore where the pot limit does not stand. Pot limits may also be varied according to the distance from the shore. In the Isle of Man, the pot limit within 3nm is set at 300, while between 3-12nm it is set at 500. Defra have considered an alternative method to control fishing effort - rights based management - whereby fishing rights are allocated to those who have been active within the fishery during a set reference period. The fishing rights would entitle the fisherman to a percentage share of a total allowable catch based on a track record.

In Northern Ireland the Unlicensed Fishing for Crabs and Lobster Regulations (Northern Ireland) 2008 was introduced by the Department of Agriculture and Rural Development to improve the management and conservation of crab and lobster and to prevent the increase in fishing by hobby fishermen who did not hold a license. Under the regulations it prevents anyone without a license from:

- Landing more than five crab and one lobster per day.
- using more than 5 pots
- using a stock cage

2.4 V-notching

V-notching has historically (i.e. over 100 years for the American lobster) been used as a tool in the management of lobster stocks. V-notching involves the notching of the tail of any berried female (usually of legal landing size i.e. 87mm CL) before returning it to the sea. Any female which has been v-notched is legally protected and should not be landed. This reduces the harvest rate on reproductive females, and, as the v-notch can last several moults, it means the female is protected for a number of years (two to four years depending on the lobster size). The aim of v-notching is to increase the total number of reproductive females and hence to increase total egg production of the fishing stock. V-notching has now become common practise throughout the UK and Ireland.

In 2001, Tully examined the impact of the south Wexford v-notching programme. In Ireland voluntary v-notching was first adopted in 1994 after concerns that the available spawning stock was limiting recruitment. Four to five years after its introduction (i.e. 1998-99) catch rates of undersized lobsters had increased by 37% over catches in earlier years. Six years after the implementation of v-notching in the area, the reproductive potential from v-notched lobsters represented 59% of the reproductive potential of the entire population.

In a more recent study, Telsnig (2014) modelled the impact of v-notching on the lobster fishing stock of Northumberland. The author reported that lobsters from the ongoing v-notching programme could now be responsible for between 0.27-9.1% of total lobster landings in the area. Furthermore, Telsnig (2014) also suggested that, based on current speed and direction of local oceanic currents, v-notching could be helping to seed areas outside of the Northumberland limits.

In Northern Ireland there are two lobster associations running V-notching schemes in parallel. That run by the North Coast Lobster Fishermen's Association (NCLFA) and the other by the North-East Lobster Cooperative (NELCO). The NELCO scheme, which has remained unchanged for over twelve years, sees berried lobsters V-notched at the site of capture. In each case, a subsample of fertilized eggs is removed and placed in preservative (storage buffer) along with the female v-notch. V-notched lobsters are returned to the site they were caught, and the eggs and v-notch are sent to Queen's University Belfast where they undergo DNA profiling analysis. A comparison of the maternal genetic profile (DNA extracted from V-notches) with that of the offspring (DNA extracted from eggs), using microsatellite DNA profiling, enables the confirmation that the V-notch is indeed from a berried lobster. This greatly simplifies the logistics of the monitoring procedure as it eliminates the need to hold/transport berried lobsters (this was initially as a form of evidence small for compensation to be paid). DNA profiling also allows for a number relevant management and conservation questions to be addressed. The profiling analysis produces genetic identity 'bar codes' for the v-notched female and her eggs. From these, the genetic profile of the unknown male who fertilised the eggs can be extrapolated (i.e. the "father DNA bar code"). This scheme has led to the establishment of a genetic database for lobster families from the County Down coast (i.e. genetically tagged families). This can be used to determine the parentage of future lobsters which are caught from the fishery. Thus, lobsters caught in future years can then have their genetic profile checked against the database to identify if they have come from families belonging to the v-notching scheme (i.e. genetically tagged in previous years). By identifying the percentage of lobsters which are derived from the v-notching scheme (i.e. which are the progeny of a v-notched female), this unique scheme can be unequivocally used to assess the effectiveness of v-notching as a management strategy. In an independent report carried out during the Northern Ireland Brown Crab Strategy, Banister (2011) emphasised the importance of rigorous methods to determine the recruiting size classes that are likely to be the progeny of v-notched animals. Indeed, this was outlined as one of the desirable, and the most challenging aspects of a good v-notching programme. To date, the NELCO v-notching scheme is the only scheme to meet this criterion.

While the NCLFA have now adopted this scheme, until 2013 they ran a different scheme whereby any berried female was brought back to port where it was verified by a port officer before being v-notched. The lobster was then returned to sea by the fisherman.

3. Methods

3.1 Landings Data

Prior to 2006 vessels under 10m in length were not required to submit landings data. The Registration of Fish Buyers and Sellers and Designation of Fish Auction Sites regulations (Northern Ireland) 2005 has changed this. Currently all fish sold (over and above 25kg per day for which sales notes are not required if being sold to the public) must be reported. In Northern Ireland a Monthly Shellfish Return must be submitted by all fishermen declaring their landings and effort (number of pots) for the month. These are then input onto the Department of Agriculture and Rural Development (DARD) database by port officers.

Landings data from 2006 to 2014 was obtained for Northern Ireland from DARD. The raw data was analysed to examine the temporal and spatial patterns in fishing activity around Northern Ireland, providing a summary of the Northern Ireland pot fishery, and in particular, that targeting lobsters. Landings were examined by landing port and for the entirety of Northern Ireland.

3.2 Data Collection Onboard Commercial Vessels

Data was collected onboard commercial fishing vessels targeting lobsters between 2013 and 2015. Data collected included the position of the strings fished (to monitor the spatial extent of the fishery), total count of lobsters caught, sex of lobsters and the incidence of soft shelled, v-notched and berried lobsters. The carapace length (CL) of lobsters was measured from the rear of the eye socket to the posterior margin of the carapace using calipers. Records of other species caught were also taken. This data was input into ArcGIS in order to determine any spatial differences in the lobsters captured around the Northern Ireland coast.

3.3 Tagging

The tagging-recapture programme was implemented alongside the observer trips. Any undersized male or female lobsters, lobsters which were caught v-notched, or those that were berried and not going to be landed were tagged using streamer tags. In addition, several fishermen asked for very large males to also be tagged. The streamer tags were inserted through the abdominal musculature using a needle. The needle was then detached from the end of the tag leaving a section of the tag visible at each side of the lobster (Figure 3). Each tag was printed with a unique identifier number. In addition to physically tagging individual lobsters, a non-destructive biopsy sample was collected for genetic analysis at QUB by cutting a small section from the end of one of the walking legs and placing it in a bottle labelled with the tag number and containing a preservative (storage buffer). Where possible the animal was released as near to the catch site as possible to minimise stress.

Tag recovery forms were provided to fishermen who were asked to record and return the details of any tagged animals. Fishermen were also provided with a set of calipers to measure any recaptured lobsters.

The tag and recapture sites were plotted using GIS to monitor the movement (distance and direction) of each lobster. Movement of lobsters has been analysed as the shortest distance from the place of release to the recapture position. The change in CL (mm) was examined to provide growth estimates.

Figure 3: A lobster tagged with a blue streamer tag.

As there is no information about stock boundaries, some of the data analysed throughout this work has been examined based on broad coastal areas (Figure 4):

1. North coast (Portstewart to Ballycastle)
2. Antrim Coast (Ballycastle to mouth Belfast Lough)
3. Outer Ards (Donaghadee to mouth Strangford Lough)
4. Strangford Lough
5. County Down Coast (mouth of Strangford Lough to South of Carlingford Lough).

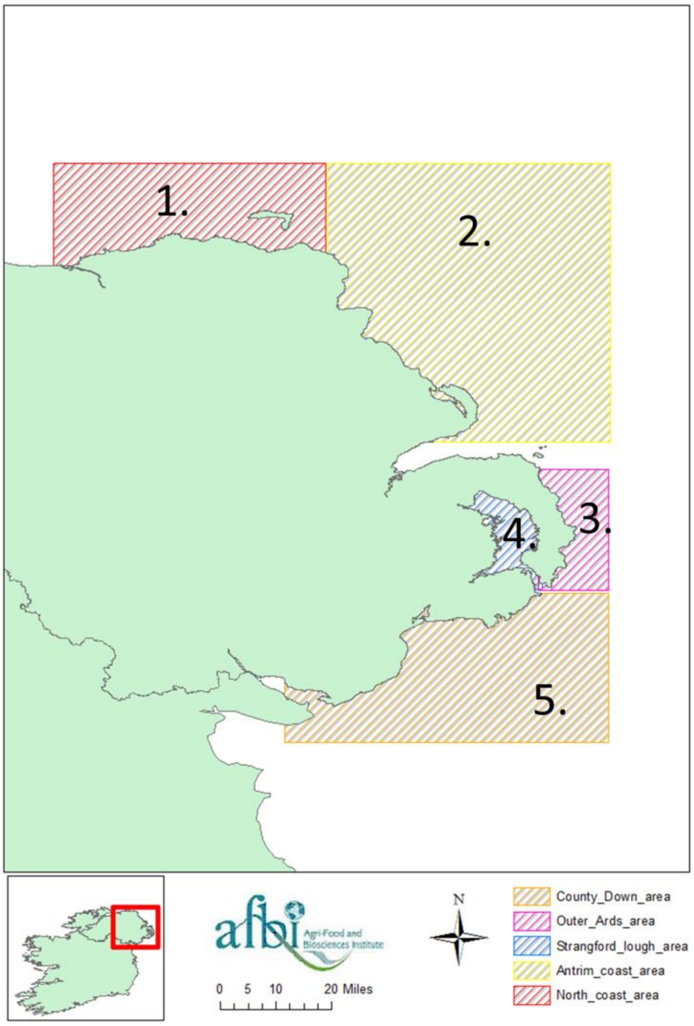


Figure 4: Coastal area of Northern Ireland, divided in sub regions, considered during this report.

3.4 Habitat Maps

3.4.1 Positional quality control

The lobster string data were quality controlled for positional information using ArcGIS 10.2, to ensure that the mid-string positions were correct and plotted appropriated.

Where further checks were needed, the original datasheets were used to verify positions and revisions made if appropriate.

3.4.2 Plotting of data

The data were divided into three sets:

(a) Lobster abundance
(b) Berried lobsters
(c) V-notched lobsters

These were then overlain on the following datasets:

Habitat maps: these were from the broadscale nearshore mapping project (Mitchell and Service, 2004) based on interpolated RoxAnn acoustic ground discrimination system (AGDS) data, ground-truthed using underwater video, grab sampling and experimental dredges. In addition, further maps for Strangford Lough, Dundrum Bay and the Skerries and Causeway area were used which were generated from high resolution multibeam sonar data, and ground-truthed using underwater video and grab sample data (see Clements and Service, 2015a, b, and Clements *et al.,* 2010). The former maps used a local habitat classification, while the latter maps used the UK Marine Nature Conservation Review Classification and its EUNIS classification equivalents.

Bathymetric data: Oceanwise Digital Elevation Models (DEMs) (© Crown Copyright, 2014. All rights reserved. License No. EK001-20140410) incorporate the best available bathymetric data from the UK Hydrographic Office were available at approximately 25m2 horizontal resolution. These were regridded using a cubic interpolation to a grid size of 10m2. The grid tiles were merged in ArcGIS to provide complete coverage around the Northern Ireland coastline and projected in UTM Complex Zone 30N (Figure 5). The slope angle was generated from the 10m2 bathymetric grid (Figure 6), and two sets of neighbourhood (“focal”) statistics calculated from the slope angles: mean slope angle over a 50m radius (Figure 7), and the standard deviation of the slope angle over a 50m radius.

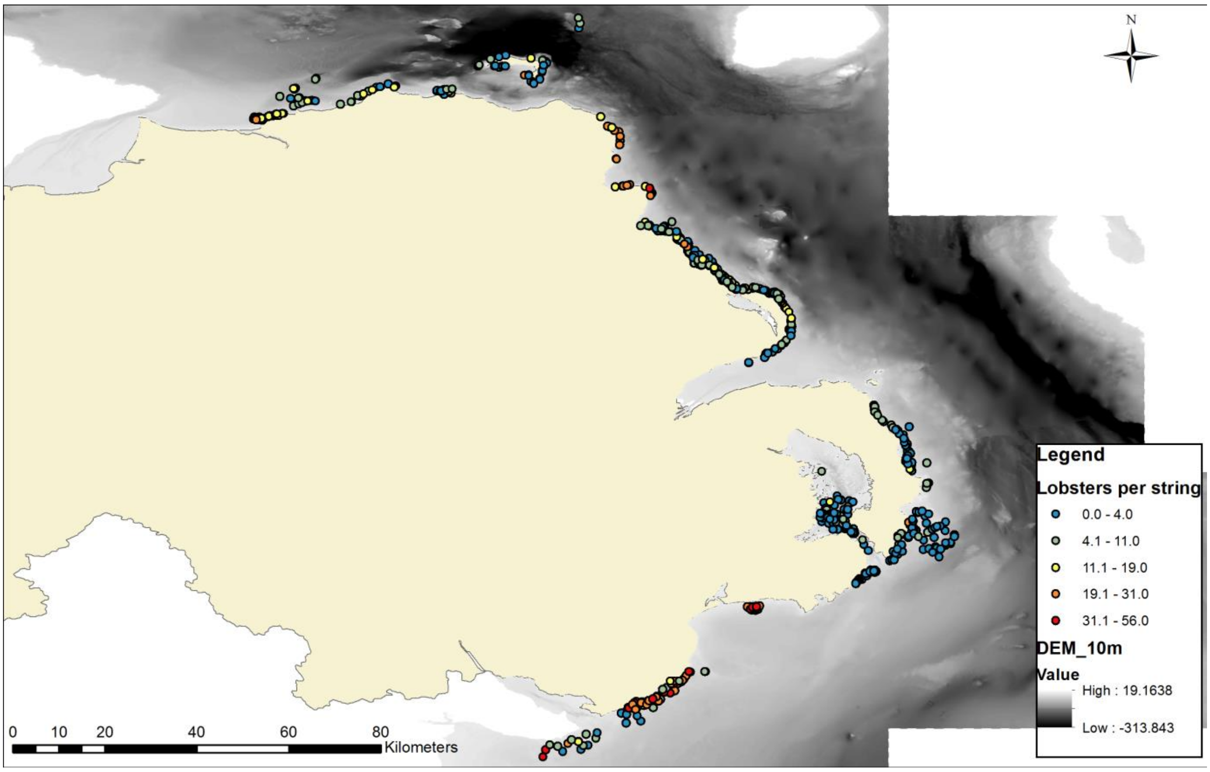


Figure 5: Bathymetric Digital Elevation Model (10m horizontal resolution) with lobster abundance per string overlain.

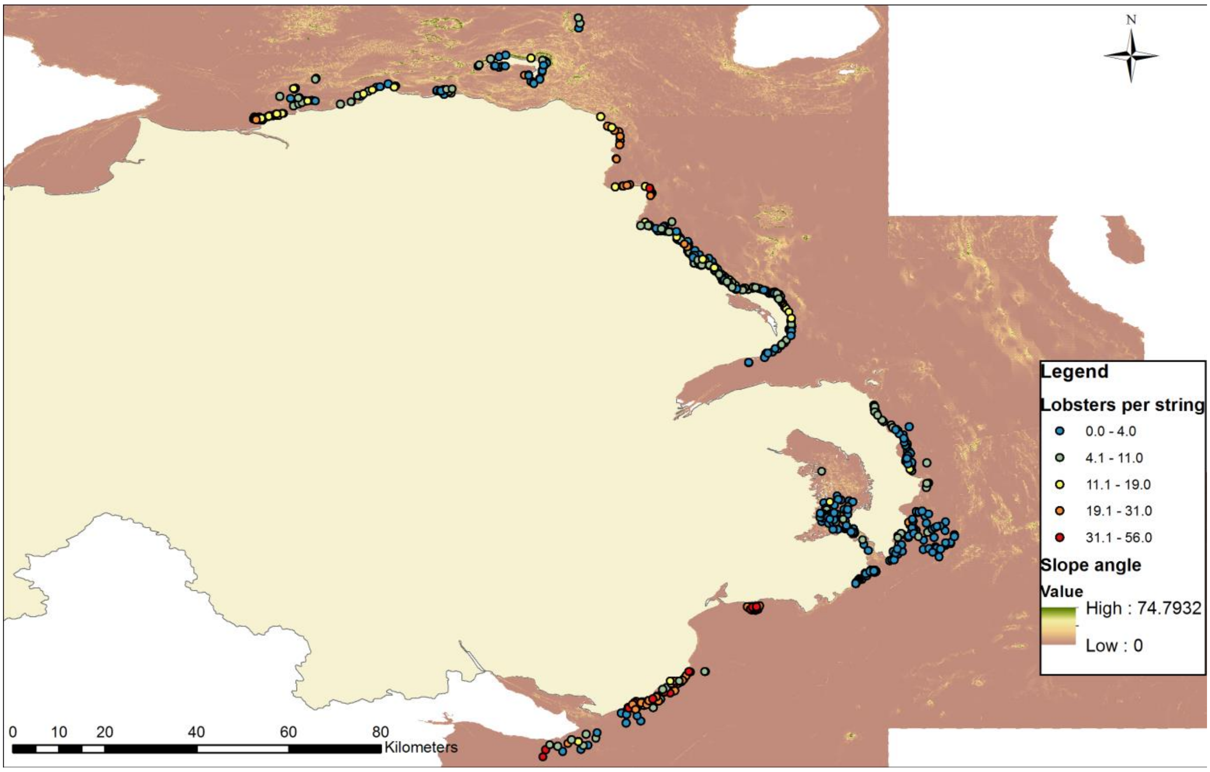


Figure 6: Slope angle in degrees with lobster abundance per string overlain.

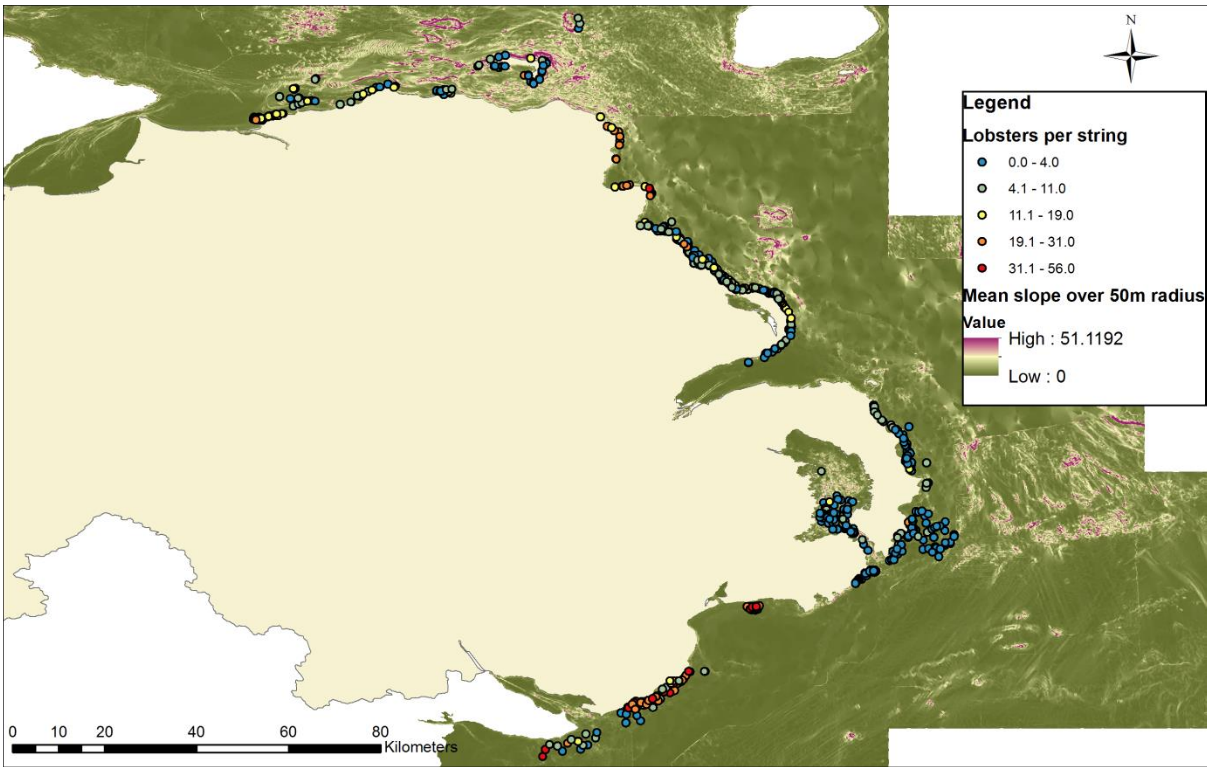


Figure 7: Mean slope angle over a 50m radius in degrees, with lobster abundance per string overlain.

Terrain ruggedness and Benthic Position Index were calculated using the Benthic Terrain Modeler extension for ArcGIS (see Wright et al., 2005; Wright et al., 2012) (Figure 8).

Ruggedness may be defined as the ratio between the surface area and the planar area of each cell in the input bathymetric dataset; it is a measure of terrain complexity. Benthic Position Index (BPI) may be defined as a measure of where a referenced location is relative to the locations surrounding it. In this study, broadscale BPI was calculated with an inner search radius of 10m and an outer search radius of 100m (see Figure 9). Data from the habitat and bathymetric data layers was extracted for the lobster abundance data to examine any potential relationships.

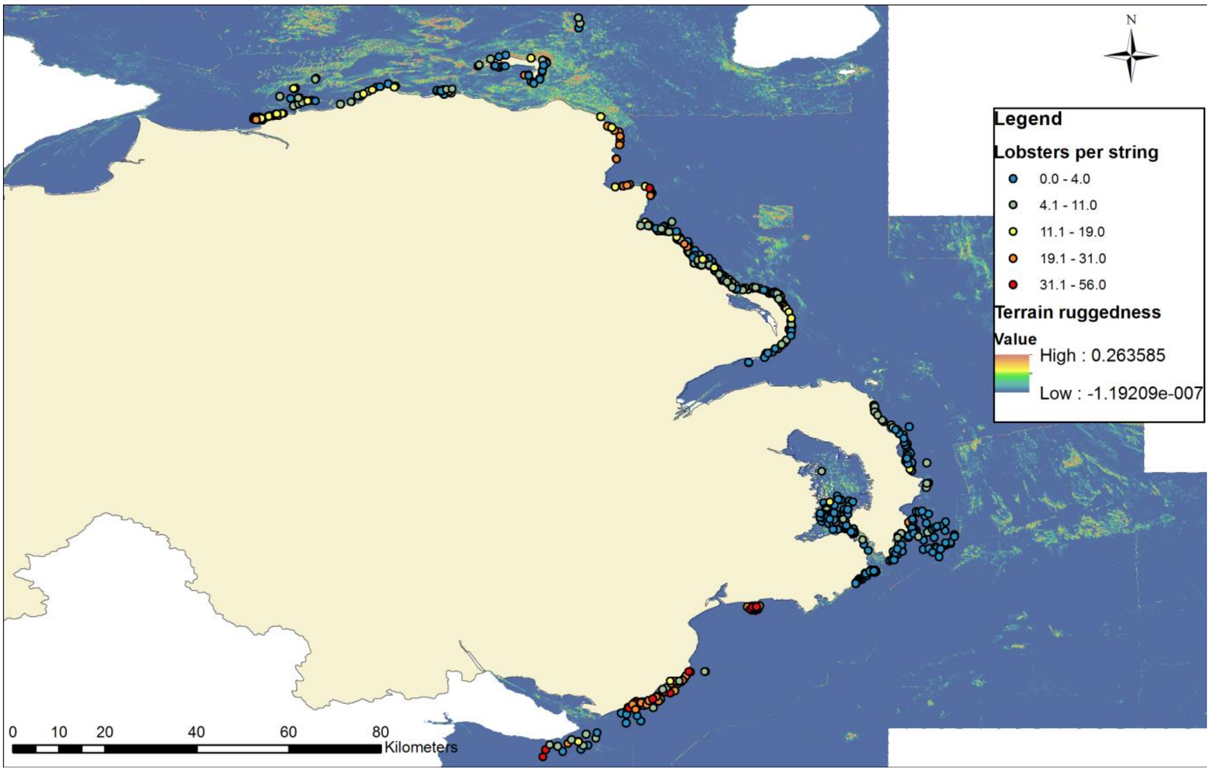


Figure 8: Terrain ruggedness with lobster abundance per string overlain.

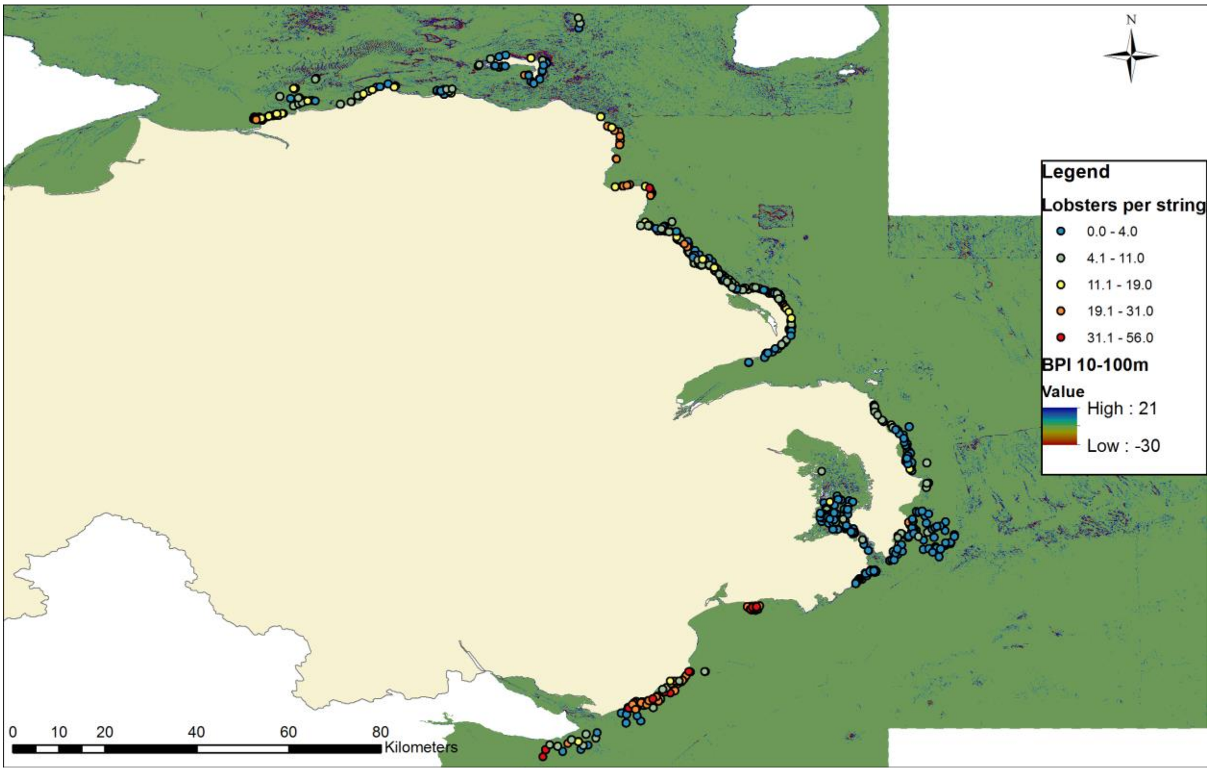


Figure 9: Benthic position index over a 10-100m range showing crests (positive values) and troughs (negative values) with lobster abundance per string overlain.

3.5 Genetic Analysis

3.5.1 Lobster sampling

The NELCO v-notching scheme, employing DNA profiling (carried out by QUB), has been running continuously since its implementation in September 2003 with DARD support (individual grant-aid to NELCO). The NELCO fishing area roughly covers both the County Down and Outer-Ards fishing areas and part of the Belfast Lough (Figure 4). As part of the scheme, from each berried female, both the v-notch and a sample consisting of 20-150 fertilised eggs have been non-destructively removed and stored in a labelled vial containing 98% molecular grade ethanol (storage buffer). Every berried female carries thousands of eggs and many of these are naturally lost during the maturation period in the wild. Thus, the removal of a small number of eggs has negligible impact on individuals. Furthermore, because individuals were rapidly returned to the sea following the procedure, egg losses were substantially reduced in comparison to previous procedures involving confinement and transportation of berried lobsters in cages. A standard V-notching tool is used by all NELCO members participating in the scheme to ensure consistency (adequate amount + quality) of biopsy material for subsequent DNA work.

The large number of samples involved in this project (over 2,000 lobsters/year since the start of the project), required the implementation of appropriate procedures for data handling. Thus, emphasis was given to the elaboration and implementation of a robust coding system that allowed for authentication and location of origin of all biological material to be screened subsequently linking to genetic data. In addition to information on the sampler (i.e. lobster fishermen), location and date of sampling, for every individual v-notched female, carapace length (mm) was also recorded.

Over the 11 years covered by the scheme, 26,473-berried lobsters have been v-notched by NELCO members (average 2,206 lobsters v-notched every year). Considering that, each sample may have 20-150 eggs provided with each v-notch, the total number of eggs sampled in the period of the scheme ranged between 529,460 and 3,970,950.

Since 2013 (period covering the present report), the NCLFA association has also adopted the genetic tagging approach for lobster v-notching and, following similar methodology described above for NELCO, has provided QUB with v-notched tissue and associated fertilized eggs for 7,097 lobsters from the County Antrim coastline of Northern Ireland (Figure 4) covering the 2013-2015 fishing period. In addition to the v-notching scheme currently undertaken by NCLFA, all samples (N=424) linked to the physical tagging scheme have also been non-destructively sampled for genetic analyses. Genetic samples from the physical tagging scheme have also been collected from the NELCO fishing area.

3.5.2 DNA extraction and microsatellite DNA profiling

Genomic DNA was extracted from the v-notch of all females and eggs (or tip of the walking leg for the NCLFA tagging scheme) using the Promega Wizard DNA Purification system (http://www.promega.com) following routine protocol for processing large number of samples implemented at QUB. Samples (i.e. resulting individual lobster genomic DNA) were screened for a panel consisting of 11 highly informative microsatellite marker loci developed during previous lobster study led by QUB (Ferguson, *et al*. 2002 http://www.qub.ac.uk/bb-old/prodohl/GEL/gel.html). Multiplex PCR reactions for microsatellite screening were carried out in 3.5 µl volumes consisting of 1 µl of template genomic DNA (5-12 ng), 1.75 µl of plain PP mastermix **(**http://www.top-bio.com) and varying concentrations of both fluorescent labelled (FAM, NED, VIC or TED) and non-labelled primer for each of the 11 marker loci analysed. Double distilled water was used to complete the volume of the reaction. PCR thermo-cycling consisted of 1 cycle at 95°C for 5 min followed by 35 cycles of 95°C for 1 min, 57°C for 30 s and 72°C for 90 s, and 1 final cycle at 60°C (further details of PCR chemistry can be obtained from Prof. P. Prodöhl at QUB). Fragment analysis was carried out on a 96 capillary ABI 3730XL DNA analyser with a 16-plate stacker. Genotyping (i.e. allele calls) was subsequently carried out using GeneMapper version 4.1 (Applied Biosystems).

To account and correct for possible genotyping errors that could compromise family analysis and parentage assignment, all genotyped lobsters and their respective eggs were verified for genetic match (i.e. each offspring/egg has to share one allele with the "mother" at all microsatellite marker screened) using a custom build Excel function (P. Prodöhl, pers. Comm.). This checking procedure greatly reduced the incidence of genotyping error in the family parental pool.

3.5.3 Statistical Analyses

Standard genetic diversity statistics for the lobster samples (e.g. expected and observed heterozygosity, mean number of alleles per locus, mean proportion of loci typed and the mean polymorphic information content) were estimated for the first lobster parental pool (i.e. lobsters families v-notched between 2003 and 2004) using the computer program *FRANZ* (Riester *et al*., 2009). *FRANZ* was also used to estimate the potential usefulness of the marker set i.e. exclusion probabilities (per locus and combined over loci) for parental analysis for: 1) the first parent known, 2) second parent known, and 3) parent pair known. As an additional assessment of the usefulness of the markers for parentage analysis, we tested their power to distinguishing between related and unrelated lobster individuals using the software Kingroup (Konovalov *et al*. 2004). While considerable effort was invested trying to avoid genotyping errors, given the size of the data set (i.e. over 300,000 genetic data points) it is extremely difficult to prevent at least some error in the data. In order to allow for a full evaluation and to incorporate this source of uncertainty in the parentage analysis, the genotyping error within the data set was estimated both from the empirical data, and from simulated analysis using the likelihood-based computer program *Colony* (Jones and Wang, 2009).

To examine possible impact(s) of the fishery in the local lobster stock, differences in genetic variability over time was tested (i.e. temporal stability of the genetic make-up of samples during the period of the project) for the 11 microsatellite loci for samples v-notched yearly from 2003 to 2014. This analysis was carried out using *diveRsity* (Keenan *et al.* 2013). The null hypothesis was that the fishery effort carried out by NELCO has had no impact on the genetic composition of the local stock. Deviations from Hardy Weinberg Equilibrium and Linkage disequilibrium (non-random association of alleles between marker loci) were carried out using the software package *GENEPOP* on the web Version 4.2 (Rousset, 2008).

3.5.4 Paternal/family reconstruction

The parental pool of 2003 and 2004 is comprised of 1,546 “mothers” and their associated eggs/offspring (average of 5.44 offspring per “mother”), thus comprising >9,900 lobster samples (mothers and eggs). For each family (i.e. dyad comprising of mother and known offspring), *Colony* (Jones and Wang, 2009) was used to identify the most likely paternal alleles per locus using genetic profiles from “mother” and offspring. A new computer programme (‘*FindMyDad*’, for details contact P. Prodöhl) was specifically written to recover this information (i.e. paternal alleles) from *Colony* and to generate multi-locus genotypes (i.e. inferred genetic profiles) for the most likely “fathers” for each lobster family screened. This custom-made programme also prepares input files for downstream parentage analysis using *FAP* (Family Assignment Program, Taggart, 2007). The result of this analysis is a data set comprising 1,546 families (i.e. genetic profiles for each v-notched female and associated male reconstructed genotype) that can be used for parentage assignment (i.e. testing whether unknown fish is the offspring of any of the families in the NELCO dataset).

3.5.5 Parentage assignment

For parentage assignment, which was based on the parental pool of 2003-2004, two independent methodological approaches were employed. The primary approach was based on the *Family Assignment Program* (*FAP*, Taggart, 2007), which is simply based on exclusion principles and assumes that all parental genotypes are known (i.e. the present design). *FAP* carries out two related tasks – *Predictive* and actual *Assignment*. In *Predictive* mode, *FAP* assesses the resolving power of the specific parental genetic data (i.e. the set of families available in the data set) to unambiguously assign a given offspring to a particular family. The outcome of the predictive analysis is the probability that, based on the available genetic information per family, progeny can be assigned unambiguously to family of origin. In *Assignment* mode, the family database (i.e. genetic family database) can be queried with potential progeny genotypes for family assignment. *FAP* allows for potential genotyping "error" to be included in the analysis to prevent missing relevant information (i.e. the exclusion of a true parental match).

To assess the power of the lobster genetic markers for parentage analysis, the lobster family 2003-2004 parental pool was run, using *FAP* in *Predictive* mode, with both the full complement of marker loci (i.e. 11) and with the 6 more informative (based on exclusion probability) markers. For this analysis, we allowed for a maximum of two and three allele mismatches respectively. For the *Assignment* mode, *FAP* was run with the full complement of marker loci. Time to recruitment stage (in here defined as 87mm minimal legal size for landing) in lobsters is related to growth rate and is highly variable in lobsters often occurring between the ages of five to nine years (Bannister *et al*., 1994; Sheehy *et al*., 1999; McCandless and Stockdale, 2004; Tully, 2004; Wahle *et al*., 2004). In here, allowing time to recruitment, we started testing (i.e. parentage assignment) lobsters from the fishery against the 2003-2004 parental pool from 2007 onwards (i.e. minimum of four years from hatching).

To account for the fact that *FAP* does not consider potential parents not included in the family database in the analysis (i.e. un-sampled berried lobsters also potentially contributing to the stock); parentage analysis was also carried using *FRANZ*, a Bayesian based family reconstruction software. This computer program has the advantage of using prior information (e.g. known relationships, age of individuals and sex) to determine genetic relationship between/among individuals in natural populations. The program algorithm can use the available genetic data to assess the potential effect of un-sampled parents in parentage assignment and also to provide an estimate of the effective number of breeding parents in the stock. To examine the accuracy of *FRANZ* for lobster parentage assignment, we initially tested its power to assign known offspring (i.e. genotyped eggs from the 2003-2004 cohort) against the 1,546 families from the 2003-2004 parental pool in the NELCO database. Considering some element of circularity (i.e. paternal genotypes were reconstructed from genotypes of both mother and offspring), we also used *FRANZ* for maternal assignment only but using known offspring (full-sibs) to assist with the maternal assignment. Thus, if an "unknown" lobster from the fishery assigns with a high probability to a "mother" within the parental pool and also shares strong genetic ties with this "mother's" known offspring, there is high probability that the "unknown" lobster is also an offspring.

.

4. Results

4.1.1 Landings Data - Northern Ireland Pot Fishery – All Species

The total value of the Northern Ireland pot fishery, between 2006 and 2014, is summarised in Figure 10. During this period, landings peaked in 2014 with a total of over 1,500 tonnes of mixed species landed with a first sale value of almost £2.5 million. In 2014 landings by pots were made in to 28 ports/harbours (Figure 11 shows the location of the main ports/harbours). A breakdown of the total value (£) of the Northern Ireland pot fishery in 2014, related to the port of landing, is summarised in Figure 12. The ports which contributed the most to the total value of the pot fisheries in 2014 landings were Kilkeel (33%), Portavogie (11%), Annalong (11%) and Portaferry (7%). Eleven of the ports attributed less than 1% to the total pot landings value.

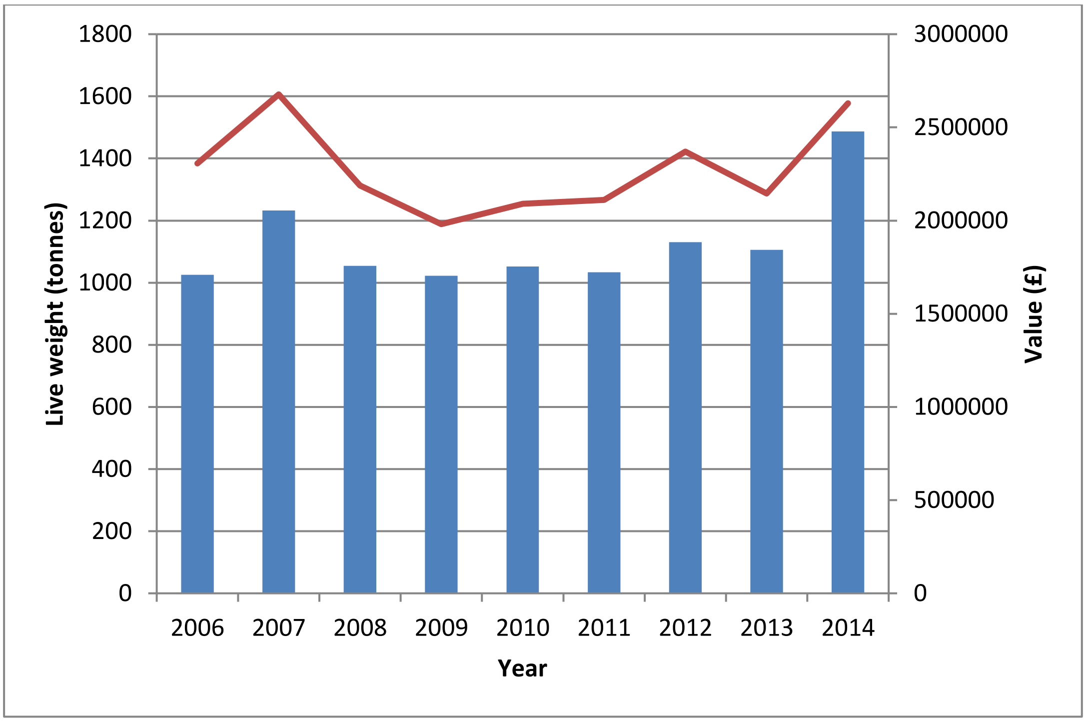


Figure 10: Total tonnage of all species landed by pots between 2006 and 2014 (blue bars) and the total value, £, of these landings (red line) (Source: DARD landings figures)

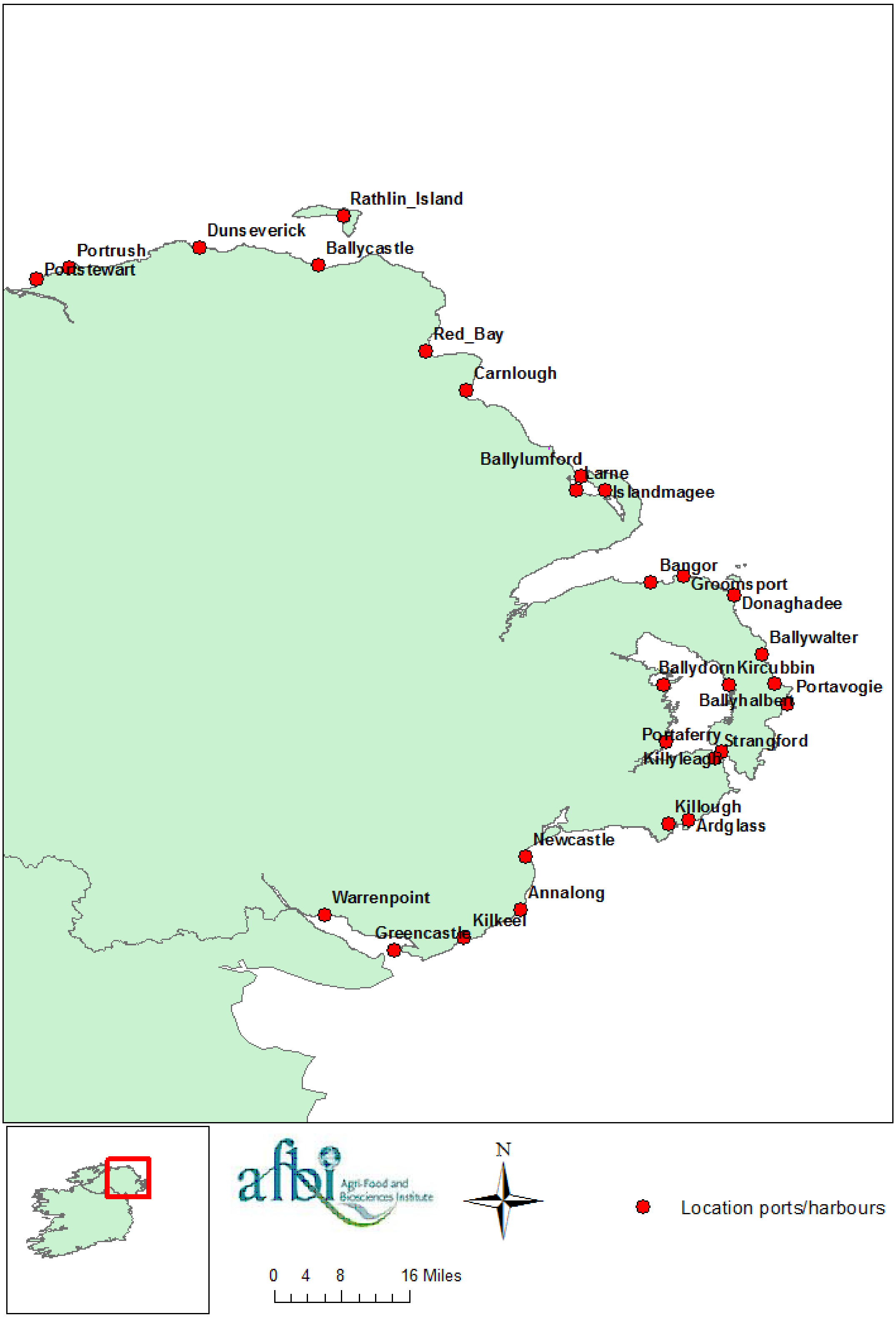


Figure 11: Location of the main ports/harbours were there are landings of pot caught species (Geographic projection: WGS 1984)

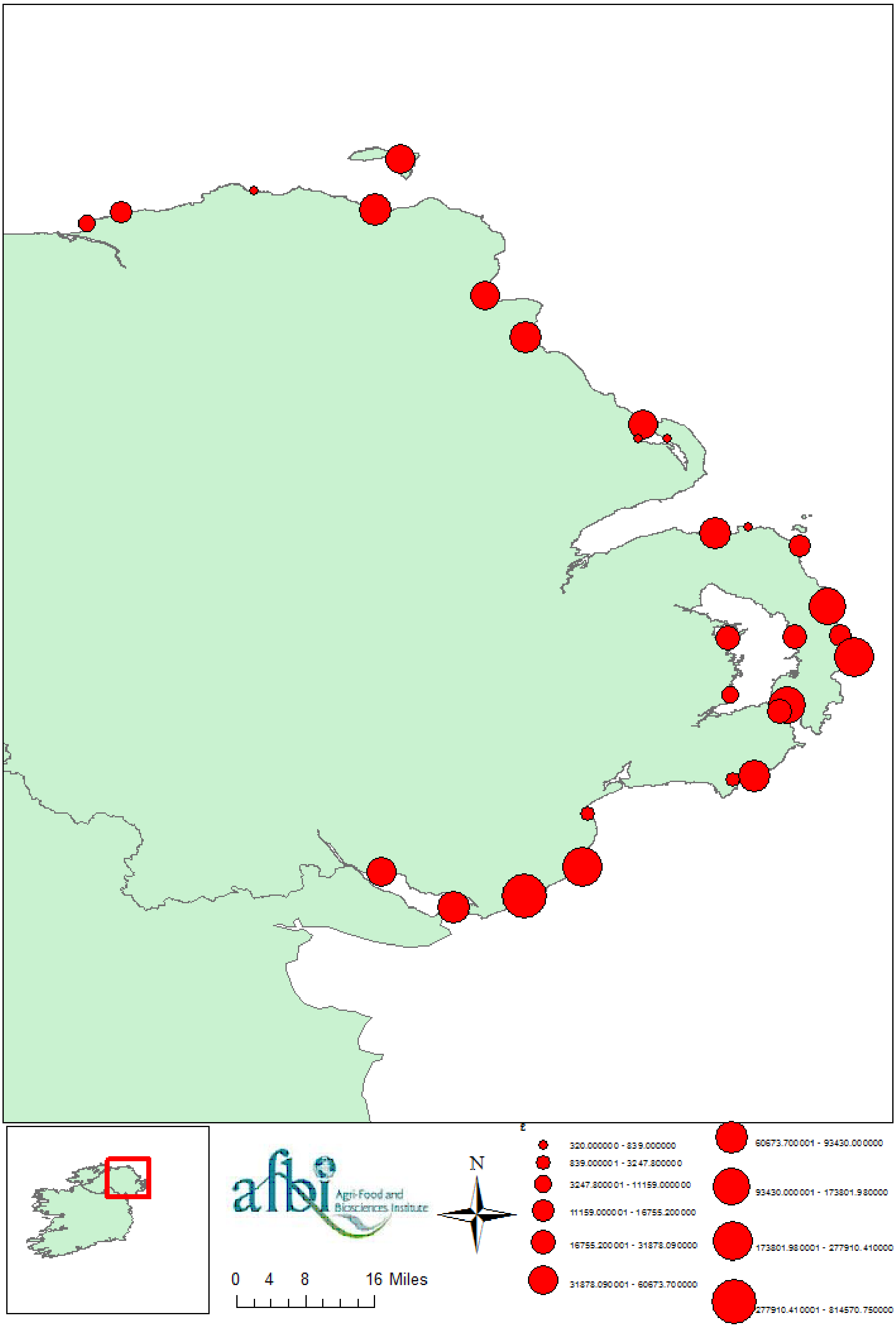


Figure 12: Value (£) of catches of all species landed by pots into Northern Ireland in 2014 (Geographic projection: WGS 1984)

Although pot fishing is considered a mixed fishery (i.e. pots are unselective as to what they catch), in Northern Ireland there are distinctive patterns in the primary catch from pots (Figure 13). Along the County Down coast, the main catch is comprised of brown crab and lobsters. In Strangford Lough and the Ards Peninsula catches are more mixed but the main catch is velvet crab and *Nephrops*. Catches from both the North and Antrim coasts have a comparatively higher proportion of lobsters.

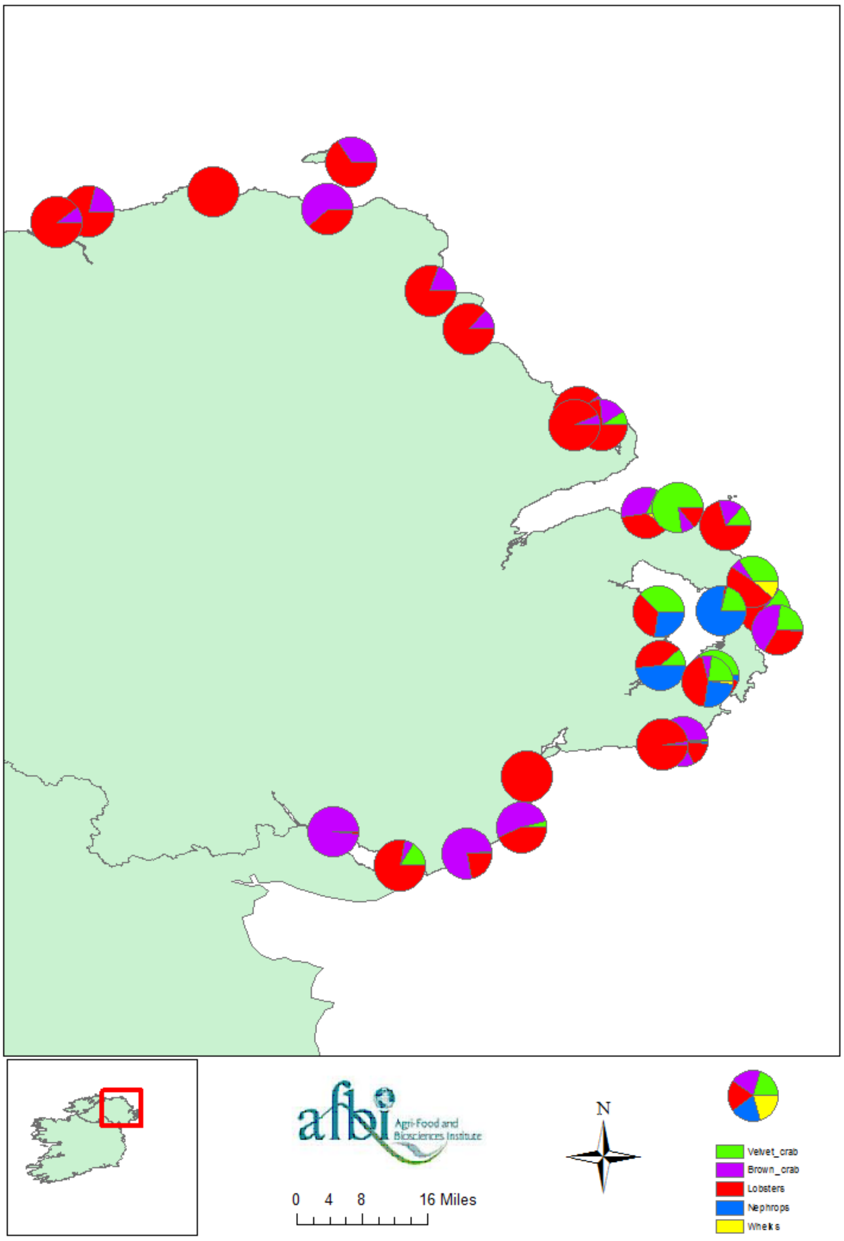


Figure 13: Geographical distribution of pot catches displayed as comparative proportions of the five main targeted species around Northern Ireland in 2014 (Geographic projection: WGS 1984).

Between 2006 and 2014, brown crab (*Cancer pagurus*) has consistently made up the highest tonnage of any individual species landed by pots (Figure 14). In 2014, 1,074 tonnes of brown crab were landed in Northern Ireland, which accounted for 68% of total pot landings. Velvet crabs were the second highest species landed in terms of live weight (8% of total landings) and lobsters the third highest with 111 tonnes landed, which represents 7% of the total pot landings in 2014.

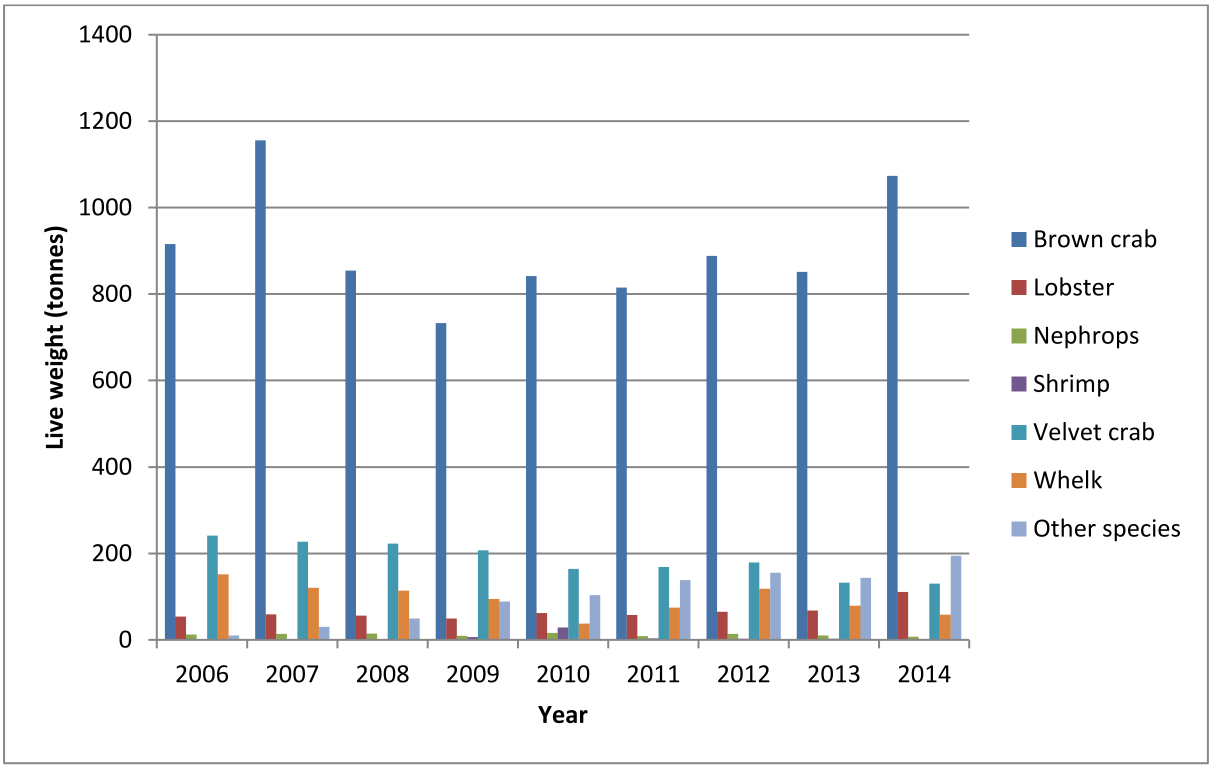


Figure 14: Live weight (tonnes) of each species landed by pots between 2006 and 2014 (Source: DARD landings figures)

In terms of landed species value (Figure 15), while brown crab is still the highest contributor to the overall value of the pot fishery, its relatively low value per weight (£1.03 per kilo in 2014 based on DARD valuation). Thus, while the species made up 68% of live weight value in 2014, it accounted only to 45% of the monetary value (i.e. value per weight). The high value of lobsters (£8.25 per kilo in 2014 based on DARD valuation) makes it the second largest contributor to the overall value of the 2014 pot fishery. Velvet crab were the third highest landings in terms of monetary value attributing 10% of the total 2014 pot fishery value, with an estimated price of £1.87 per kilo based on DARD valuation.

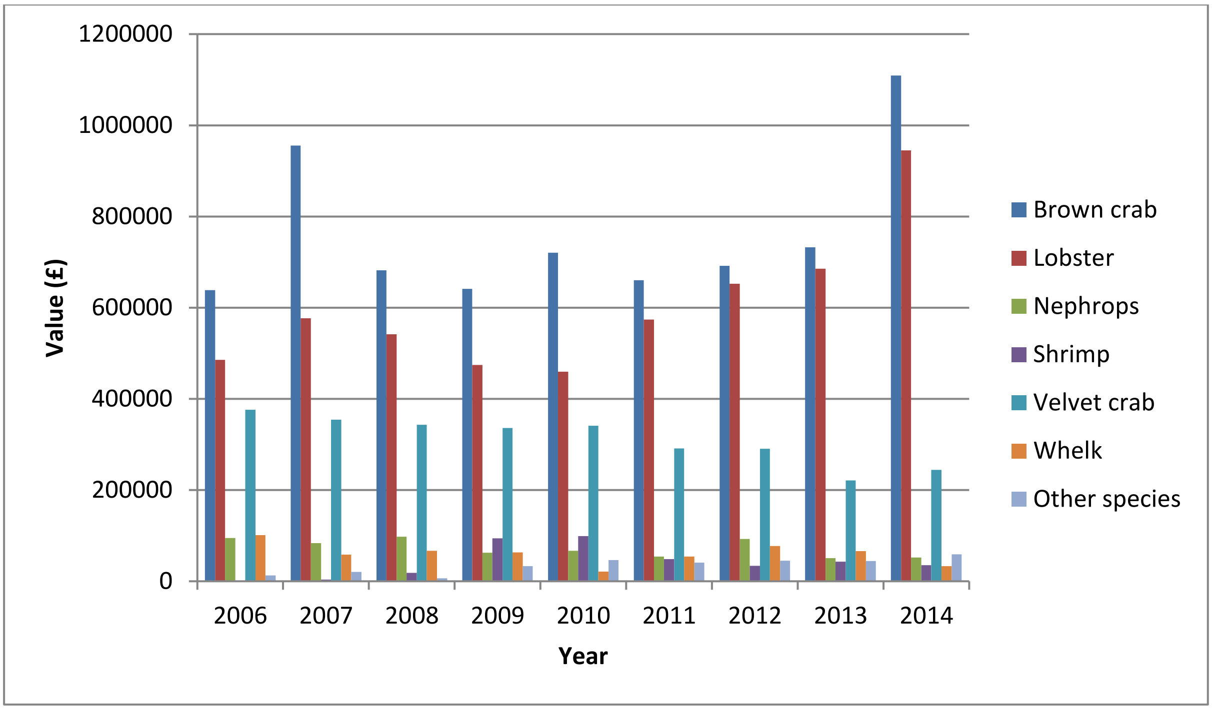


Figure 15: First sale value (£) of each species landed by pots between 2006 and 2014 (Source: DARD landings figures)

During 2006 and 2014, 240 vessels landed species caught by pots into Northern Ireland. The majority of these vessels (92%) were less than 10m in length. From 2013 it is a legal requirement under EU regulations that all vessels greater than 12m in length have a vessel monitoring system (VMS) onboard. From this time, less than 2% of vessels fishing pots have been affected by this requirement. The annual number of boats fishing pots from 2006 to 2014 averaged at 140. Boats from Kilkeel, Portavogie, Portaferry and Annalong make up almost 50% of all of the boats fishing pots. Figure 16 shows the number of vessels fishing out of each port between 2012 and 2014.

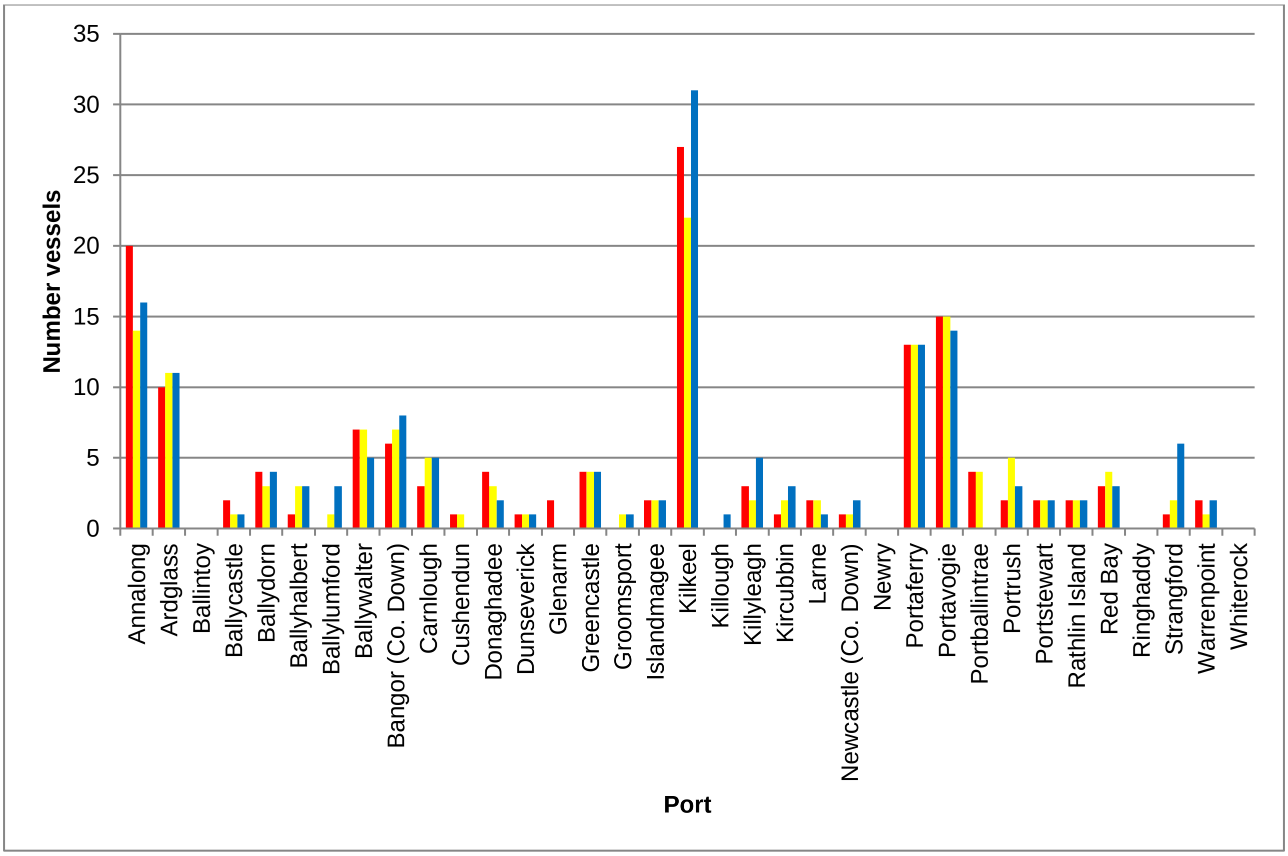


Figure 16: Number of vessels fishing out each port between 2012 (red), 2013 (yellow) and 2014 (blue)

4.1.2 Landings data - Lobster landings

Figure 17 shows the landings of lobsters into the United Kingdom between 1953 and 2013 whilst Table 2 shows the landings of lobsters into Northern Ireland between 2006 and 2014. While the landings declared for Northern Ireland are only a small fraction of the UK total, 2% in 2013, it is, nevertheless, extremely valuable to the Northern Ireland economy.

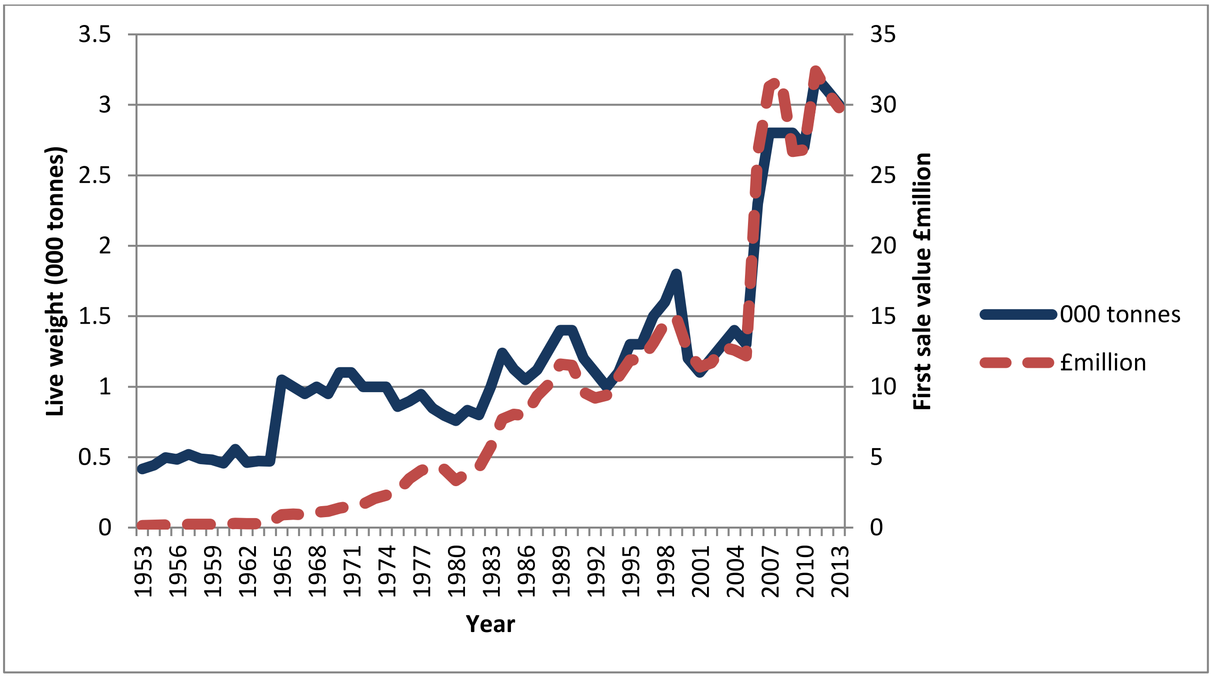


Figure 17: Landings of lobsters into the United Kingdom by UK vessels from 1953-2013 (Source: Marine Management Organisation)

Table 2: Landings of lobsters into Northern Ireland between 2006 and 2014 (Source: DARD landings figures)

Year	Live Weight (Tonnes)	Value (£)
2006	55	485,480
2007	59	577,062
2008	56	541,985
2009	49	474,064
2010	62	459,749
2011	58	573,647
2012	65	652,343
2013	68	685,662
2014	111	944,874

As outlined above, lobster landings are the third most important pot caught species in Northern Ireland in terms of live weight landed, and the second most important in terms of the monetary value of species landed. Figure 18 shows the percentage contribution of lobsters to the total landings by pots (all species) into each port from 2012 to 2014. Lobsters make up the highest proportion of total landings for both the North Coast and Antrim Coast (Table 3). From 2012 to 2014 lobsters were the only species landed into Dunseverick on the North Coast. In 2014 lobsters made up 100% of landings into Newcastle, County Down.

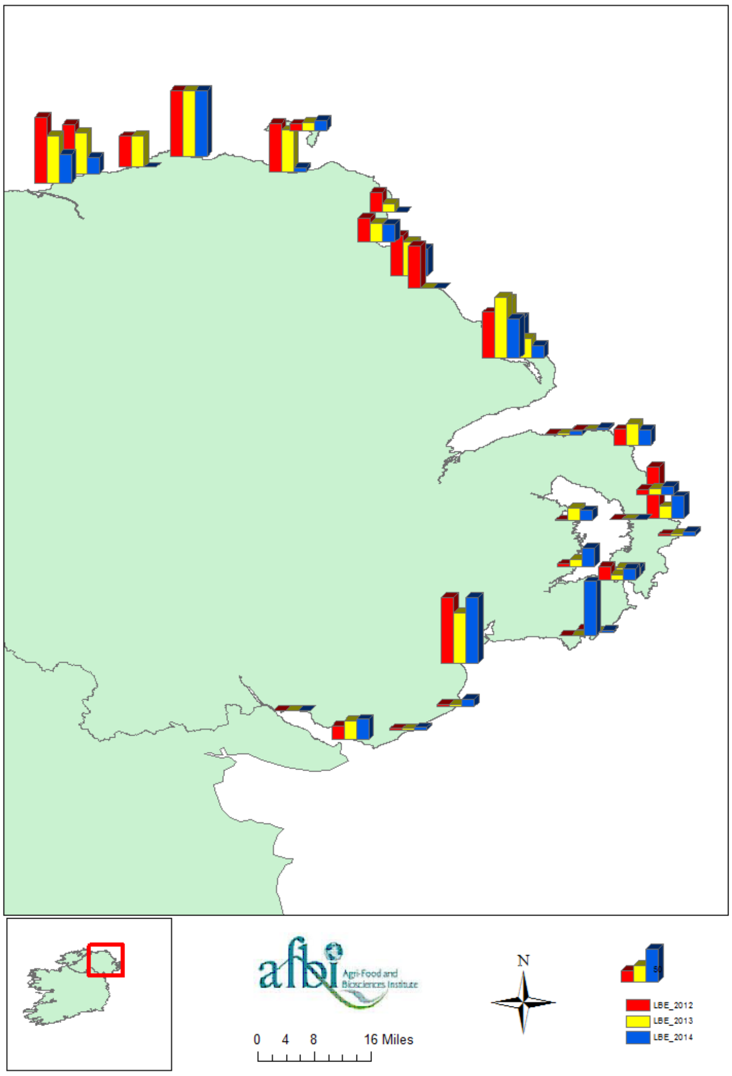


Figure 18: Percentage of total pot landings into each port which is attributed to lobsters in 2012 (red), 2013 (yellow) and 2014 (blue) (Geographic projection: WGS 1984).

Table 3: The average contribution of lobsters to total catch from pots for each of the main geographic regions, covered in this report, between 2012 and 2014.

Area	Average 2012 (%)	Average 2013 (%)	Average 2014 (%)
Antrim coast	48.47965	48.04667	38.27371
County Down	26.2907	22.64955	33.03041
North Coast	67.50712	59.55099	37.90419
Outer Ards	23.08469	11.25006	14.31851
Strangford Lough	7.445344	10.09034	14.44402

In 2014 lobsters were landed in to 28 ports with Annalong having the biggest landings (25 tonnes representing 22% of total lobster landings in 2014), followed by Kilkeel (18 tonnes) and Portavogie 10 tonnes. Figure 19 shows the landings of lobsters into each port between 2012 and 2014.

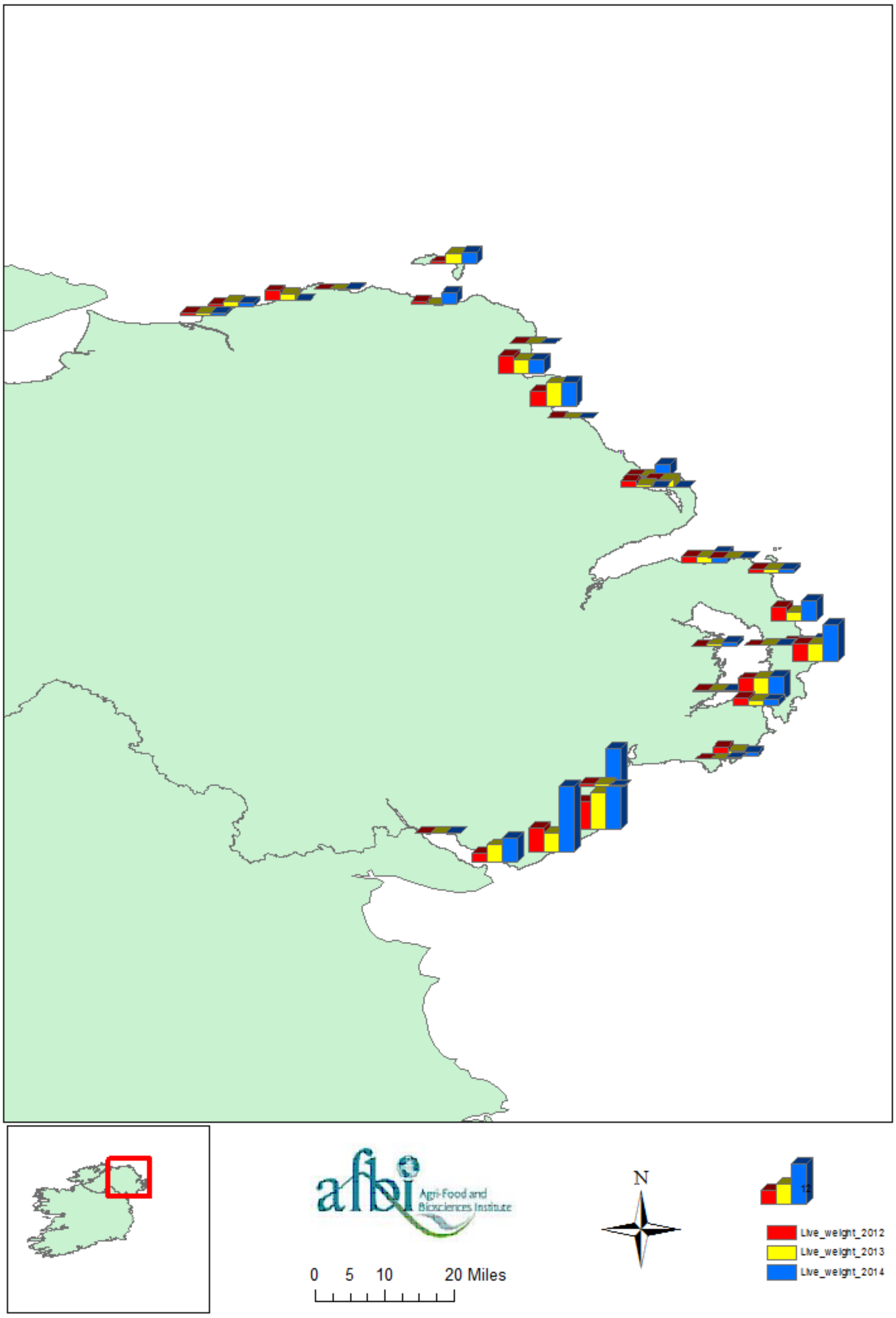


Figure 19: Lobster landings (tonnes) by port 2012 (red), 2013 (yellow) and 2014 (blue) (Geographic projection: WGS 1984)

Between 2006 and 2014 the average number of vessels annually landing lobsters was 108, ranging from 95 in 2006 to 120 in 2011, with some vessels landing lobsters in to more than one port in any given year (Figure 20). In 2014 112 vessels landed lobsters to ports around Northern Ireland. The majority of these vessels landed into County Down, with only nine vessels reporting landings from the North Coast in 2014 (Table 4). In 2014, Kilkeel had the highest number of vessels reporting landings of lobsters with 27 vessels (Figure 21), followed by Annalong (16 vessels) and Portavogie (14 vessels).

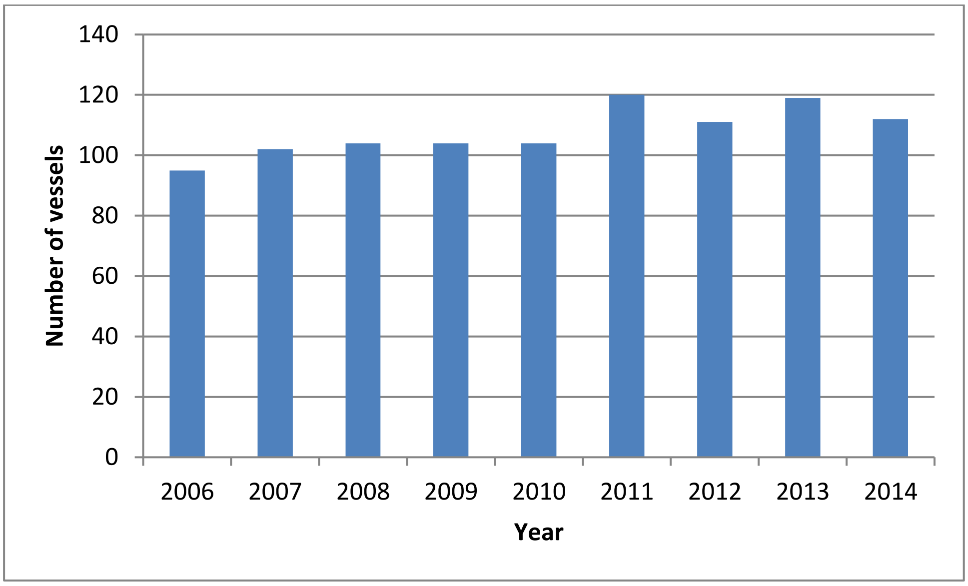


Figure 20: Number of vessels landing lobsters into Northern Ireland between 2006 and 2014

Table 4: Number of vessels landing lobsters into each geographic region covered by this report. Note the number of vessels landing to ports will be greater than the total number of vessels due to some boats landing to several ports in one year.

Geographic Area	2012	2013	2014
Antrim Coast	13	15	14
County Down	53	49	57
North Coast	13	15	9
Outer Ards	29	33	31
Strangford Lough	16	21	25

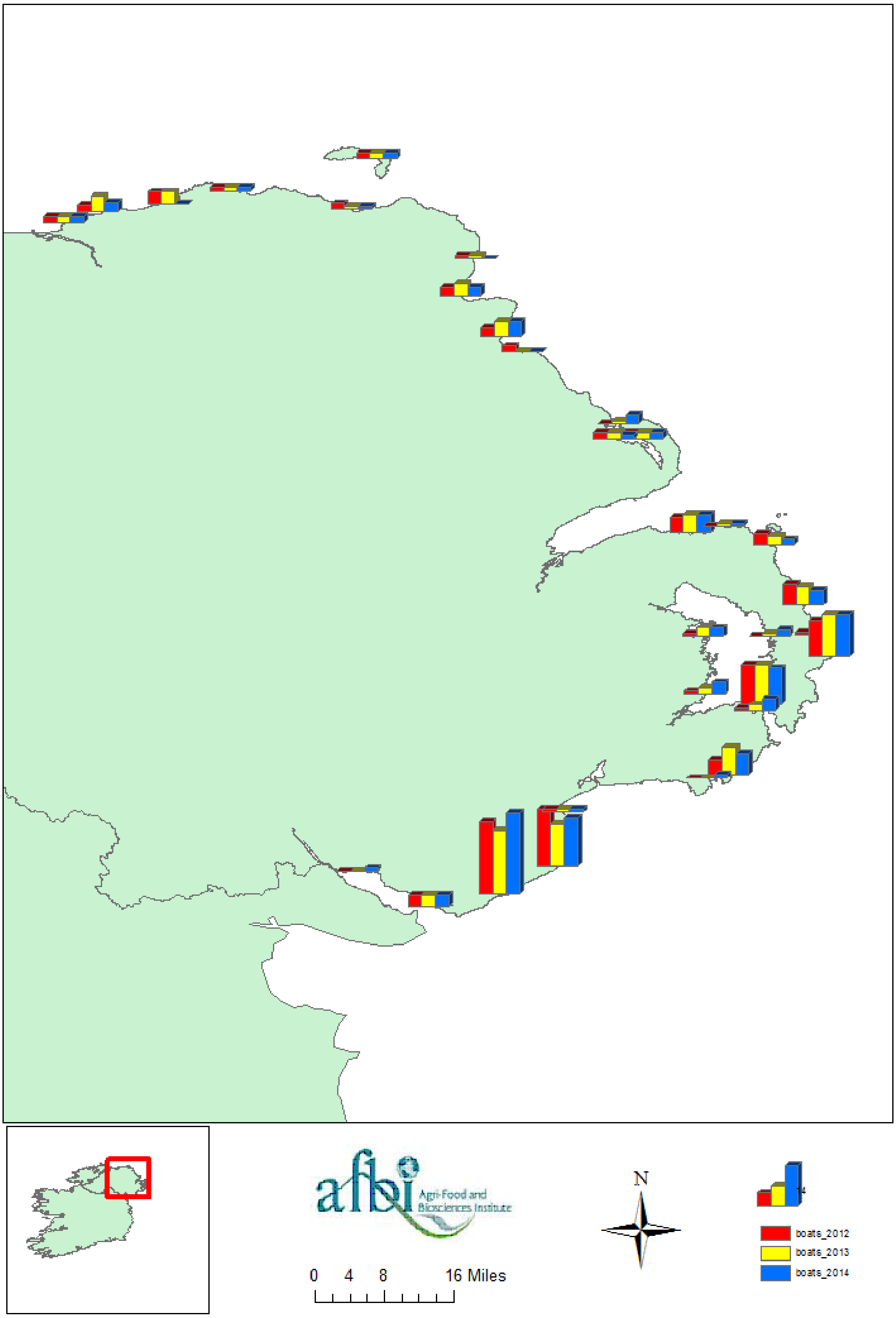


Figure 21: Number vessels landing lobsters into each of the ports between 2012 and 2014 (Geographic projection: WGS 1984)

While the largest lobster landings are in to Kilkeel and Annalong (Figure 19), there is also a higher effort placed on the fishery in these areas. Whilst examining the average catch per vessel (total catch landed into that port divided by the total number of vessels making these landings) still shows Kilkeel and Annalong to have the highest catch rate (Figure 22). However some of the boats fishing out of these ports fish a large number of pots on long strings. Taking this into account, and calculating the average catch of lobsters per pot, these areas have a lower catch per unit effort (CPUE) than on the North Coast (Figure 23). The North Coast, while having lower total landings, also fish a smaller number of pots (the average number of pots fished monthly along the North Coast in 2014 was just over 2,768 as opposed to 6,637 fished along the County Down Coast). The seasonality of catches, effort and CPUE is summarised in Figure 24. Data indicates that in 2014, for the Outer Ards area, there was a large peak in CPUE during the summer months, which was not evident in 2013.

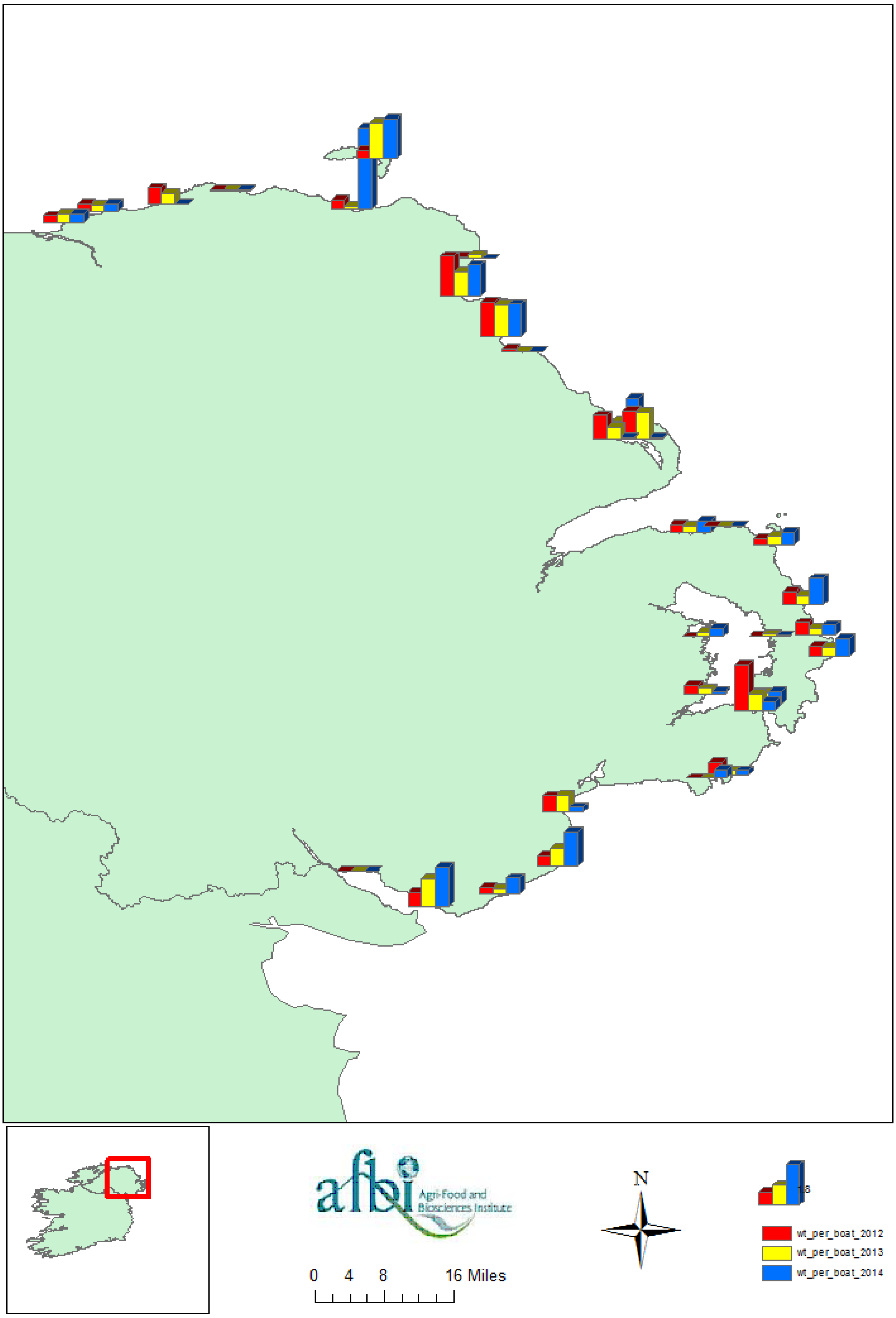


Figure 22: Average landings of lobsters per boat between 2012 and 2014 (Geographic projection: WGS 1984)

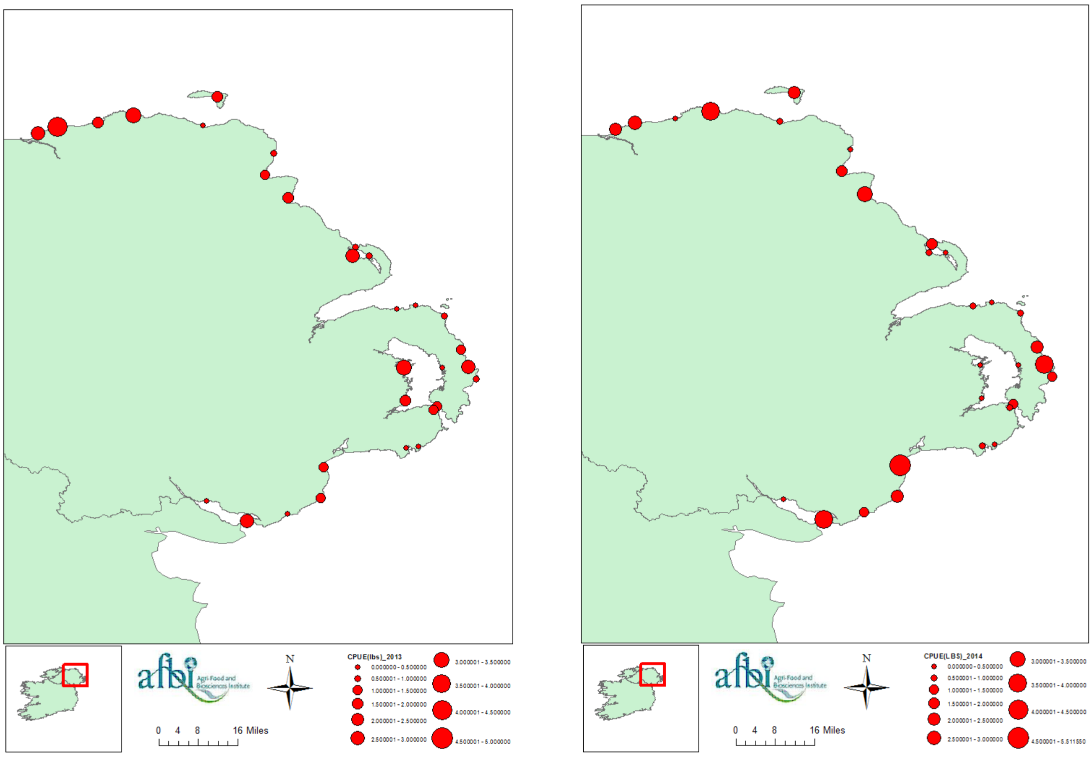


Figure 23: Catch per unit effort (CPUE) of lobsters to ports around the coast of Northern Ireland in 2013 (left) and 2014 (right). Displayed as weight (lbs) per pot. Geographic projection: WGS 1984)

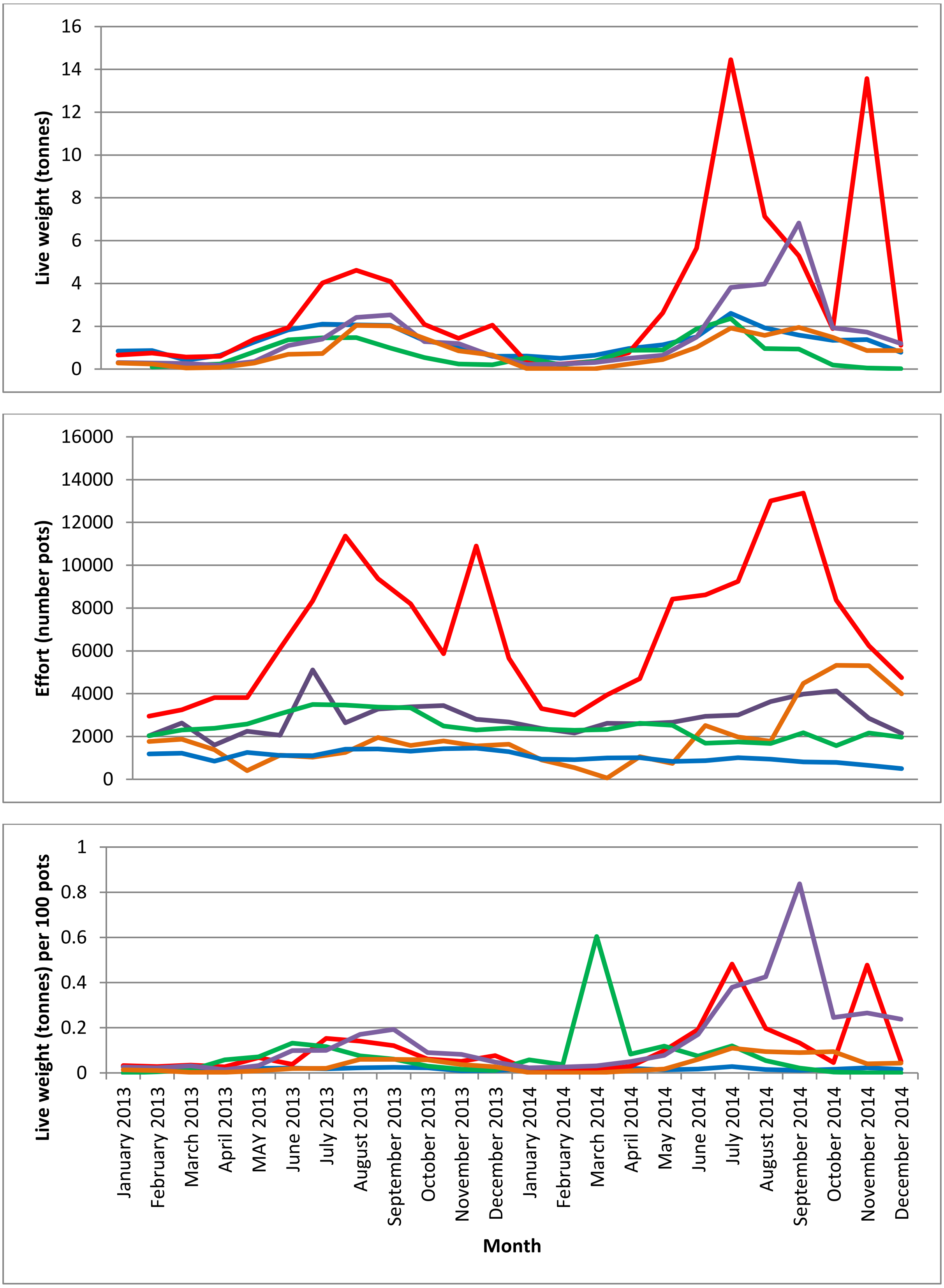


Figure 24: Summary of lobster landings by geographic region between 2013 and 2014 (Antrim Coast – blue, County Down – red, North Coast - green, Strangford Lough – orange, Outer Ards - purple) the total annual effort (number of pots) and the CPUE for each area.

4.2 Data Collection Onboard Commercial Vessels

Between May 2013 and July 2015, 64 observer trips were carried out onboard commercial fishing vessels targeting lobsters. These trips were split up over the geographic areas as shown in Table 5. There is a seasonality to the fishing around the coast. The Antrim coast is the only area where the majority of pot fishermen target lobster all year round. On the North Coast the main season for lobster fishing is April/May to September/October. The less sheltered conditions along the North Coast mean that from October to March the weather is too bad to allow the small vessels regular access to pots. Along the County Down and Outer Ards coast the majority of vessels tend to turn their attention away from lobsters to brown crab around August/September time. In Strangford Lough, which is the most mixed fishery, velvet crabs and pot caught Nephrops are fished alongside brown crab, shrimp and lobster. This seasonality had somewhat of an impact on the observer trips carried out, with more being carried out along the Antrim coast due to the year-round lobster fishing in this area.

Table 5: Number of observer trips carried out at each geographic area.

Geographic Area	Number trips
Antrim Coast	20
County Down	13
North Coast	13
Outer Ards	12
Strangford Lough	6

The number of pots on each string was recorded on the observer trips. On occasions when the number of pots on a string was not recorded, the average number of pots per string for that fisherman was used. From the trips surveyed, County Down had the largest number of pots per string averaging at 24. Strangford Lough had the lowest averaging at eight.

Using the number of pots recorded per string and the catch of lobsters from that string, CPUE was recorded for each trip. The observer work reported seasonality in the CPUE around the coast (Figure 25). Analysis of the available data indicates that the greatest CPUE was recorded for all areas, except Strangford Lough, between the months of July to September. Of the three quarters where data is available for Strangford Lough, the greatest CPUE was recorded in quarter 4 (Q4), October to December.

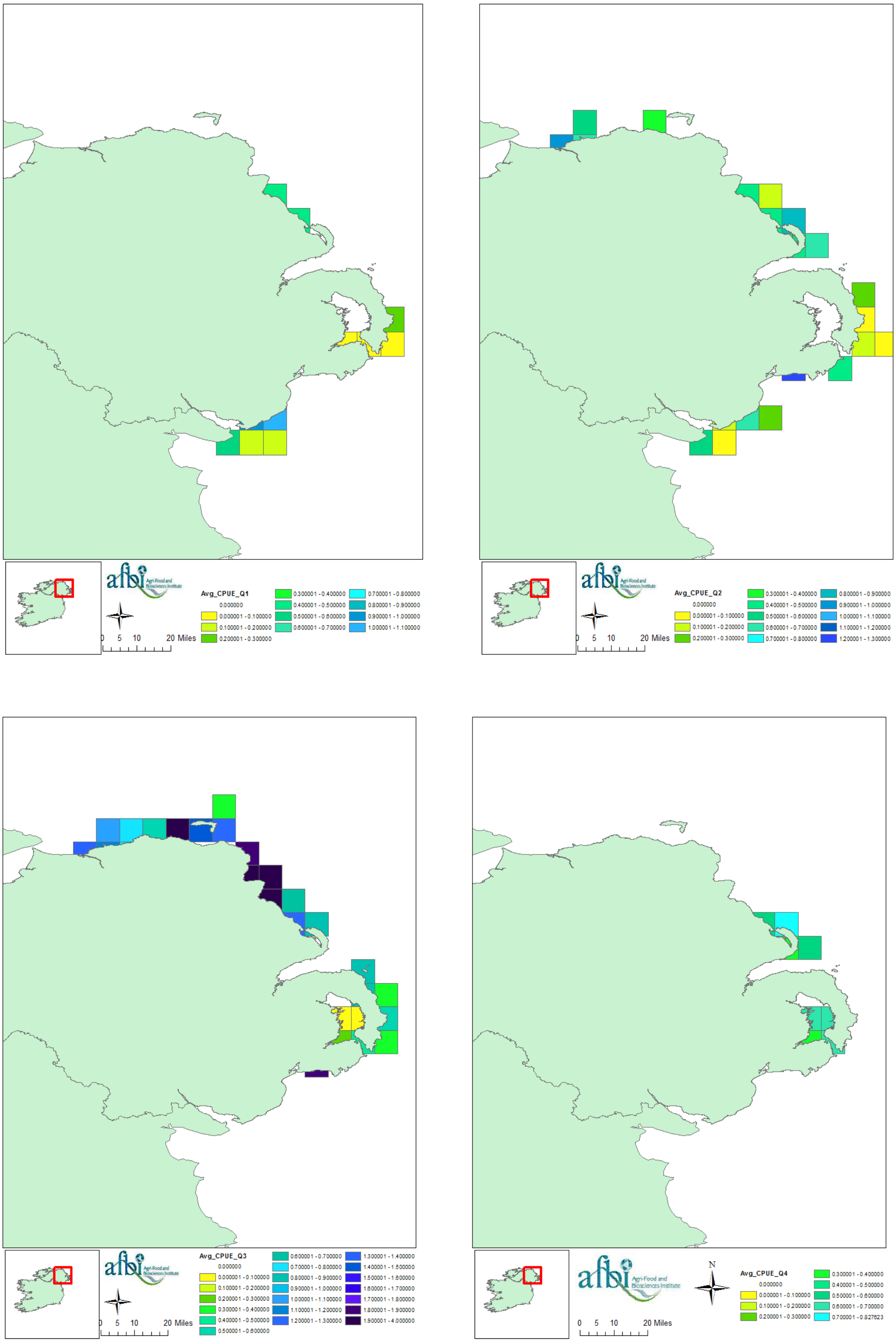


Figure 25: The catch per pot of lobsters recorded by observers by quarter (Q1-January-March, Q2 – April-June, Q3- July-September, and Q4 – October-December). A fishnet was produced with each grid square being 70.7km^2 (Geographic projection: WGS 1984)

The length (CL) of all lobsters caught during the observer trips was measured using callipers. The smallest lobster recorded was 45mm CL and the largest recorded was 168mm CL. Both of these lobsters were caught in Strangford Lough. Length frequency data of lobsters caught from the five different geographic areas is illustrated in Figures 26 to 30 and further summarised in Tables 6 to 10.

For the North Coast, there is a significant difference ($p<0.001$) in carapace length between males and females, with females being significantly larger than males. However, when v-notched lobsters are removed from analysis, there is no significant difference in CL between males and females ($p>0.05$). Therefore, the v-notching scheme in these areas is skewing the length frequency by protecting females in comparison to males. The same observation was noted for the Antrim Coast and County Down areas.

There is no significance in CL between male and female lobsters caught from the Outer Ards or from Strangford Lough. Thus, v-notching does not seem to have an effect on the length frequency from these areas.

There is a significant difference in the CL of females from around the coast both with the inclusion of v-notched females and with their exclusion (Figure 31). Female lobsters from County Down and Antrim coast have a similar CL size but are significantly different from female lobsters from Outer Ards, Strangford Lough and North coast. There is also a significant difference between the lengths of males around the coast (Figure 31). Male lobsters from County Down and the Antrim Coast are similar while those from Outer Ards and North coast are similar. Strangford Lough male lobsters are significantly larger than lobsters from the other regions.

County Down and the Antrim Coast had the smallest average size of lobsters at an average size of female of 82mm and 81mm for males. Lobsters measured from Strangford Lough were on average the largest with female length averaging 87mm and the male length averaging 89mm, both above the MLS (there were no escape gaps on any pots sampled in Strangford Lough which would allow small lobsters to escape the pot and thus increase the average size reported). Figure 32 shows the average carapace length of lobsters landed based on their actual position caught.

Of all the lobsters caught the majority were smaller than the MLS. In County Down only 20% of all lobsters kept were greater than the MLS. The area with the highest percentage of lobsters bigger than the MLS was Strangford Lough where 47.5% of all lobsters were of a landable size (Figure 33).

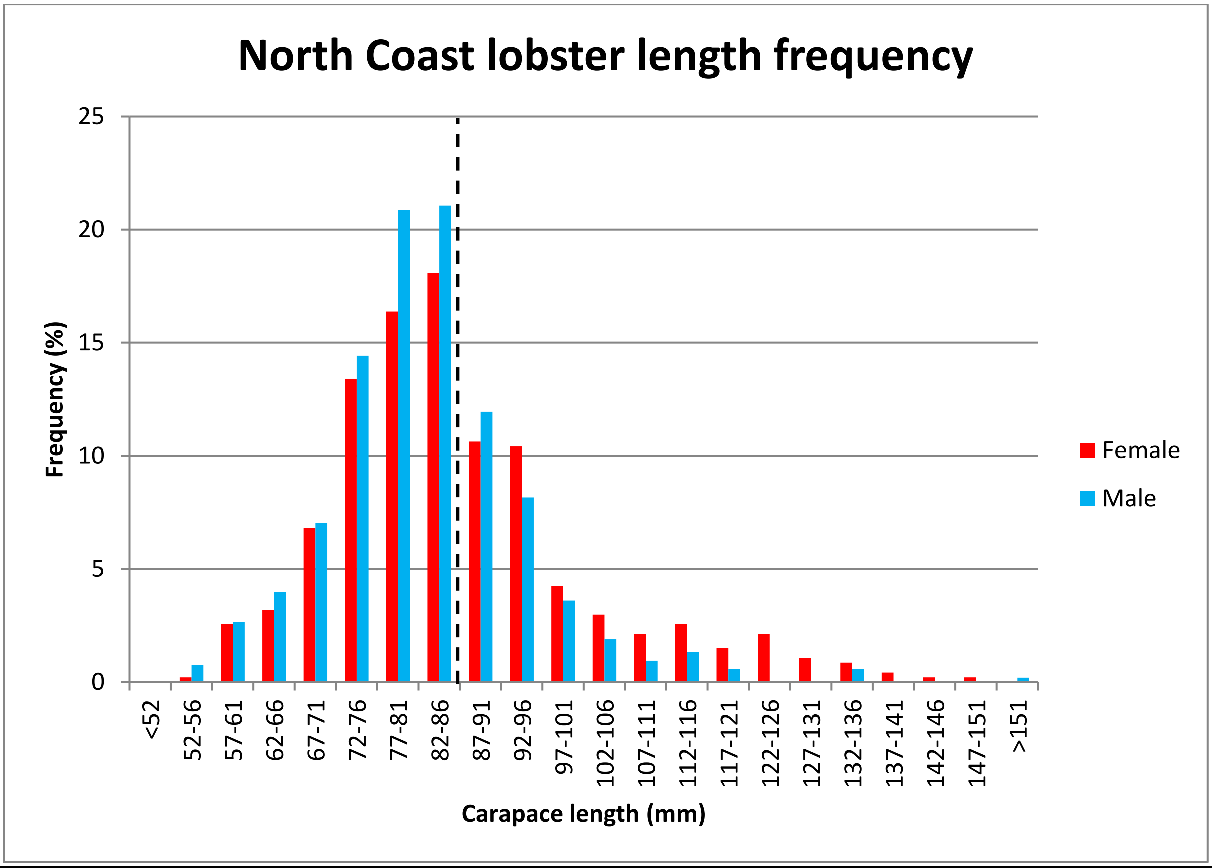


Figure 26: Length frequency of lobsters measured from the North Coast. The dashed line represents the MLS of 87mm.

Table 6: North Coast descriptive statistics – carapace length

	Female (including v-notched)	Male
Number measured	470	527
Average (mm)	86	82
Median (mm)	84	82
Mode (mm)	85	80
Minimum recorded (mm)	55	54
Maximum recorded (mm)	150	155
% MLS or greater (mm)	39	29
% less than MLS (mm)	61	71

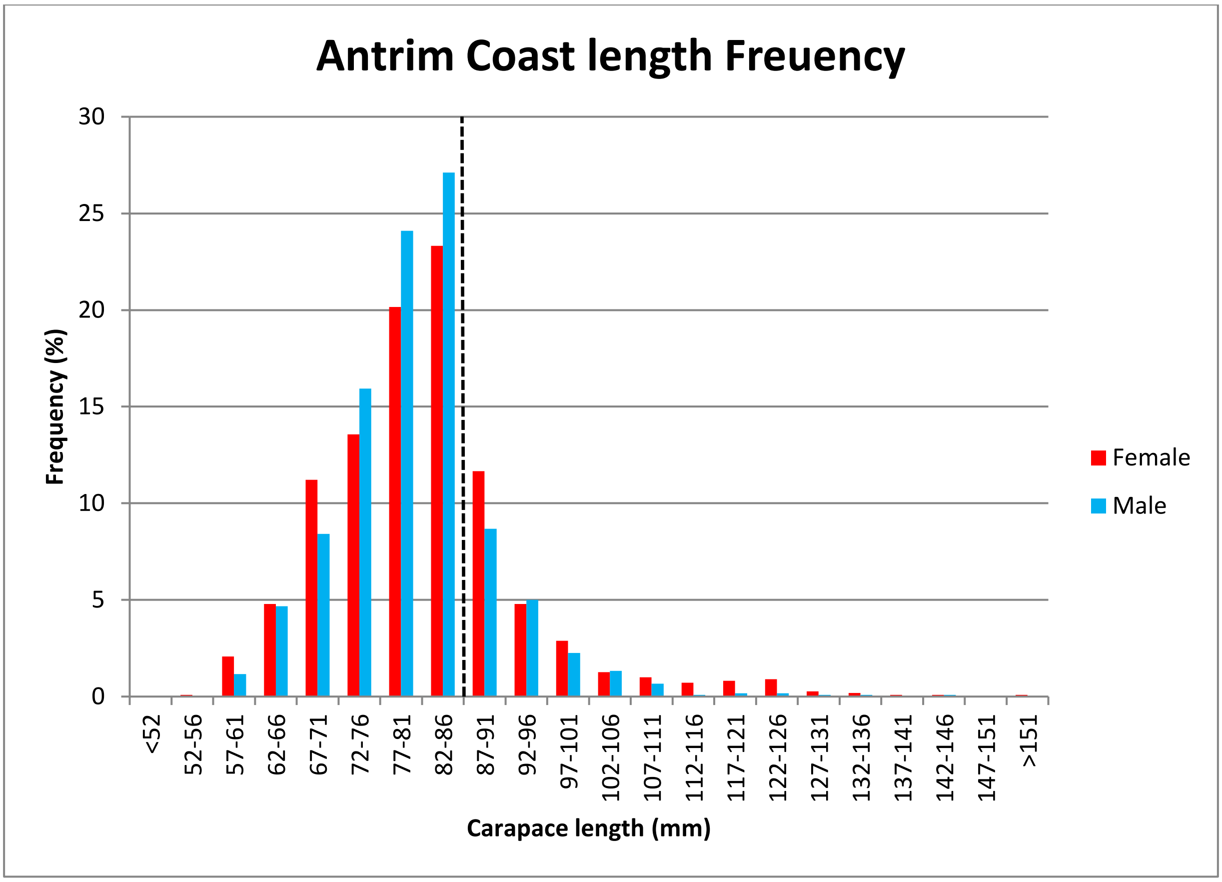


Figure 27: Length frequency of lobsters measured from the Antrim Coast. The dashed line represents the MLS of 87mm.

Table 7: North Coast descriptive statistics – carapace length

	Female (including v-notched)	Male
Number measured	1107	1199
Average (mm)	82	81
Median (mm)	81	80
Mode (mm)	80	80
Minimum recorded (mm)	53	58
Maximum recorded (mm)	159	146
% MLS or greater (mm)	25	19
% less than MLS (mm)	75	81

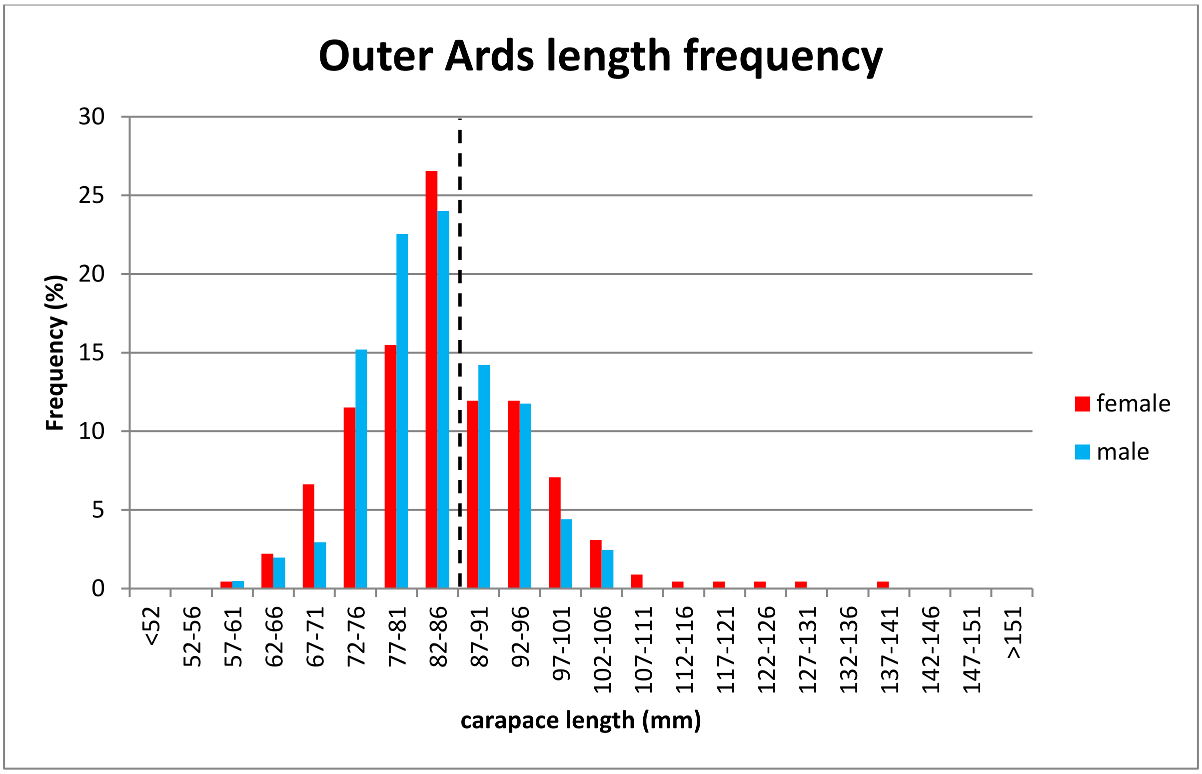


Figure 28: Length frequency of lobsters measured from Outer Ards. The dashed line represents the MLS of 87mm.

Table 8: Outer Ards descriptive statistics – carapace length

	Female (including v-notched)	Male
Number measured	226	204
Average (mm)	85	84
Median (mm)	85	82.5
Mode (mm)	85	81
Minimum recorded (mm)	58	61
Maximum recorded (mm)	140	106
% MLS or greater (mm)	37	33
% less than MLS (mm)	63	67

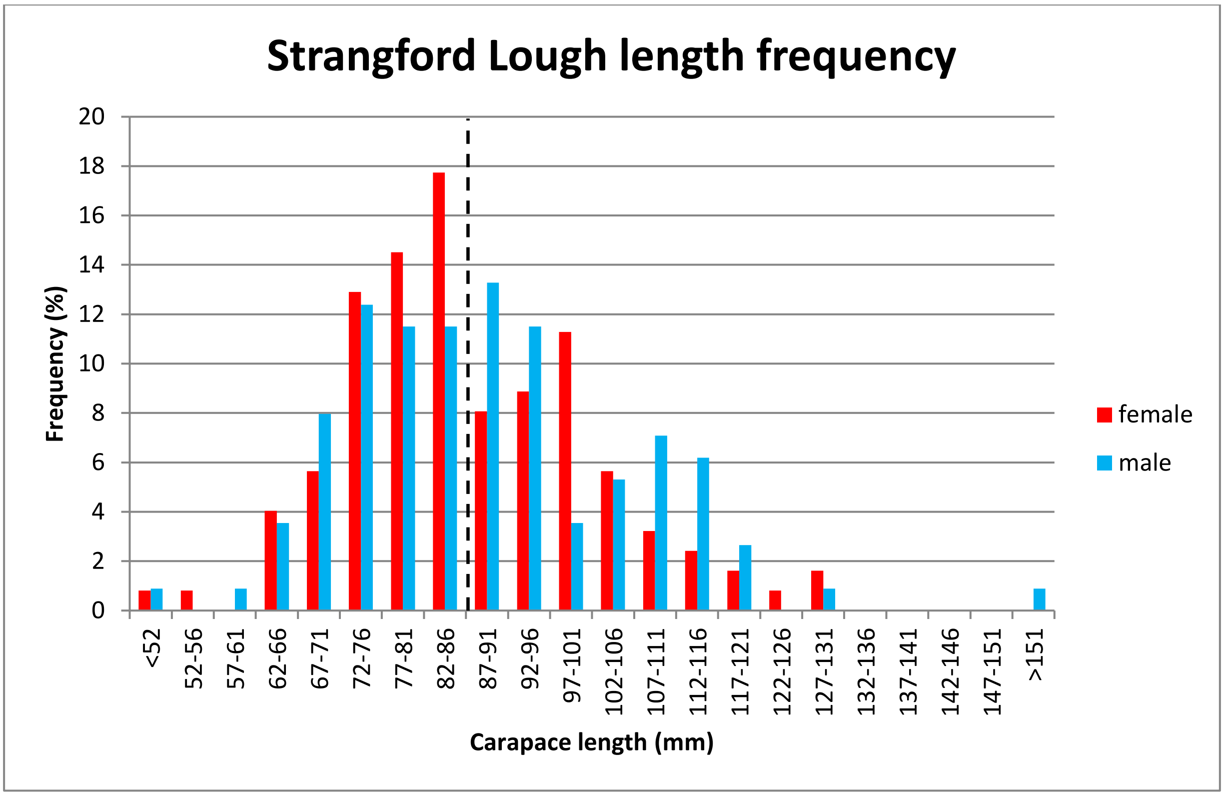


Figure 29: Length frequency of lobsters measured from Strangford Lough. The dashed line represents the MLS of 87mm.

Table 9: Outer Ards descriptive statistics – carapace length

	Female (including v-notched)	Male
Number measured	124	113
Average (mm)	87	89
Median (mm)	85	88
Mode (mm)	80	90
Minimum recorded (mm)	45	49
Maximum recorded (mm)	130	168
% MLS or greater (mm)	44	51
% less than MLS (mm)	56	49

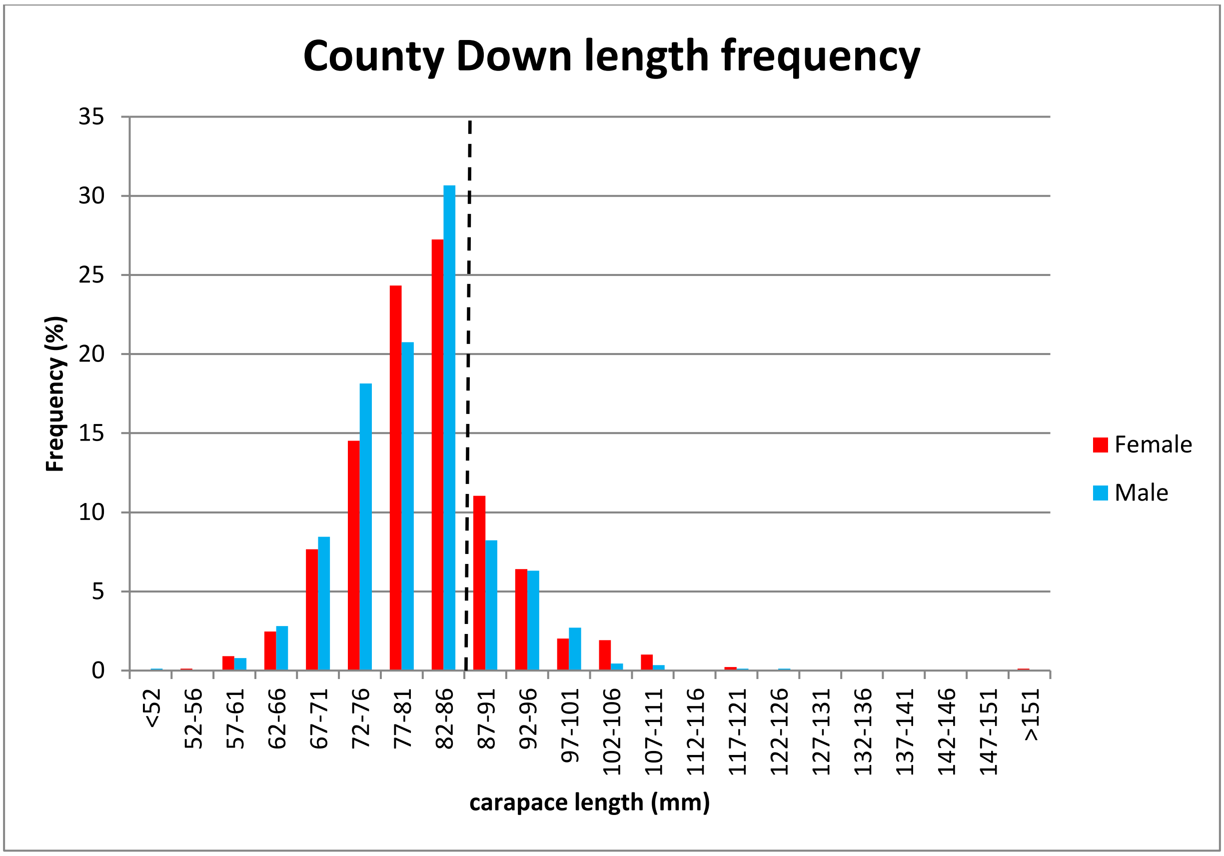
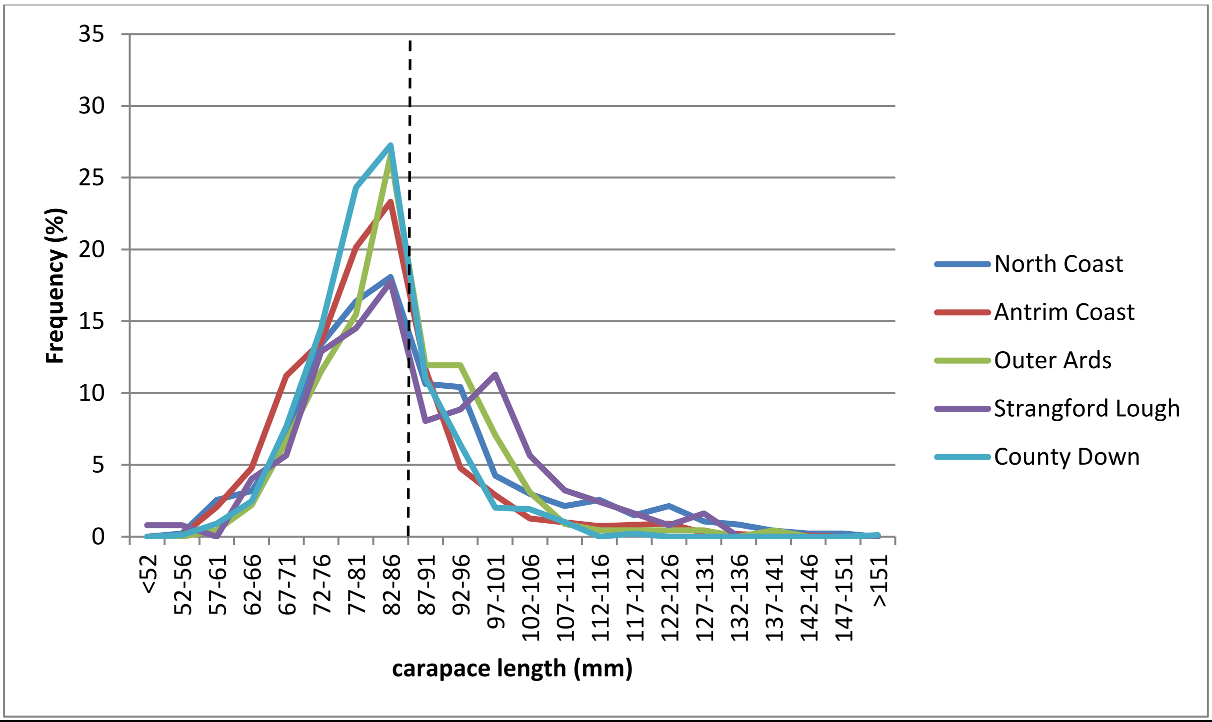


Figure 30: Length frequency of lobsters measured from County Down. The dashed line represents the MLS of 87mm. Note – lobsters landed are underrepresented as for two of the trips not all of the landed lobsters were measured.

Table 10: Outer Ards descriptive statistics – carapace length

	Female (including v-notched)	Male
Number measured	888	887
Average (mm)	82	81
Median (mm)	81.5	81
Mode (mm)	80	80
Minimum recorded (mm)	54	50
Maximum recorded (mm)	160	125
% MLS or greater (mm)	23	18
% less than MLS (mm)	77	82



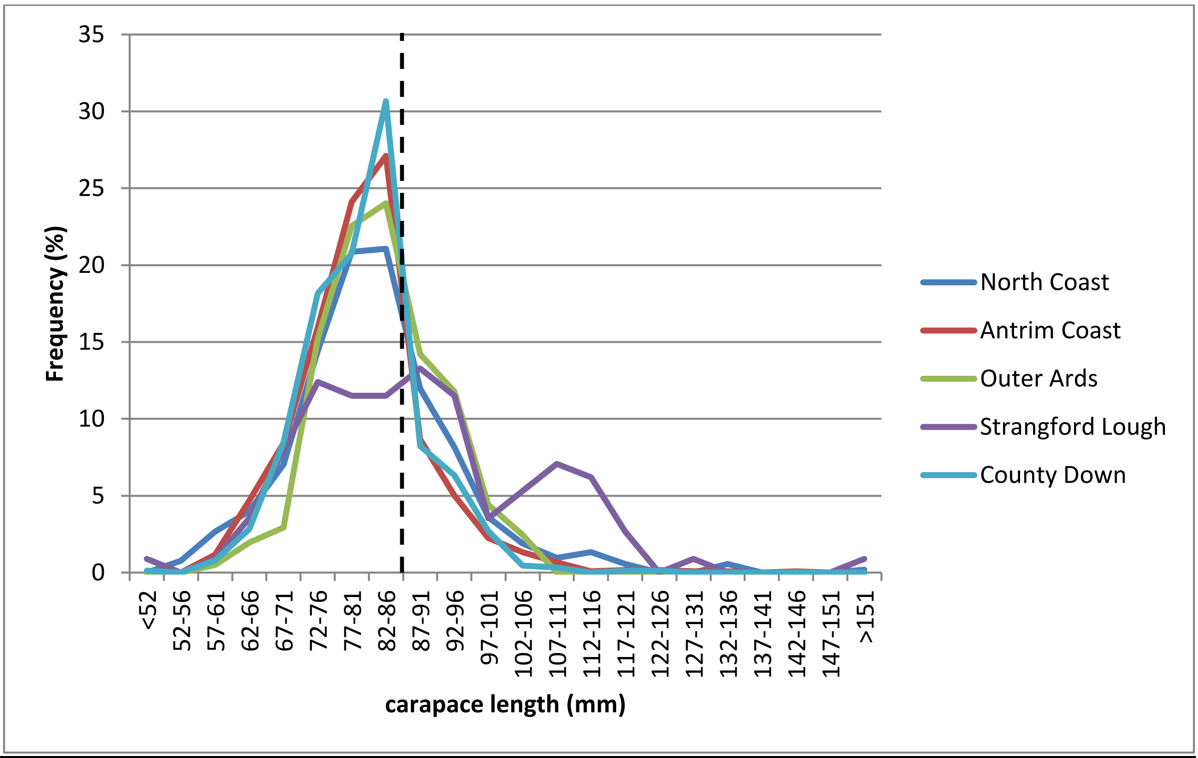


Figure 31: The carapace length (mm) of female (top) and male (bottom) lobsters from the five different geographic areas. The dashed line represents the MLS.

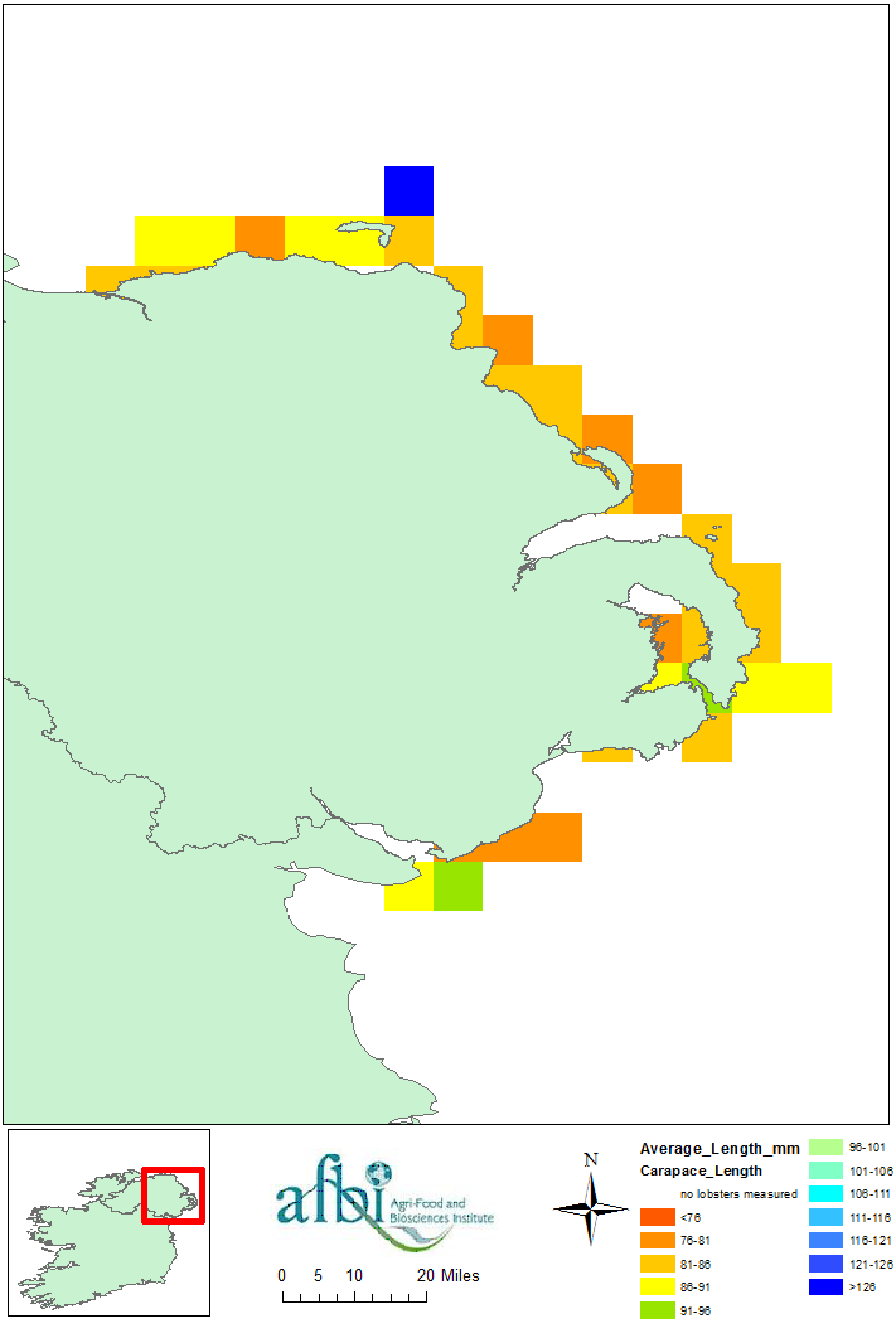


Figure 32: Average carapace length of all lobsters measured related to position of where they were caught (a fishnet was produced with each grid square being 70.7km^2) (Geographic projection: WGS 1984)

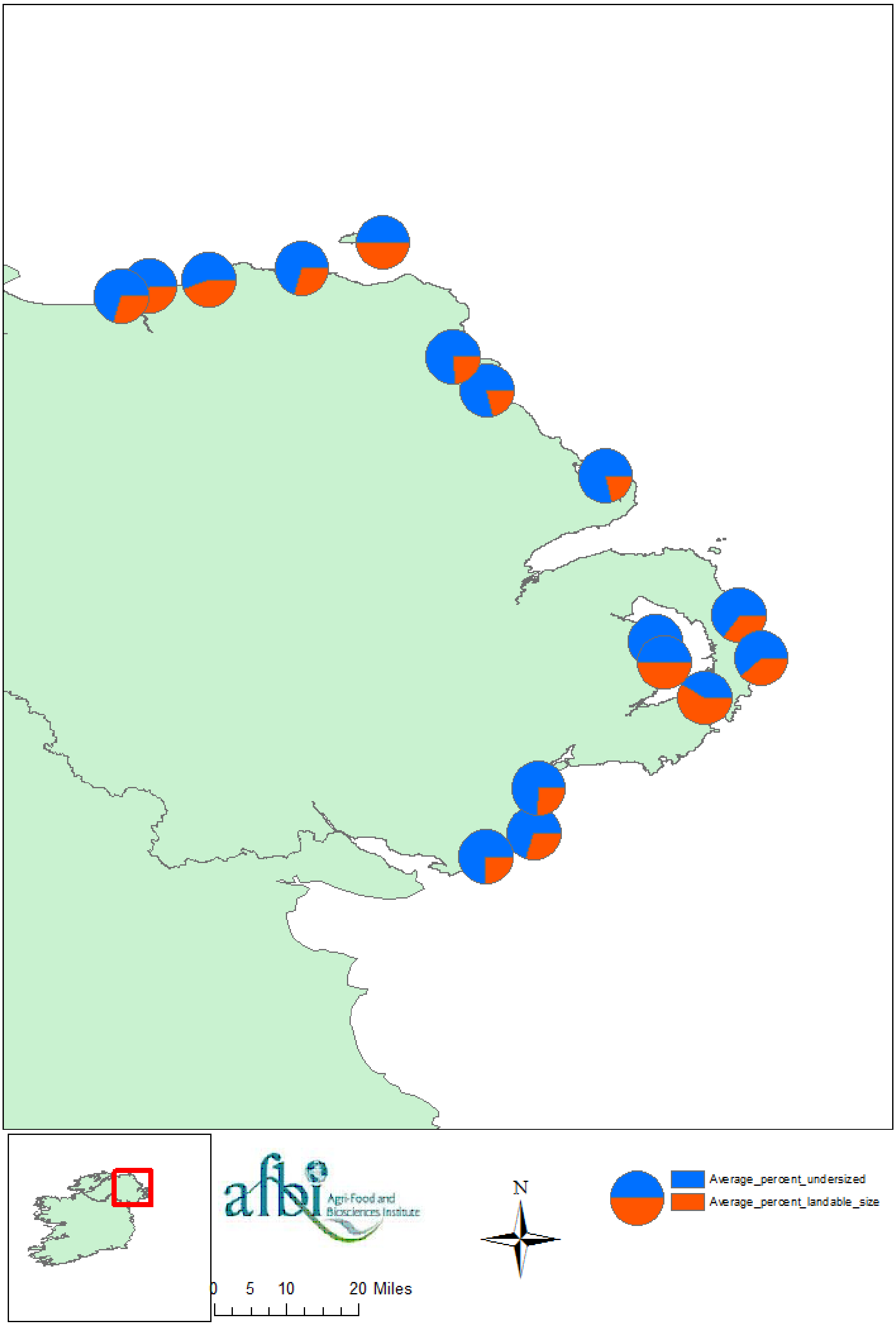


Figure 33: The ratio of lobsters smaller than the MLS (blue) compared to those greater than the MLS (orange) associated with the port from which the fishing vessel left. (Geographic projection: WGS 1984)

Across Northern Ireland the lowest incidence of percentage of female lobsters in the catch was between January and March when they accounted for 46% of the total catch. The highest incidence of females was between April and June when they made up 53% of the total catch. Figure 34 shows the % catch of females.

The CPUE of v-notched lobsters was highest around Rathlin Island and Ballintoy on the North Coast (Figure 35). However, the highest percentage of v-notched lobsters reported from any one trip was from County Down in May 2015 when 35% of all female lobsters caught were v-notched. Table 11 shows the percentage of v-notched lobsters in the catches from the five geographic areas. The smallest v-notched lobster reported was 74mm whilst the largest was 159mm. Figure 36 shows the length frequency of v-notched lobsters from the five geographic areas. There are lobsters under the MLS which are v-notched in all areas except Strangford Lough. For all areas except Strangford Lough the peak in length of v-notched lobsters is between 87 and 96mm. In Strangford Lough the peak is between 107 to 111mm. However, only eight v-notched lobsters were caught in Strangford Lough and so there is not sufficient data to provide a true estimate.

Figure 37 provides the length frequency of berried lobsters. The smallest berried female recorded was 70mm recorded from the North Coast. The largest was 159mm caught along the Antrim Coast. 29% of berried lobsters caught during this study were less than the current MLS of 87mm.

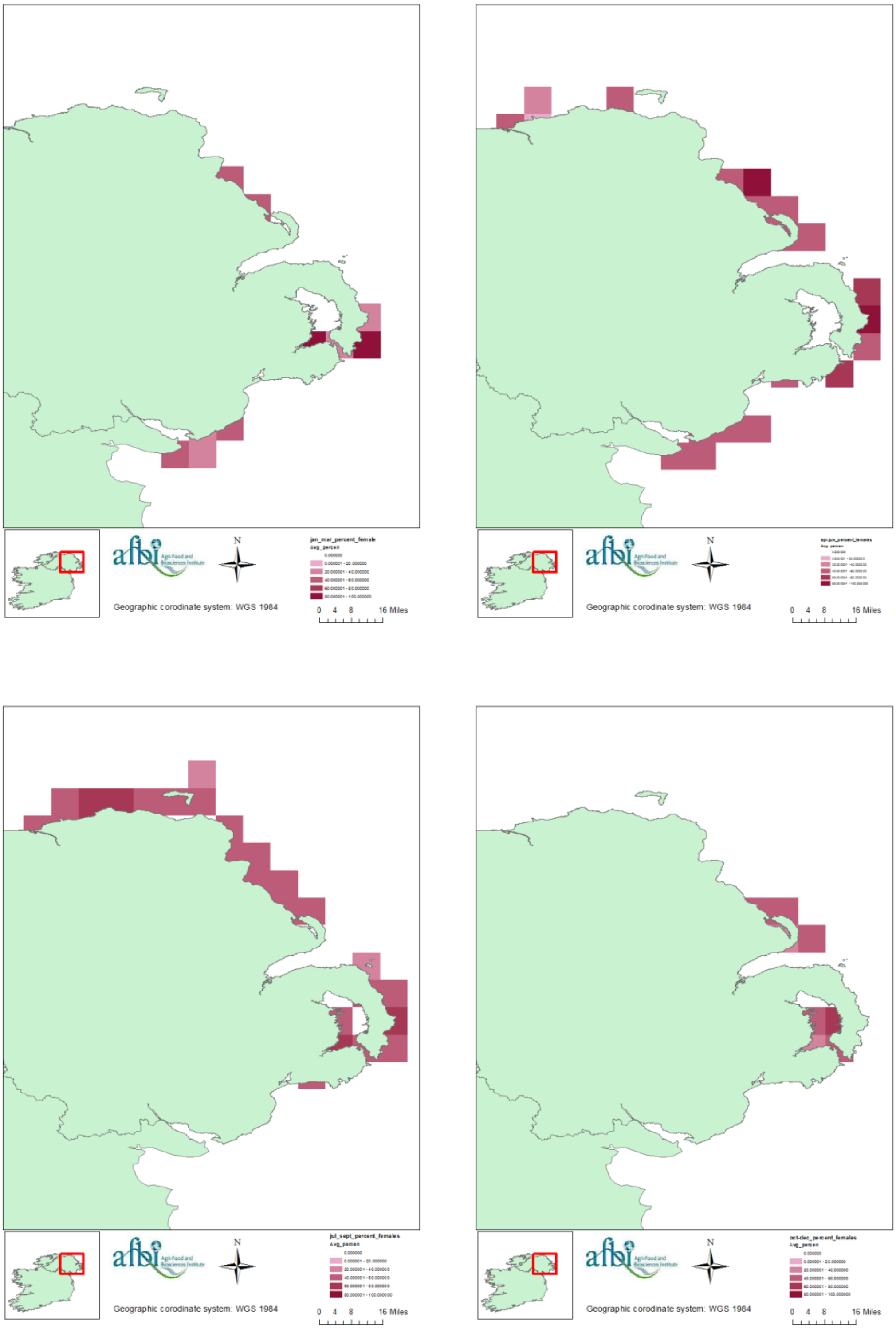


Figure 34: Percentage of females in the catch from the observer trips for all four quarters (top left – Quarter 1, top right – quarter 2, bottom left – quarter 3, bottom right – quarter 4). A fishnet was produced with each grid square being 70.7km^2 (Geographic projection: WGS 1984)

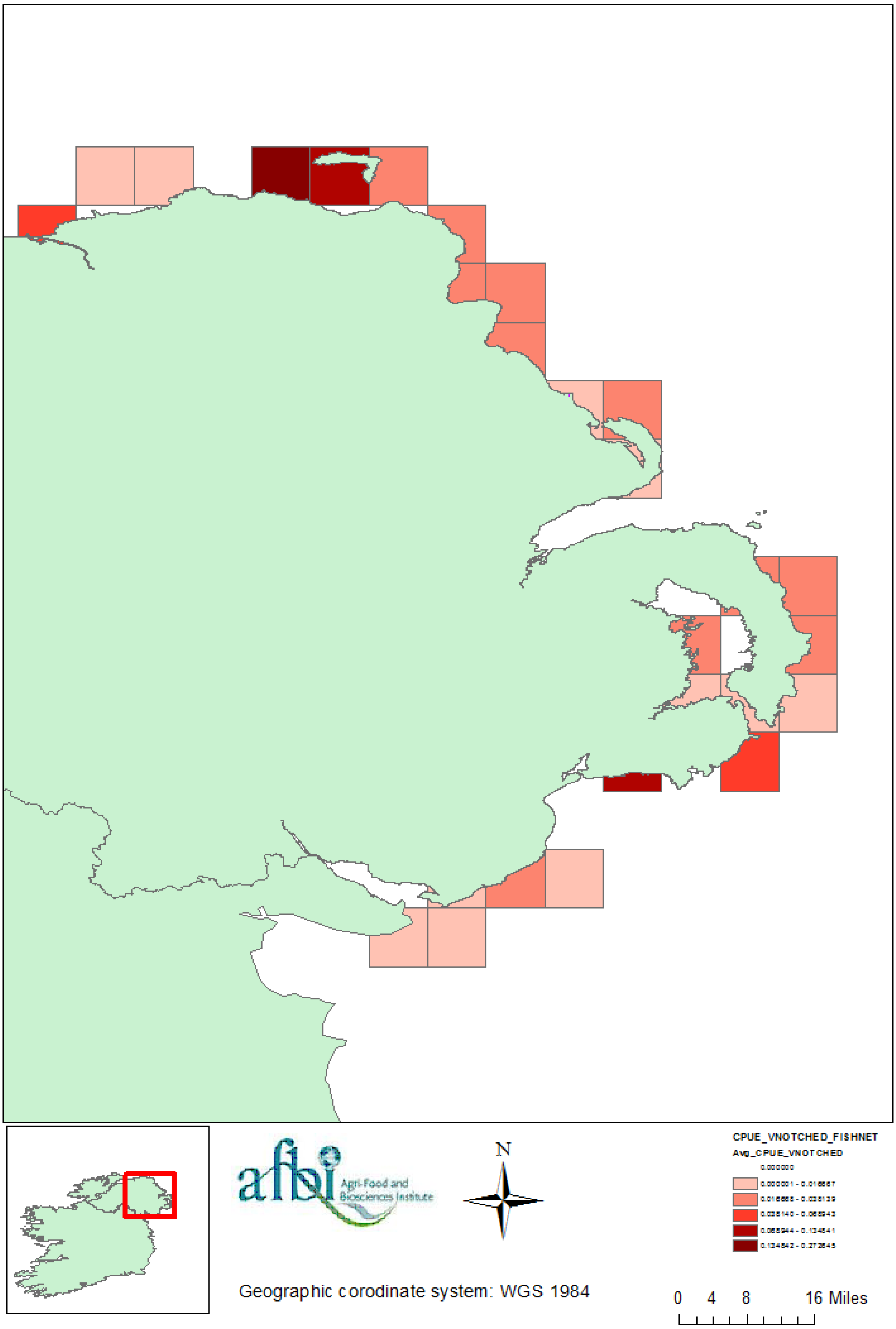


Figure 35: CPUE of v-notched females (a fishnet was produced with each grid square being 70.7km^2) (Geographic projection: WGS 1984)

Table 11: The average percentage of female lobsters caught which are v-notched from the five geographic areas.

Geographic Area	Average % of lobsters v-notched in catch
Antrim Coast	6.4
Outer Ards	6.5
County Down	9.6
North Coast	13.3
Strangford Lough	6.1

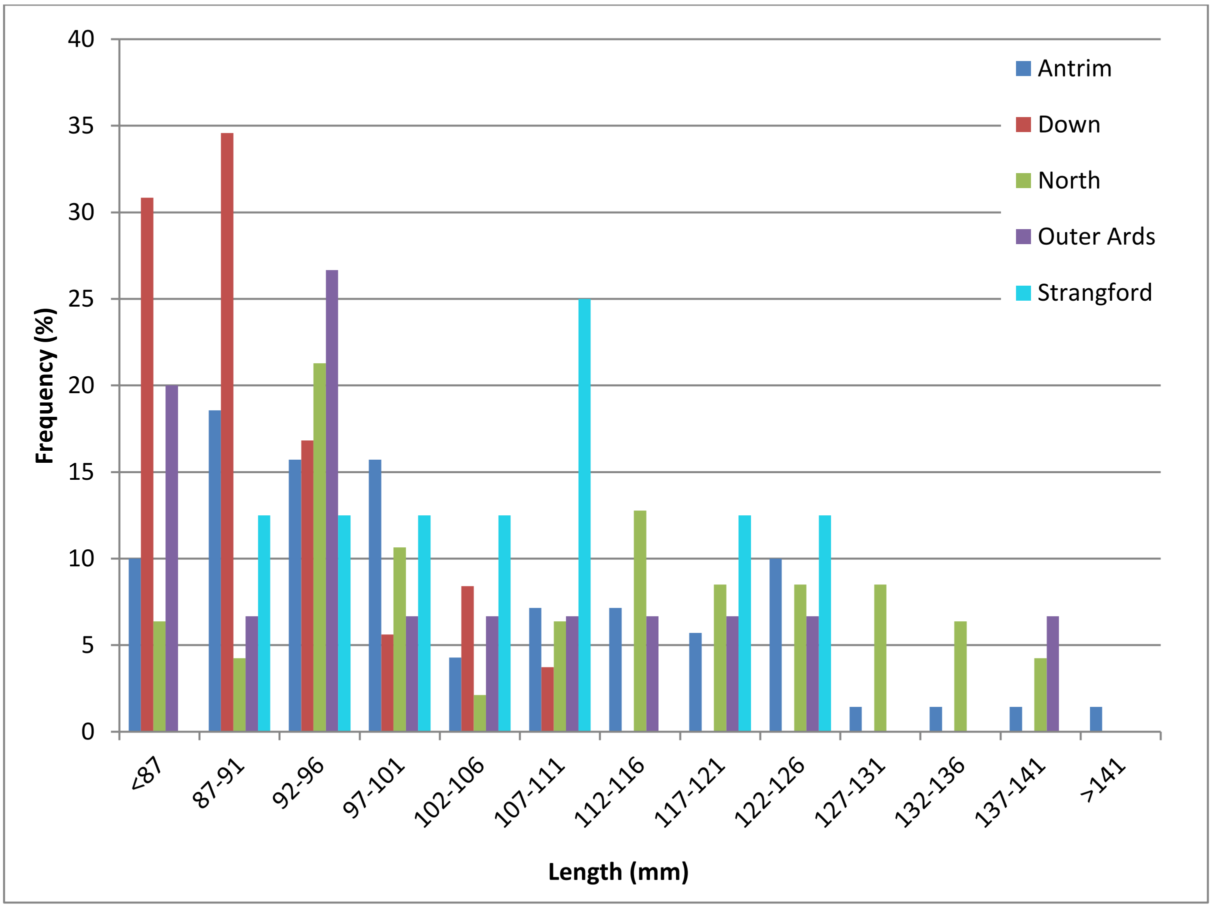


Figure 36: Length frequency of v-notched lobsters from the five geographic areas

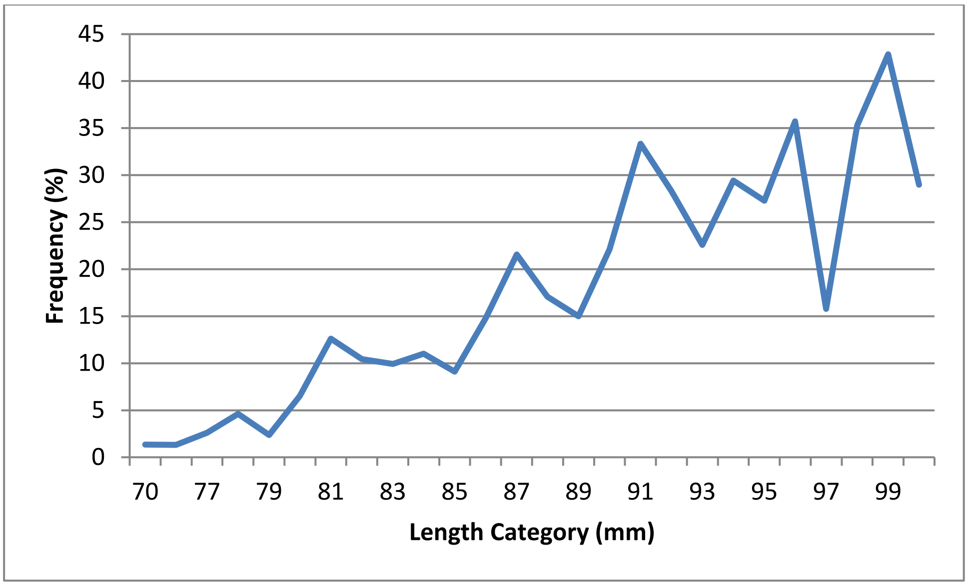


Figure 37: Length frequency of berried lobster. Due to the low numbers of lobsters greater than 100mm percentage frequency is very noisy for these large lobsters and so only lobsters smaller than 100mm have been included in this plot.

4.3 Tagging

Over the project, 4,034 lobsters were tagged around the coast of Northern Ireland. Table 12 provides a summary of all lobsters tagged broken down by category. The location of where these lobsters were tagged is shown in Figure 38. The details of 357 tagged recaptured lobsters were reported by fishermen in their catch (a return of 8.8%). A breakdown of the recaptures, based on the category in which the lobster was in at the time it was tagged, is provided in Table 13. A higher percentage of tagged male lobsters were recaptured. Of the 357 recaptures, 297 were individual recaptures, 28 were from lobsters that were caught twice, 4 were caught on three separate occasions, and one of the lobsters was recaptured four times after tagging. In addition, a number of fishermen also reported having caught lobsters with a tag but did not return any information as the number on the tag was illegible. Also, there were further reports of tagged lobsters being caught but no information was returned. This may be due to the lack of reward offered for recapture information.

The main month for returns of recaptured lobsters was September (Figure 39). By September 2014 a total of 1,604 lobsters had been tagged. However, 22 of these tagged lobsters had been recaptured and landed leaving 1582 tagged lobsters remaining in the population. During this month 176 of these tagged lobsters were recaptured (1.07%). In September 2014 total lobster landings for Northern Ireland were 16.6 tonnes. If it is assumed that the percentage of tagged lobsters caught equates to the total weight of lobsters caught, this produces an estimated total tonnage of lobsters at 1,544. However, in some months there were few returns and therefore the estimates of tonnages were much higher. For example, in October 2014 there were only 3 returns of the potential 2089 tagged lobsters still available for recapture. Using these values provides an estimated stock biomass of 4,760 tonnes. Therefore the 2014 low levels of recapture do not make this an efficient tool as estimating the size of the stock (see recommendation section).

Table 12: Lobsters tagged with streamer tags in Northern Ireland

Category	Male	Female	Unknown sex
≤ 87 mm	1933	1632	100
≥ 87mm	33	24	
≤ 87 mm, v-notched	2	18	
≥ 87mm, v-notched	6	43	
≤ 87 mm berried, not v-notched		30	
≥ 87mm berried, not v-notched		29	
≤ 87 mm berried, v-notched		67	
≥ 87mm berried, v-notched		117	
Total	1974	1960	100

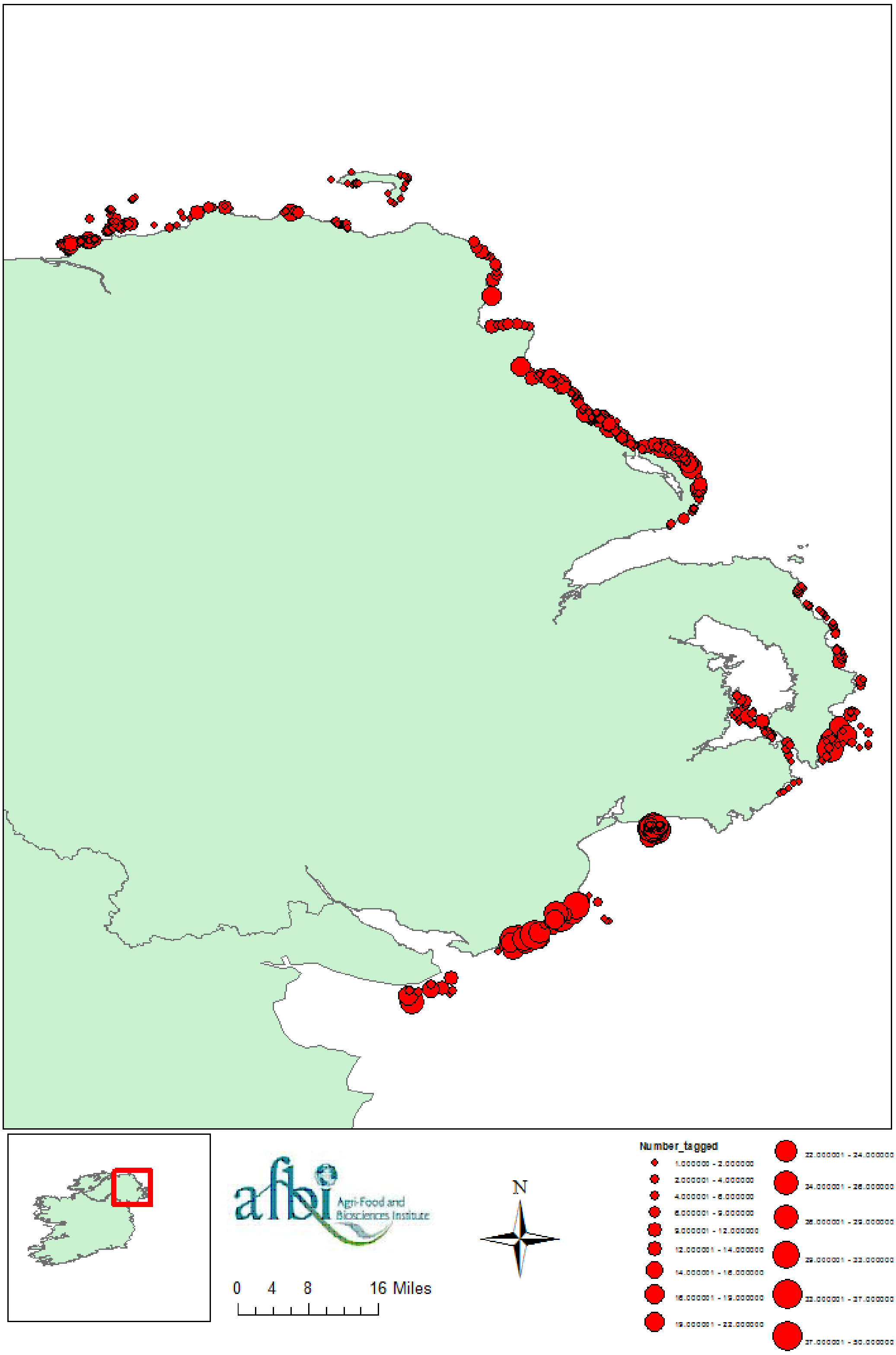


Figure 38: Location of lobsters tagged around Northern Ireland. The size of the circle is indicative of the number of tagged lobsters released in that area. (Geographic projection: WGS 1984)

Table 13: Tagged lobster recaptures based on category when tagged.

Category	Male		Female		Unknown (tag number not reported)
	Number	%	Number	%	
≤ 87 mm	171	8.8	115	7.0	11
≥ 87mm	3	9.1	3	12.5	3
≤ 87mm v-notched	0	0	1	5.6	
≥ 87mm v-notched	2	33.3	1	2.3	
≤ 87 mm berried, not v-notched			3	10	
≥ 87mm berried, not v-notched			2	6.9	
≤ 87 mm berried, v-notched			6	9.0	
≥ 87mm berried, v-notched			4	3.4	
Total	176	8.9	135	6.9	11

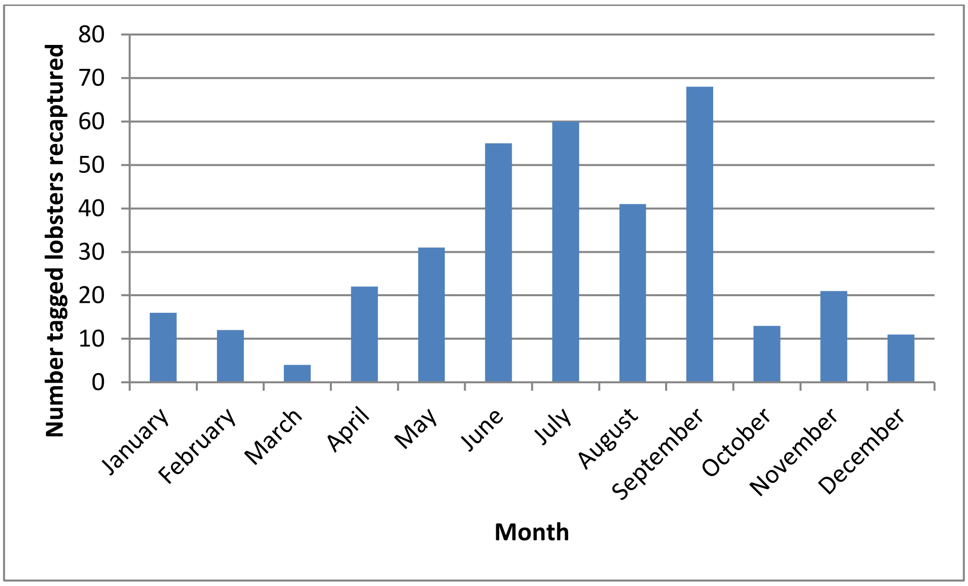


Figure 39: Number of recaptured lobsters by month

The minimum time between tagging and recapture for any given lobster was two days (an 85mm male that was caught 150m from where it was released after tagging). The longest time between tagging and recapture was 1,001 days, which was attributed to an 82mm female that was tagged of Islandmagee. On average, most lobsters were recaptured around 90 days or less after being tagged (Figure 40).

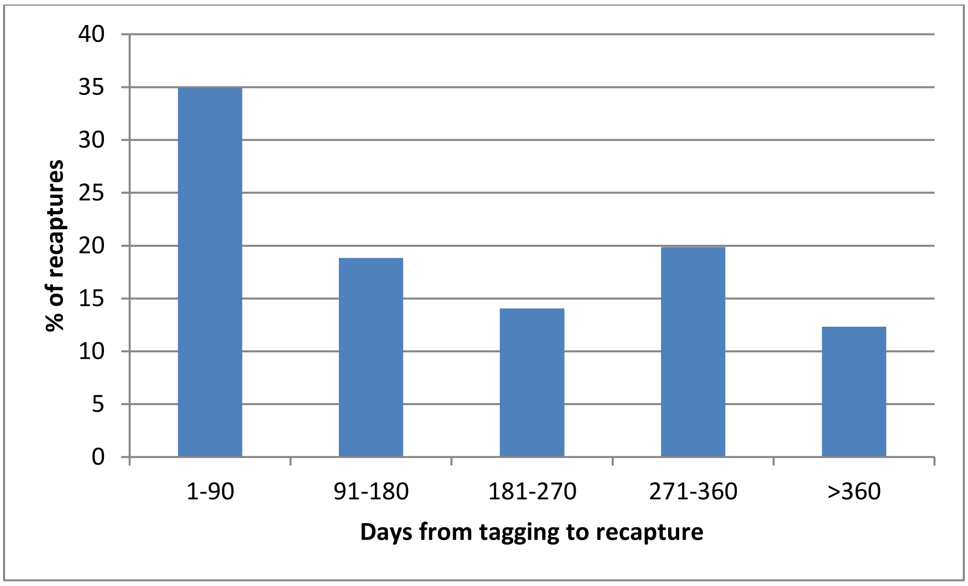


Figure 40: The percentage of animals recaptured by length of days from initial tagging to final recapture.

For 297 of the tag lobster recaptures positions were available to calculate the movement of the lobsters (Figure 41 shows the areas where movement was recorded during the project). The distance moved was calculated as a straight line from the place of initial release to the site of recapture. Where a headland intersected the line, it was angled to remain on the seaward side. The minimum distance recorded was 9m. This movement was reported for three lobsters, a 76mm male, an 80mm male and an 82mm female, all tagged at Dundrum Bay. The maximum distance was 105km attributed to a 72mm male lobster which was tagged of Portstewart and recaptured at Tory Island, Ireland. Figure 42 links the number of days the tagged lobster was at large to the distance moved. There is only a weak correlation (r=0.01) between the number of days between captures and the distance moved. There was also no correlation between the length of the animal and the distance that it had moved (Figure 43). Whilst the average distance moved of male lobsters was 2.4km and the average for females was shorter at 2km, there was no significant difference in movement between the sexes (p>0.05). There were not enough returns of berried lobsters to indicate whether there are differences in distance moved between berried and non-berried females.

Overall, 54 lobsters were recorded moving more than 2km. The direction of movement of these lobsters is shown in Figure 44. There are clear patterns in movement along the coastline for the Antrim Coast, where 33 lobsters had moved more than 2km. There was no movement offshore by these lobsters. For Outer Ards the majority of the movement was south, down the coast. For the seven lobsters which had moved greater than 2km from County Down, whilst there were different directions recorded, the lobsters with the greatest movement had moved offshore.

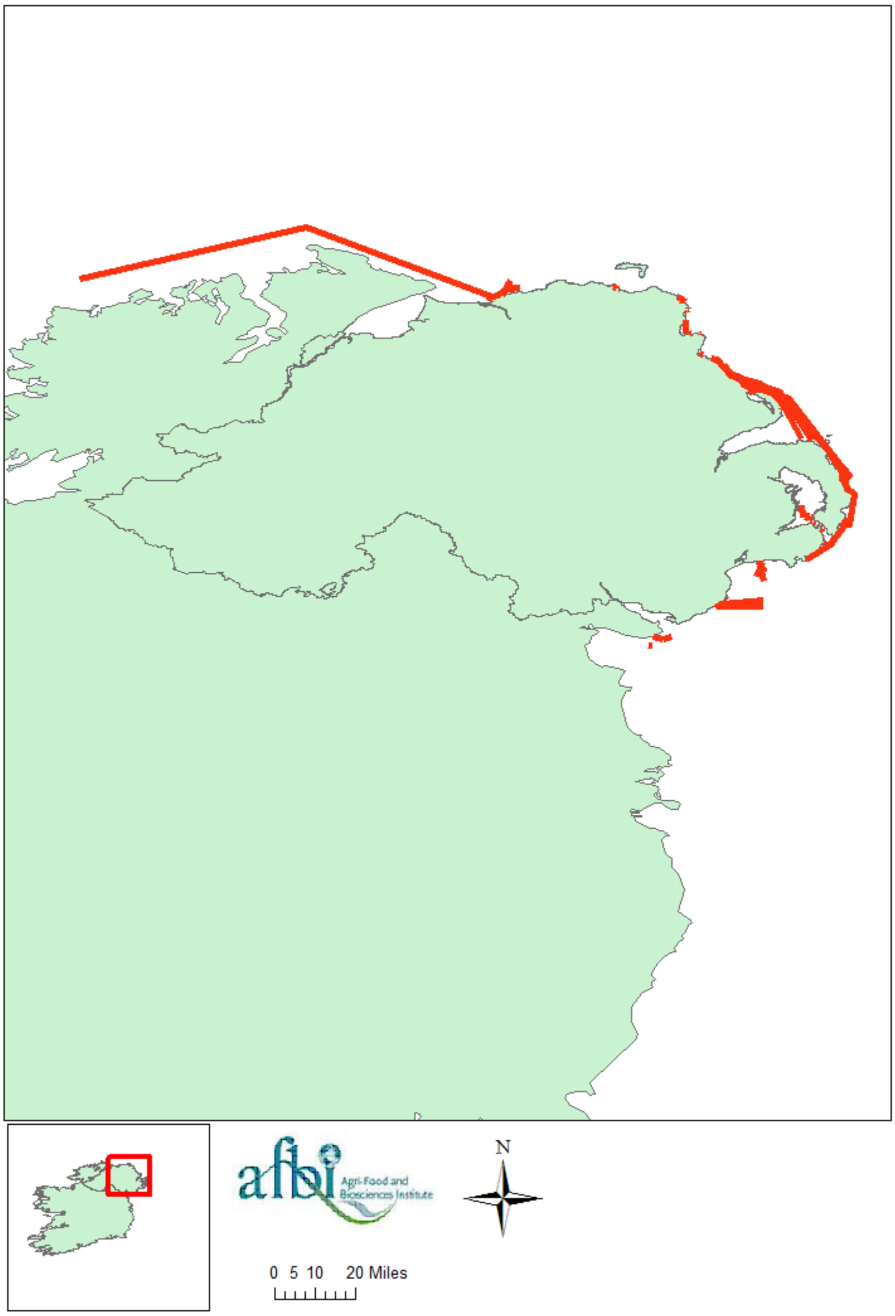


Figure 41: The movement of lobsters around the coast of Northern Ireland (Geographic projection: WGS 1984)

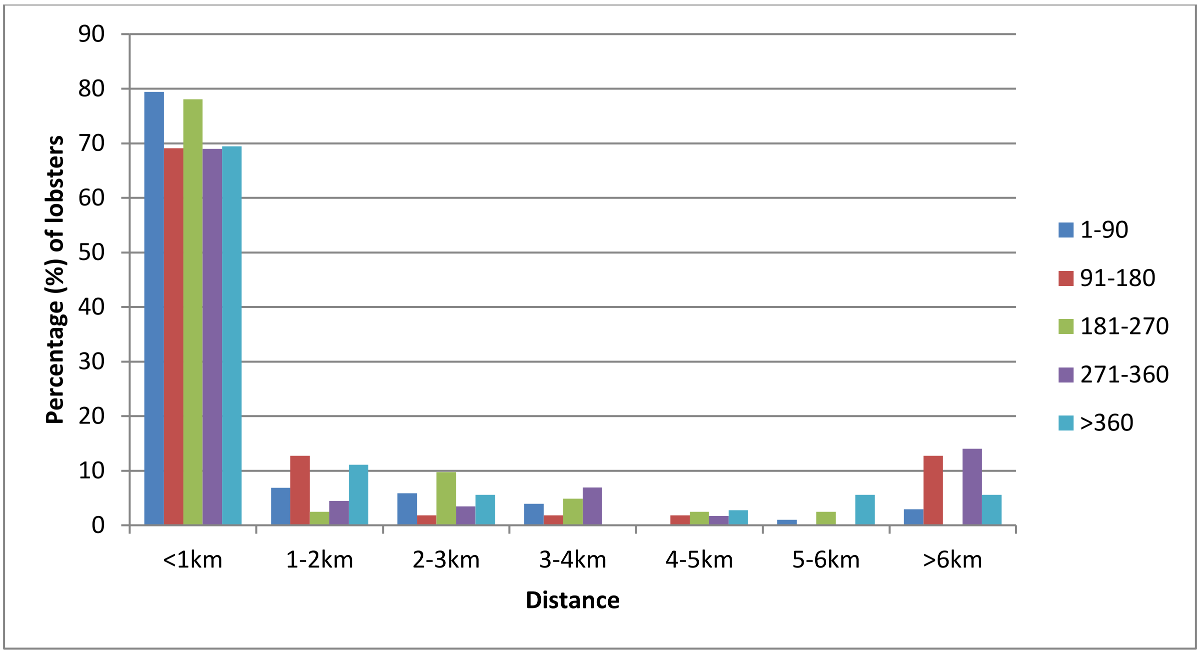


Figure 42: Distance moved by tagged lobsters associated with the number of days between initial tagging and final recapture.

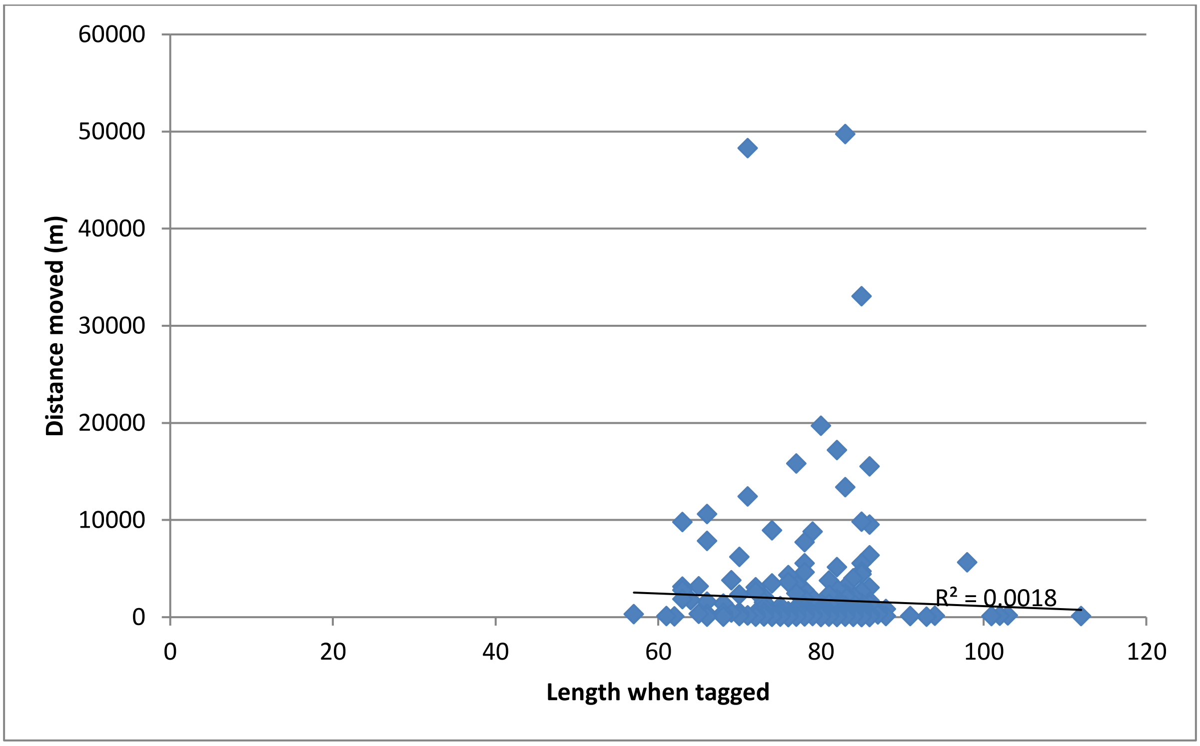


Figure 43: Relationship between the length of the lobster when tagged and the distance that it was caught from the site where it was tagged.

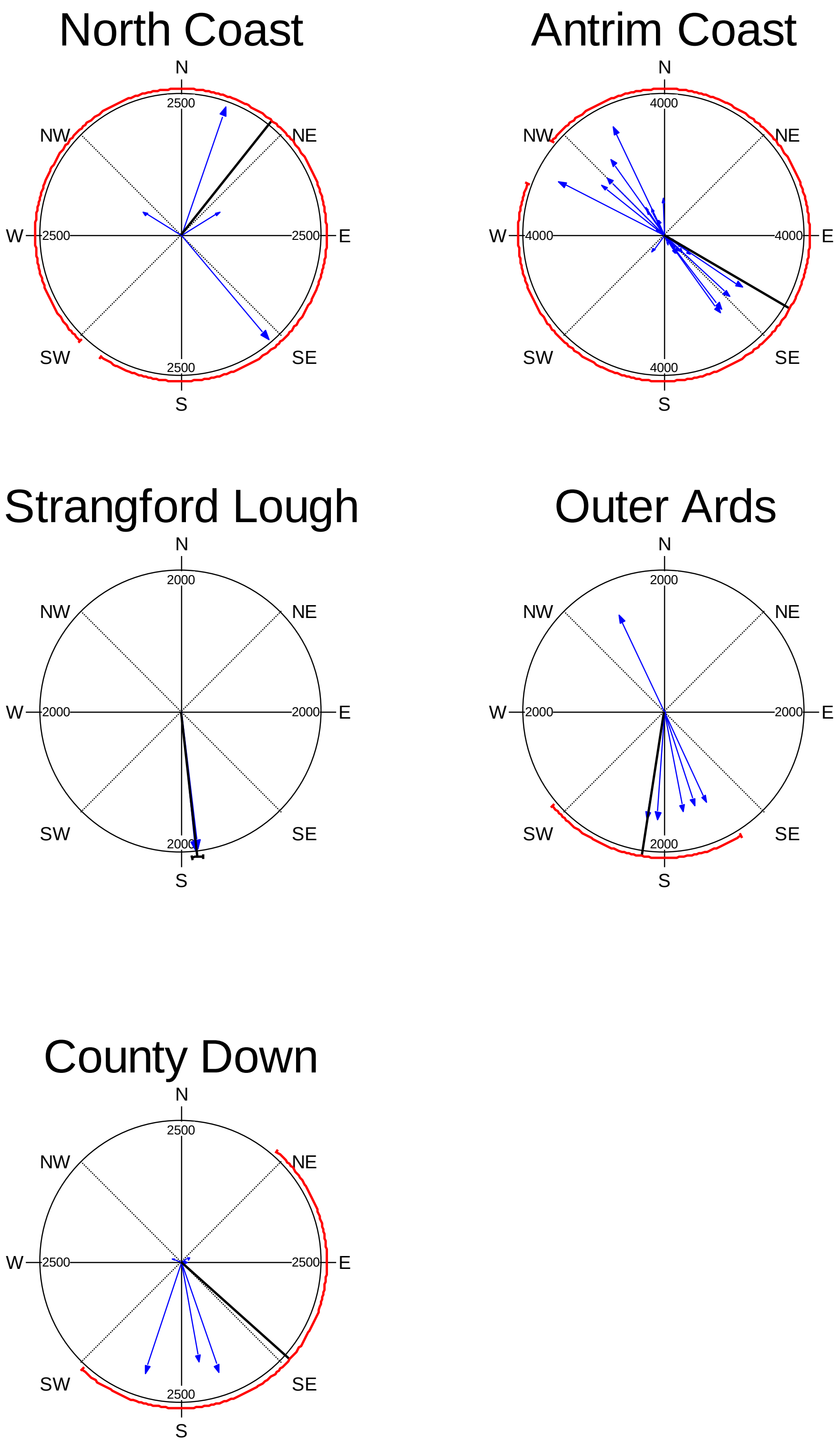


Figure 44: Direction of movement of lobsters which were recaptured more than 2km from the tagging release position.

For 70 of the recaptured tagged lobsters, length data (actual or an estimate) was not provided and therefore we cannot establish whether these animals had moulted or not. Thirty-three were reported as still being undersized when recaptured, with no actual measurement provided. Therefore, it is also not possible to establish whether these lobsters had moulted or not. A further 13 were reported as being greater than the MLS (87 mm). As these lobsters had all been below the MLS when tagged we can assume that they have moulted, but we cannot establish how much they have grown between the time of tagging and recapture. Ninety lobsters had not moulted during the time from tagging to recapture. The number of days between tagging and recapture of these 90 lobsters ranged from 2 to 767. A negative relationship was observed, with the chance of a lobster not moulting decreasing with increased time between tagging and recapture (Figure 45).

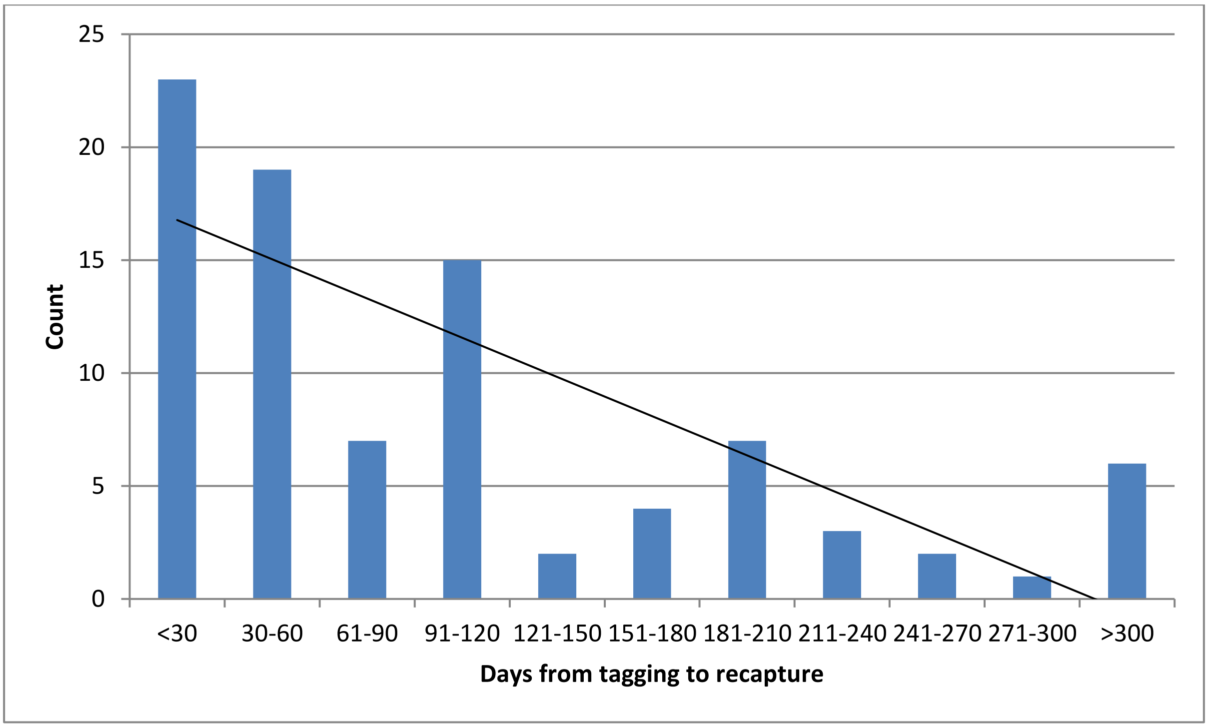


Figure 45: Relationship between the days between tagging and recapture and the count of lobsters which had not moulted.

To compensate for possible measuring errors, any increase less than 5mm was discounted. Differences in length from tagging to recapture ranged from 5mm to 28mm. Figure 46 shows the positive relationship between the number of days between tagging and recapture and the growth of the lobster i.e. the longer the lobster is at large the more moults are possible. There is a negative relationship between the initial carapace length of the lobster and its growth with smaller lobsters having a bigger growth at moult (Figure 47).

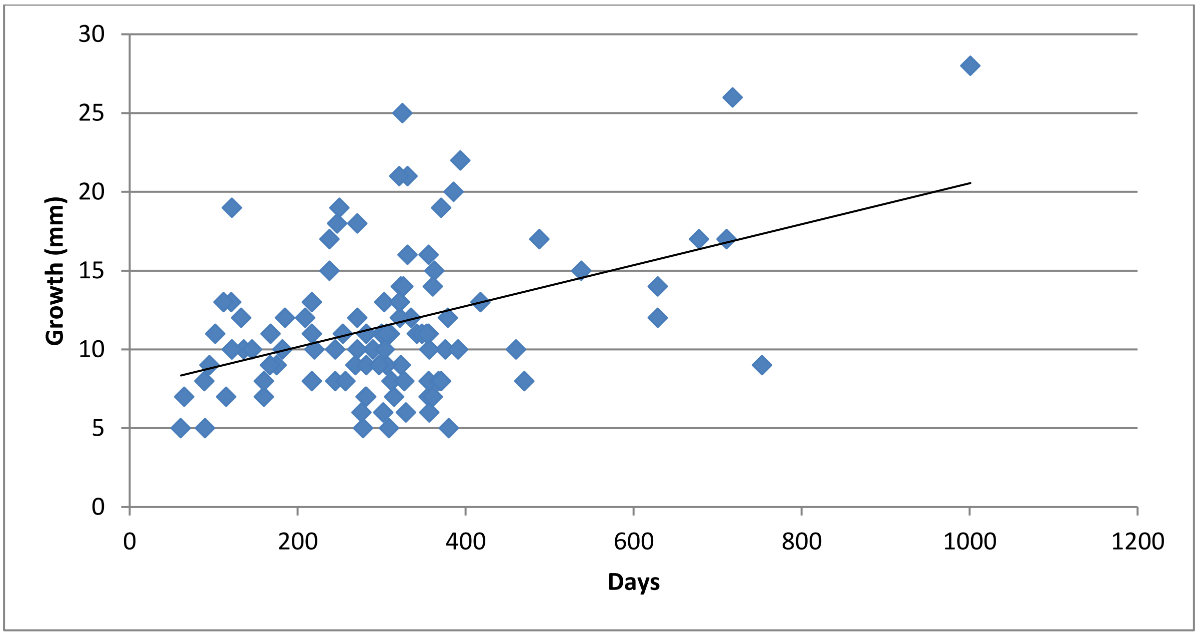


Figure 46: The number of days between tagging and recapture against the growth of lobsters (mm). The black line represents the relationship (r=0.42).

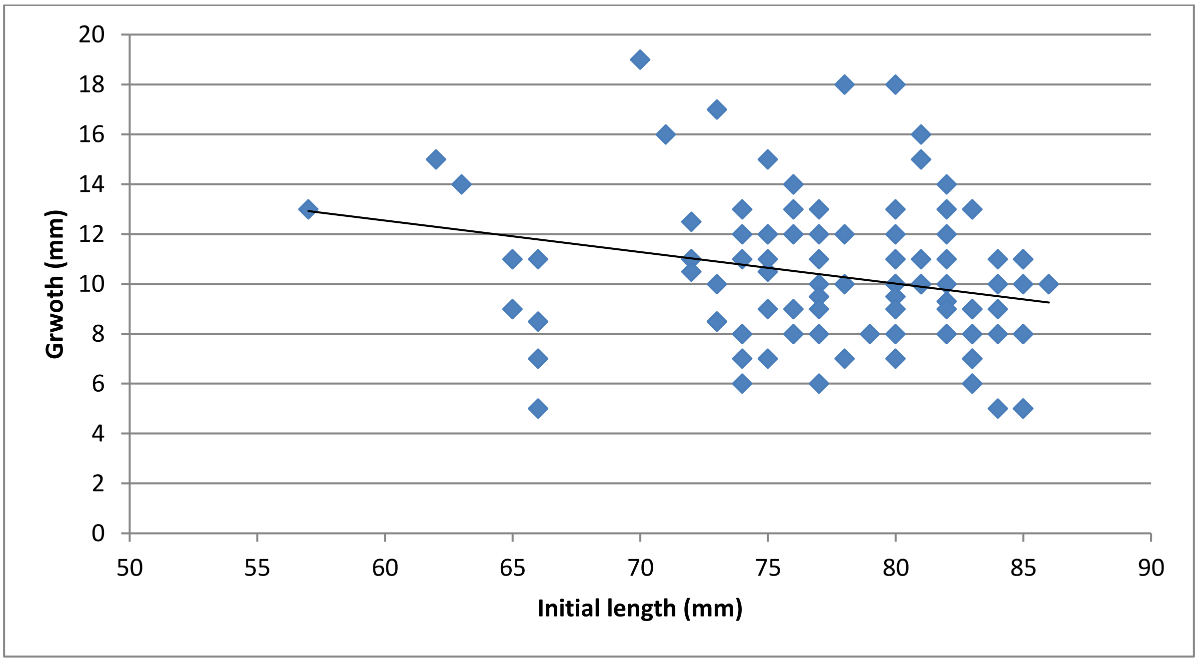


Figure 47: The growth of lobsters at moult in relation to the initial carapace length

Whilst on average males appear to have higher growth rate than females (10.6mm as opposed to 9.7mm), this was found to be not significant. The higher growth for males is more evident in the 80mm and upwards classes (Figure 48).

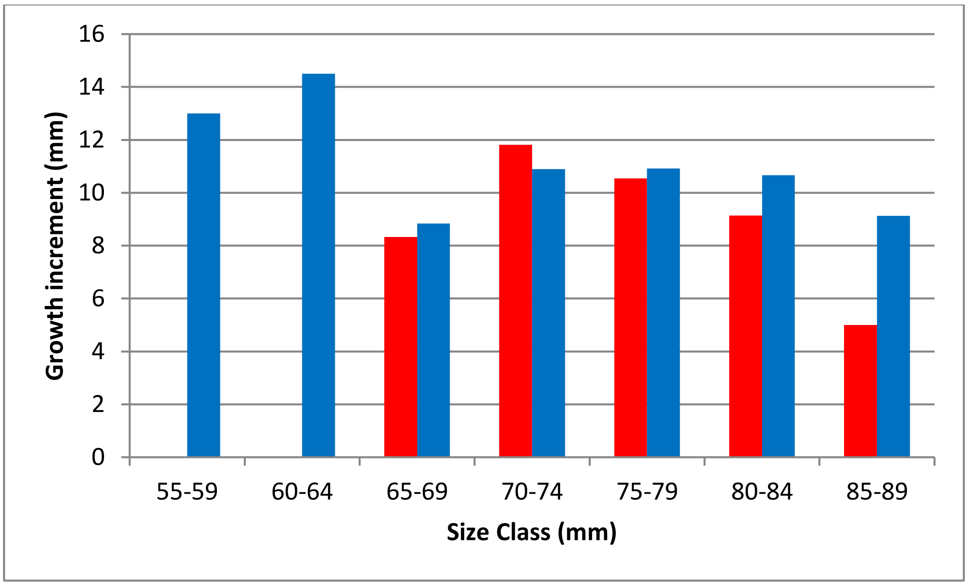


Figure 48: Growth increment of male (blue) and female (red) lobsters for all Northern Ireland across the different size classes

Along the Antrim coast, the shortest duration between tagging and recapture at which a moult took place was the 112 days between 31 July 2014 and 20 November 2014. This animal had increased in carapace length by 13mm. Eight lobsters along the Antrim coast had a growth of between 16 and 26mm. Based on the time and season between moult and recapture it was assumed that these lobsters had moulted twice. A further lobster that had increased by 28mm and had spent almost three years between tagging and recapture was estimated to have moulted three times. Taking this into account the average growth was shown to be 9.9mm (±0.4) annually.

Along the North coast the shortest duration between tagging and recapture at which a moult took place was the 61 days between 11 June 2015 and 11 August 2015. This lobster had increased by 5mm. It was estimated that three of the lobsters from the North Coast had moulted twice from being tagged to recapture. Taking this into account the average growth for the North Coast was estimated to be 9.4mm (±0.7) annually.

Only 11 of the lobsters recaptured off the County Down coast had moulted with all appearing to have moulted only once (the longest time from tagging to recapture was 376 days). The average growth at moult for lobsters from County Down is estimated at 9.5mm (±0.49).

Only 9 of the lobsters recaptured off the Outer Ards coast for which length data was available had moulted. Three lobsters which ranged in length from 72mm to 77mm had increased in length by 19 to 25mm within one year. It is assumed that these lobsters have moulted twice within the one year. The average growth at moult for lobsters from County Down is estimated at 10.1mm (±0.95).

In Strangford Lough the shortest duration between tagging and recapture at which a moult took place was the 90 days between 21 June 2012 and 19 September 2012. This lobster had increased by 5mm. It was estimated that the lobsters which had moulted within Strangford, where the time from tagging to recapture for all lobsters was less than 1 year, had moulted only once. The average growth for the North Coast was estimated to be 12.1mm (±0.94) annually. The growth increment in lobsters from Strangford Lough was found to be significantly higher than the other Areas (p=0.85).

4.4 *Habitat Maps*

4.4.1 Lobster abundance

The distance from land (defined as 0m chart datum) from the mid-point of each string was calculated in kilometres within ArcGIS 10.2. Figure 49 shows the results of the number of lobsters plotted against distance from land. The majority of strings with greater than 10 lobsters caught per string were located within 4km of the coast; this may be dictated by (a) seabed habitat type, (b) vessel type, (c) fuel costs and (b) weather.

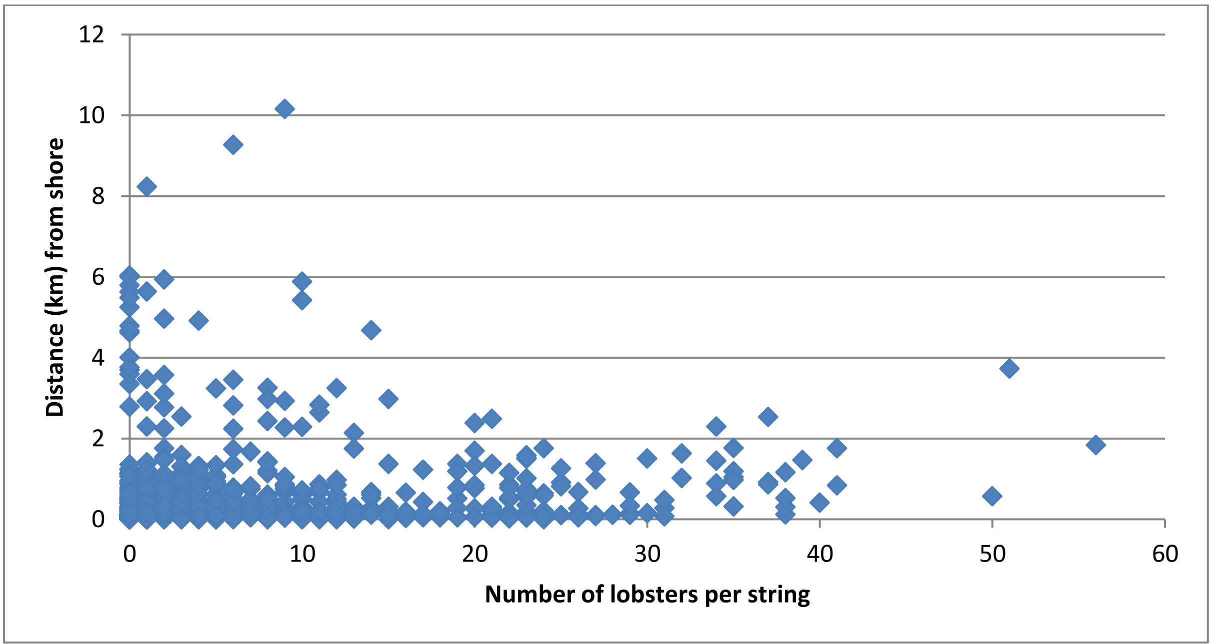


Figure 49: Number of lobsters per string versus distance from land.

The vast majority of lobsters were caught from strings located in water depths of 20m or shallower (Figure 50). In general, the numbers of lobsters per string caught in water depths of greater than 20m numbered less than 30 per string, and in waters deeper than 40m lobster numbers were below 10 per string.

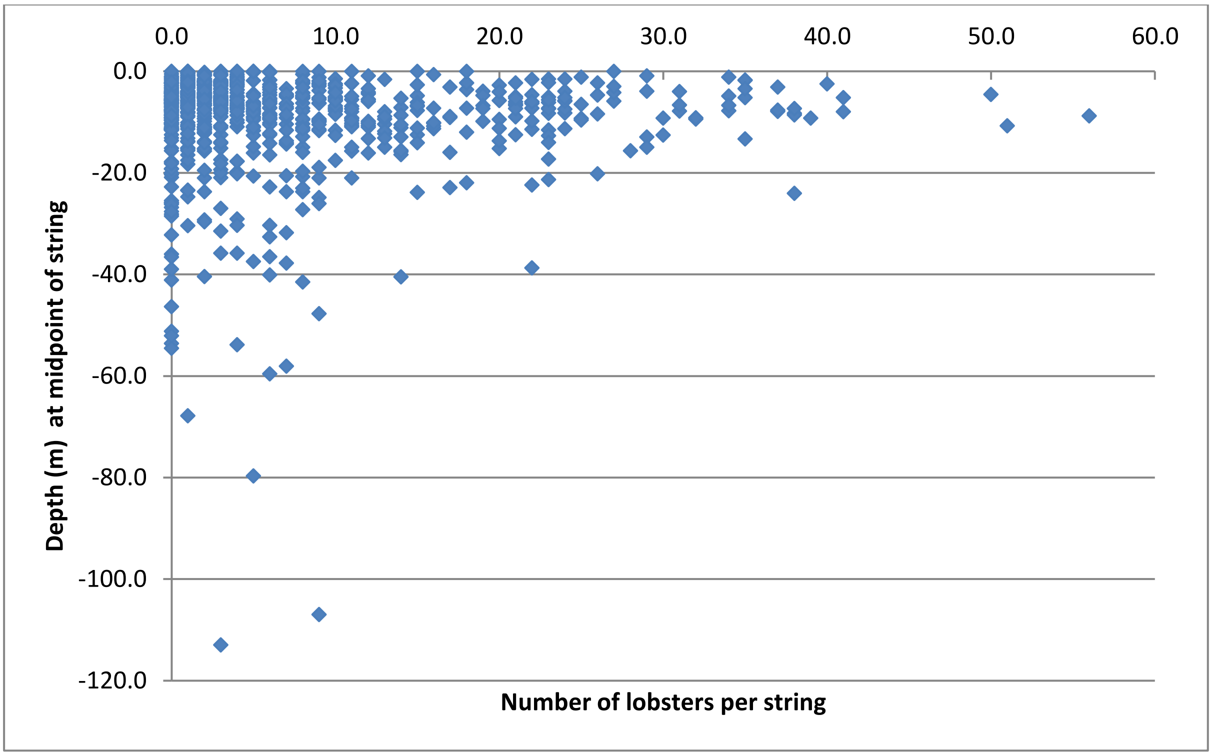


Figure 50: Number of pots per string plotted against water depth (depth below chart datum, in metres).

Mean seabed slope angle in a 50m radius around the midpoint of each string varied substantially from 0° to 35°. There appears to be an inverse relationship between increasing slope angle and the number of lobsters per string (Figure 51), with the highest numbers of lobsters caught per string (e.g. 20 per string or more) at slope angle of less than 10°. However, slope angle here has been averaged over a broad scale, which is necessary due to the original resolution of the bathymetric data ($25m^2$). This scale however may not be a good representation of the habitat requirements of lobsters, but due to the spatial scale and uncertainties both in the positions of the string (taken from handheld GPS which may have a positional error of up to 20m) and the resolution of the bathymetric data these are the best available data.

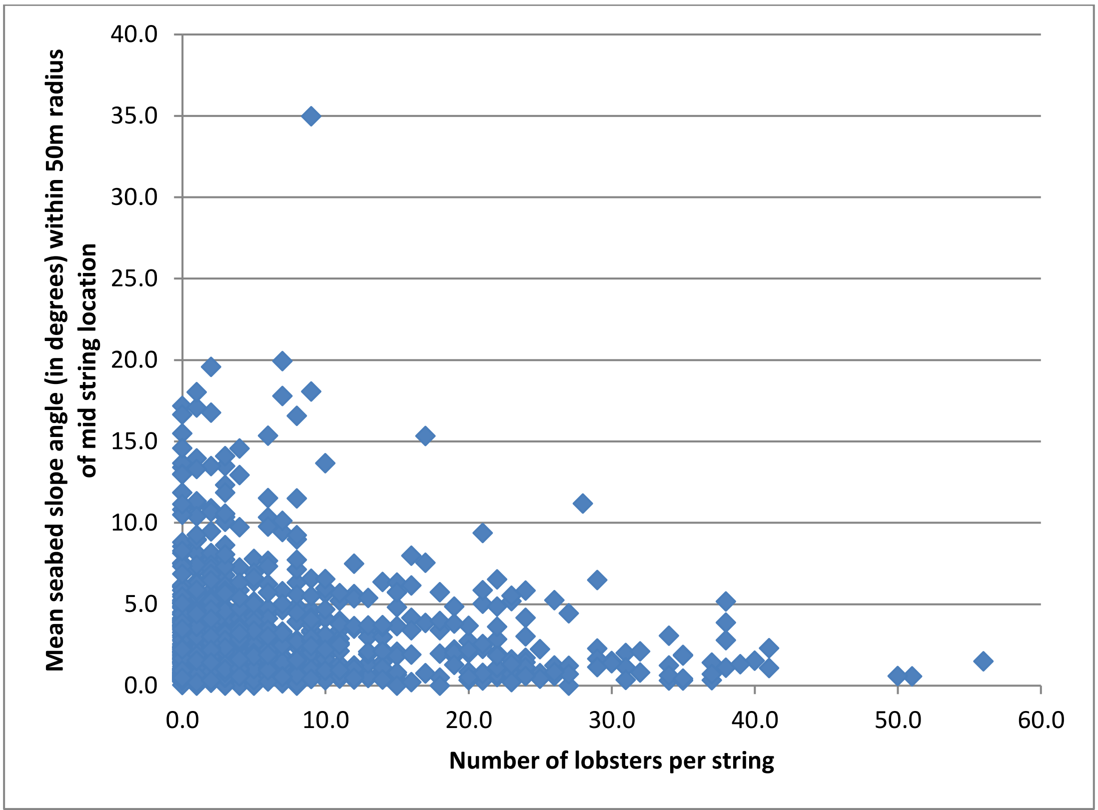


Figure 51: Number of lobsters per string against seabed slope angle.

Terrain ruggedness also appears to vary greatly between string locations, with the majority of lobsters caught in areas of low ruggedness (at a scale of $50m^2$) – as shown in Figure 52. The same issue of spatial scale pertains to ruggedness as it does slope angle.

Benthic position index spatial analysis shows that the majority of strings in which lobsters were caught can be found in areas of "slopes" (negative BPI values) or "crests" (positive BPI values) at a scale of 10-100m around each string; however a number of high lobster catches were also found in level areas (zero BPI values) (Figure 53).

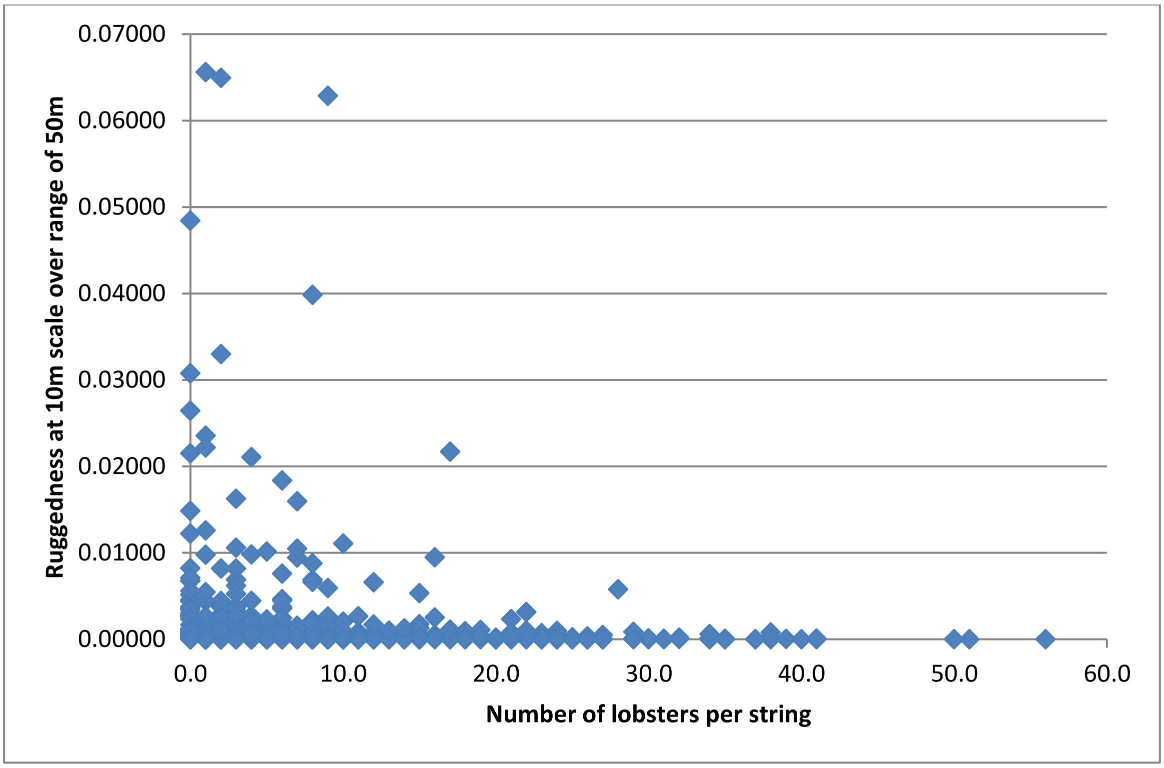


Figure 52: Number of lobsters per string against terrain ruggedness at a scale of 50m.

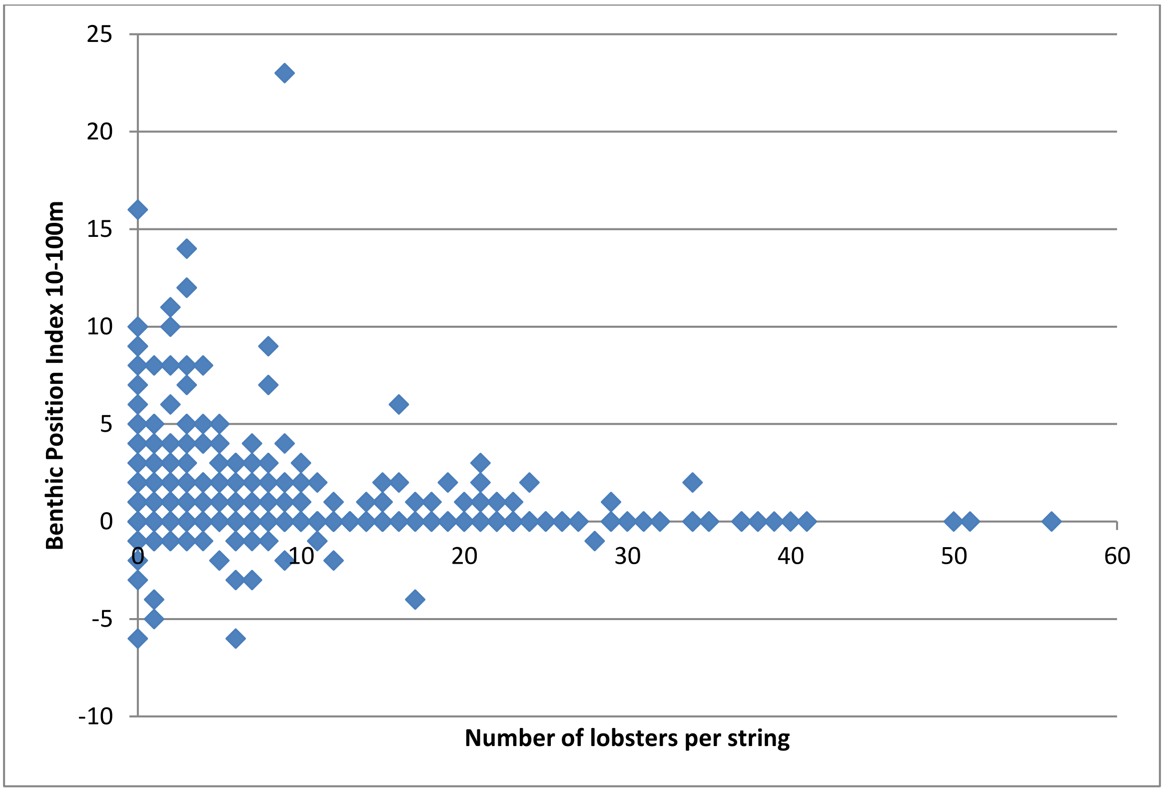


Figure 53: Benthic Position Index around each string location plotted against number of lobsters per string.

The drawbacks of using digital elevation models with original data at 25m2 is the relevance of the derived habitat information for lobsters at that spatial scale. The habitat maps were created at finer spatial scales in the majority of cases (from 2m2 to 20m2) and incorporate substratum information which may be of most relevance to habitat preference of lobsters (see Figures 54 and 55 below). This substratum information does correlate at an appropriate scale to some bathymetric-derived parameters such as slope angle, ruggedness and BPI, but this is not simple to predict, and the habitat maps were therefore based on additional datasets such as acoustic backscatter and, importantly, ground-truthing data relating to biological community and sediment types.

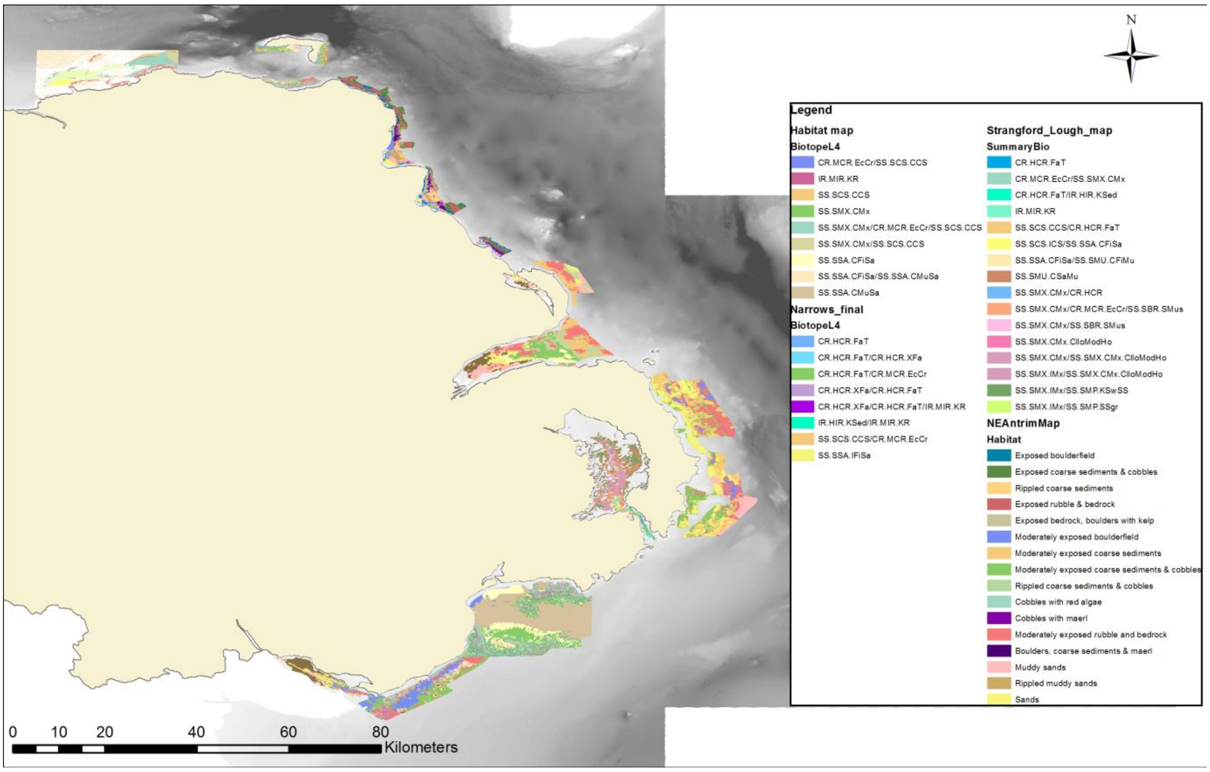


Figure 54: Nearshore habitat maps used in analysis.

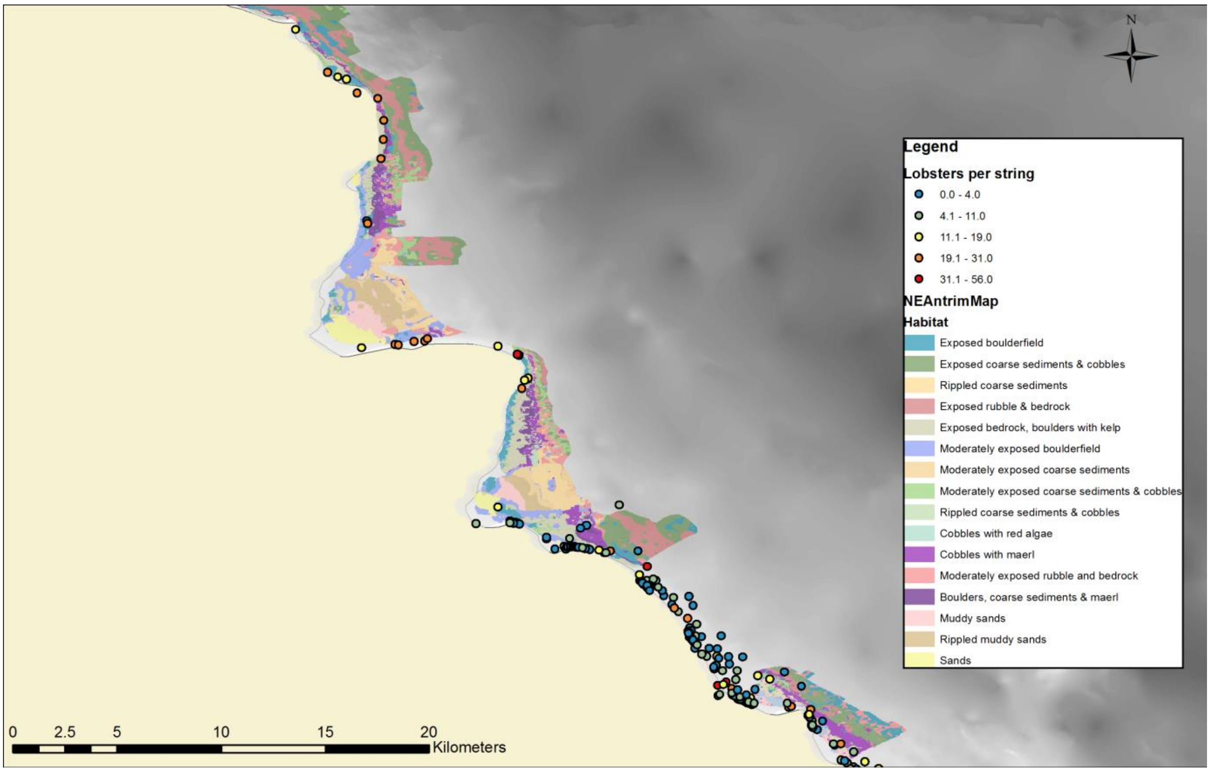


Figure 55: Example of lobster abundance per string overlaid on NE Antrim Habitat Map.

The habitat maps used in this analysis were reclassified into a simple set of substratum types, and the proportion of lobsters caught in each habitat calculated (Figure 56). These substratum types follow the modified Folk classification used in the EUNIS and UK MNCR habitat classifications (see: http://www.emodnet-seabedhabitats.eu/PDF/GMHM3_Detailed_explanation_of_seabed_sediment_classification.pdf). 48% of lobsters were caught over areas classified as bedrock or boulders (bedrock reef areas), with a further 21% caught over mixed sediments with cobbles (which could be considered as stony reef areas). The remaining 31% were caught on strings with a midpoint over coarse sediments (e.g. gravels), sands, muddy sands and megarippled mixed sediments. It is possible that the strings may extend over more than one substratum type and many of these areas exhibit high heterogeneity over short spatial scales.

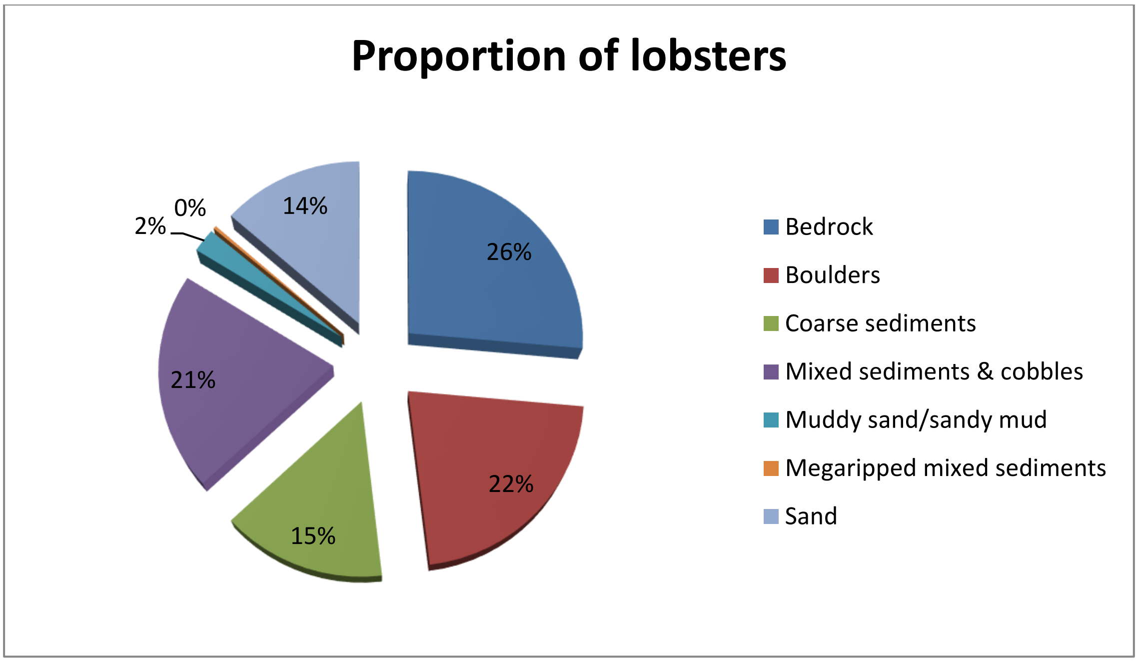


Figure 56: Proportion of lobsters caught from strings over each substratum type.

4.4.2 Berried and V-notched lobsters

The number of berried and V-notched lobsters were plotted on habitat data, and on the bathymetric DEM derived layers. Figure 57 below shows the distribution of berried lobsters (numbers per string) on the higher resolution habitat mapping data.

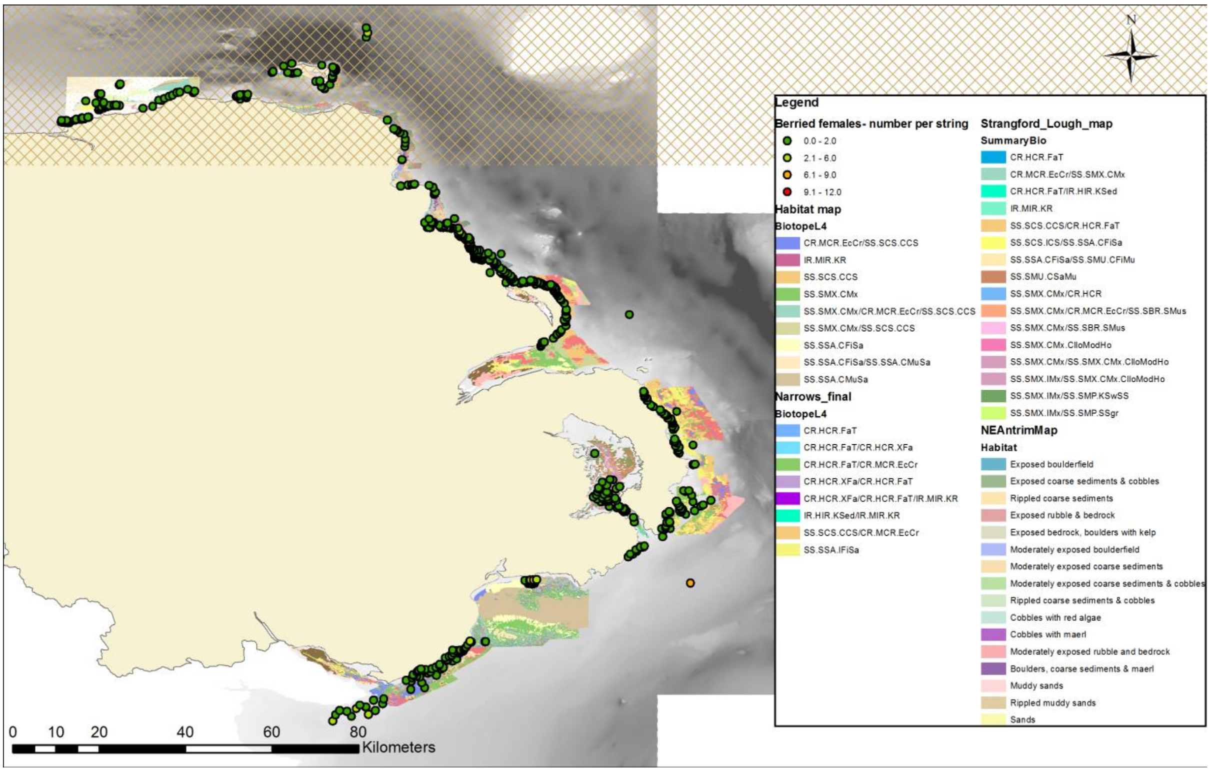


Figure 57: Berried lobsters per string overlaid on habitat map data.

An inverse relationship is shown between water depth and numbers of berried lobsters caught per string, which follows the same pattern as overall lobster abundance per string. Higher numbers of berried females are caught in shallower waters (less than 20m notably), as shown in Figure 58 below.

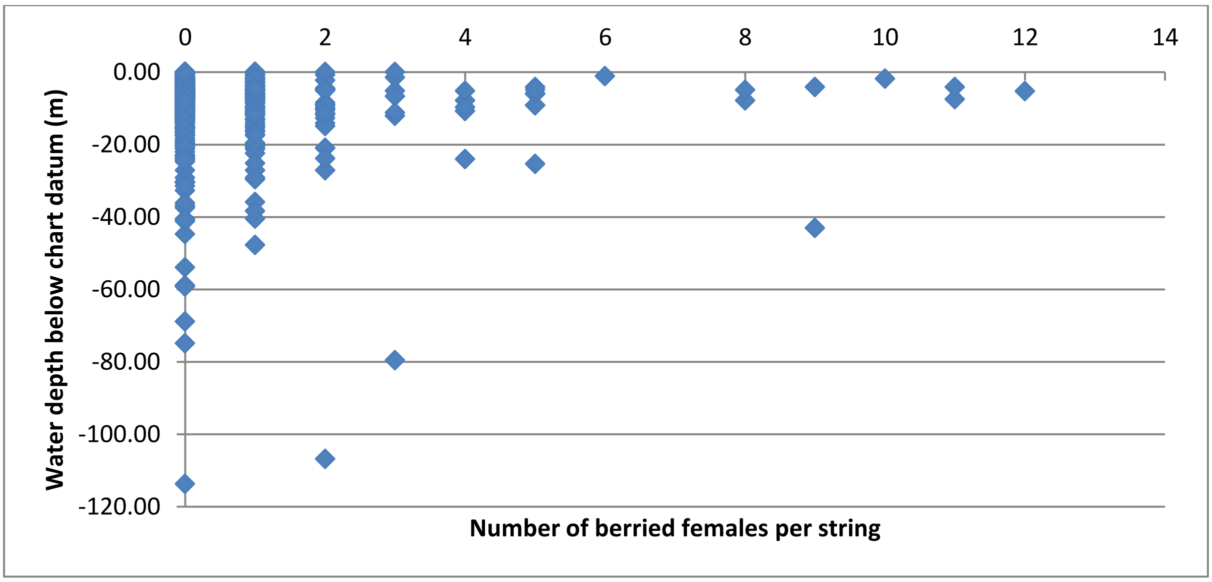


Figure 58: Number of berried females per string plotted against water depth.

A similar inverse relationship is also shown with seabed slope (Figure 59), although over 50% of berried females are found at slope angles of greater than 5°. When habitats were classified into broad substratum categories, it appears that 48% of berried females were caught over bedrock or boulders, and a further 21% over cobbled areas (see Figure 60). Notably there was a higher proportion (21%) of berried females caught over sand habitats than in the overall numbers caught (which equated to 14%).

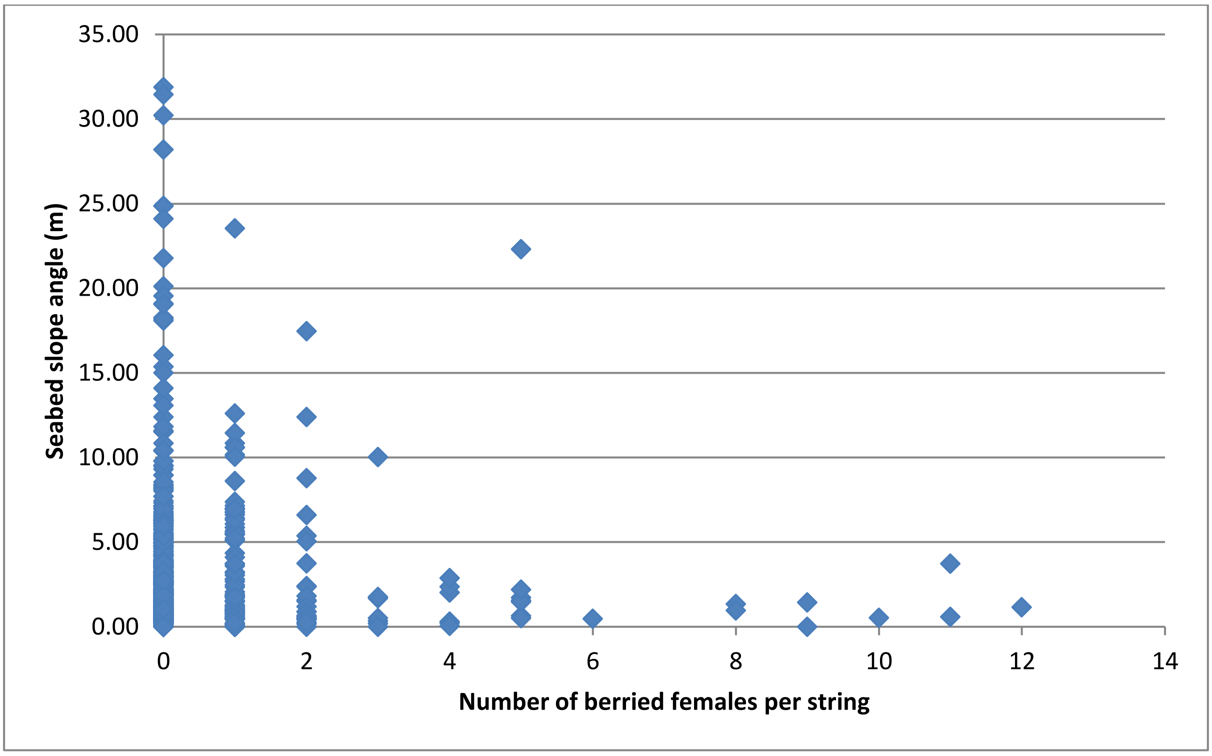


Figure 59: Number of berried females per string plotted against seabed slope angle.

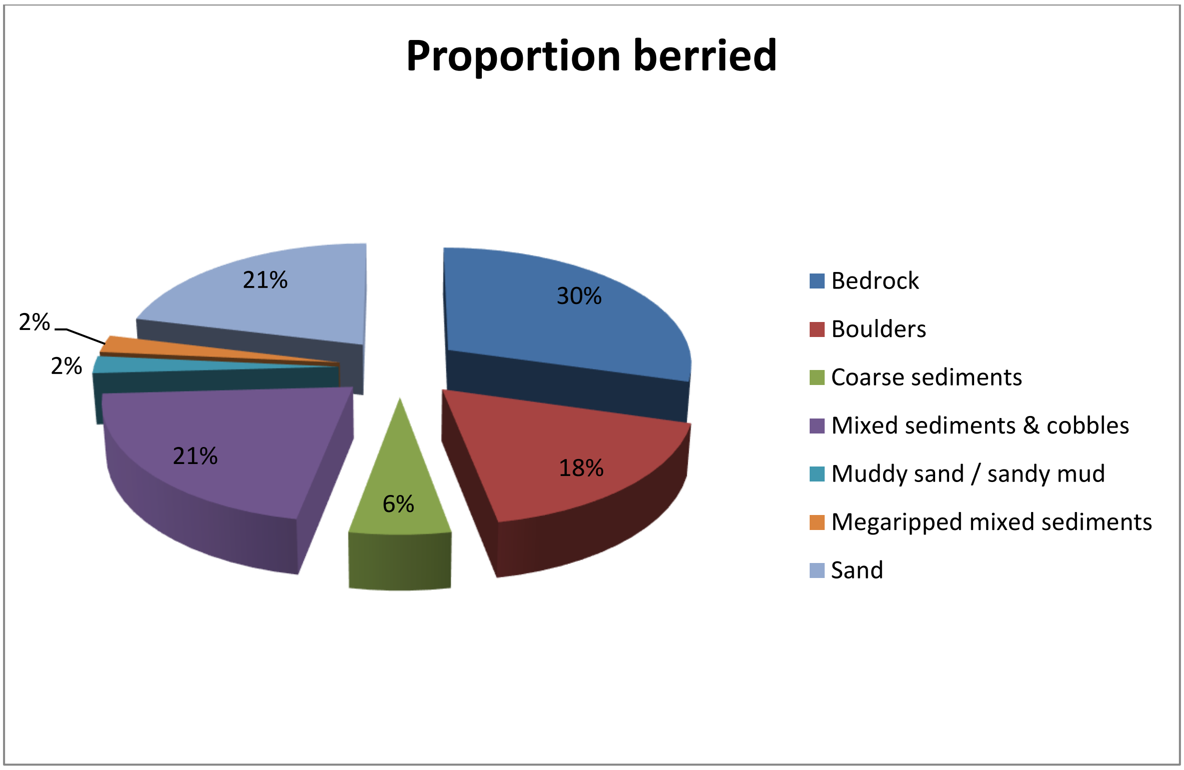


Figure 60: Proportion of berried lobsters caught from strings over each substratum type.

V-notched lobster abundance was plotted against habitat type, as shown in Figure 61 below. Very similar relationships with water depth and seabed slope angle were found for V-notched lobsters as for berried females and the lobster abundance per string overall (see Figures 62 and 63 below). Similar proportions of V-notched females were found in each substratum category derived from the detailed habitat maps as for berried females (see Figure 64 below), although fewer were found over sandy areas and more on coarse sediment areas. When the V-notched females which were also berried (Figure 65) are examined, 56% were caught on bedrock and boulder habitats, 16% on mixed sediments with cobbles and 13% on sand. If sand and coarse sediments are considered, the proportion of berried or V-notched females caught on these substrata seems to be similar.

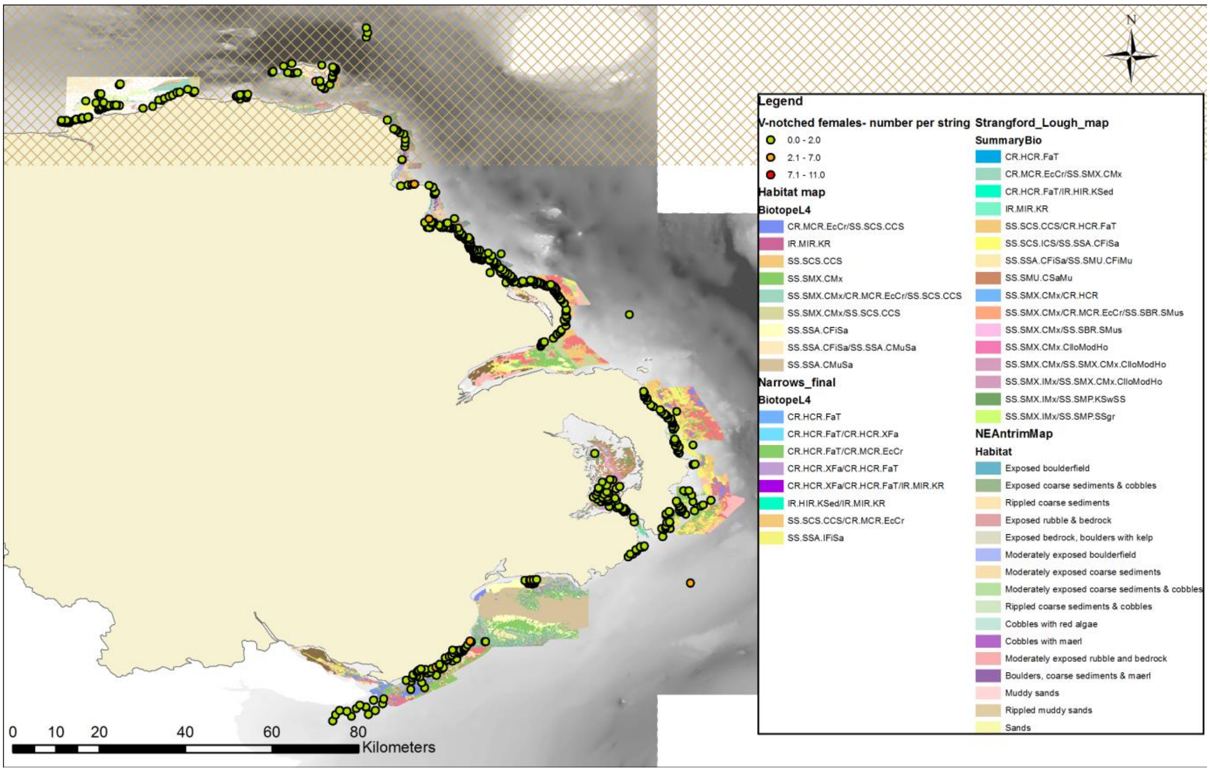


Figure 61: V-notched lobsters per string overlaid on habitat map data.

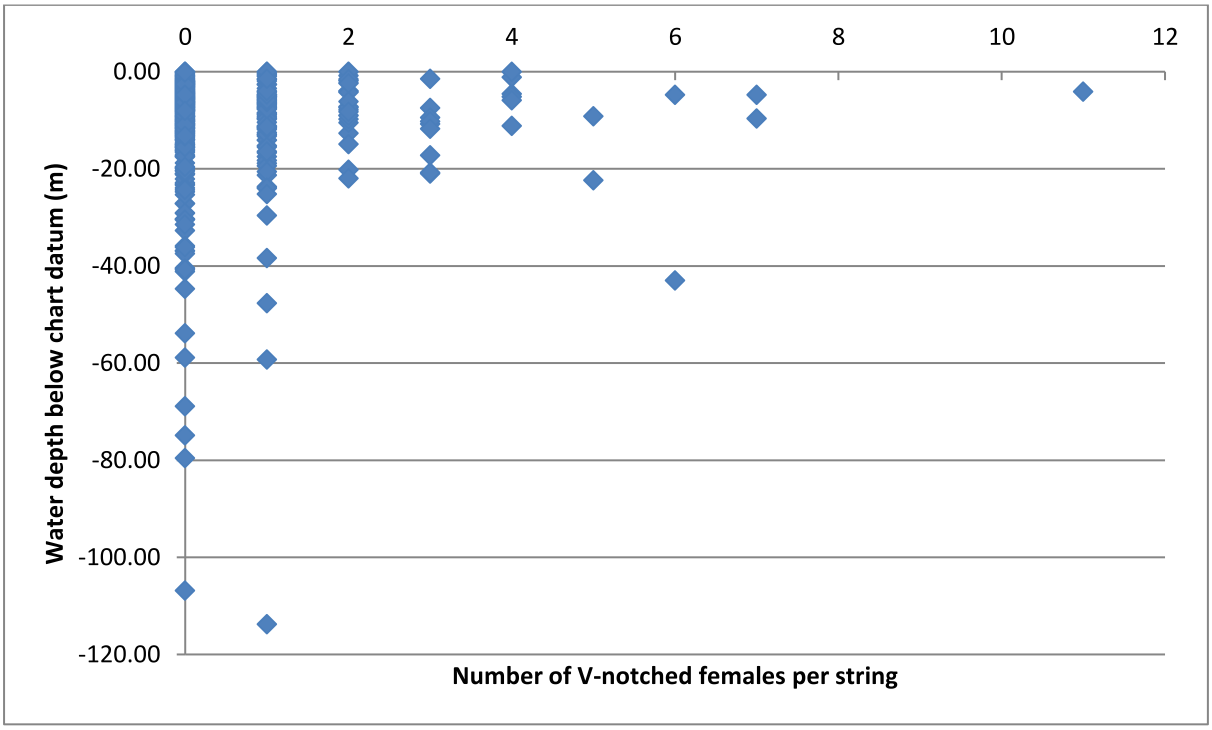


Figure 62: Number of V-notched females per string plotted against water depth.

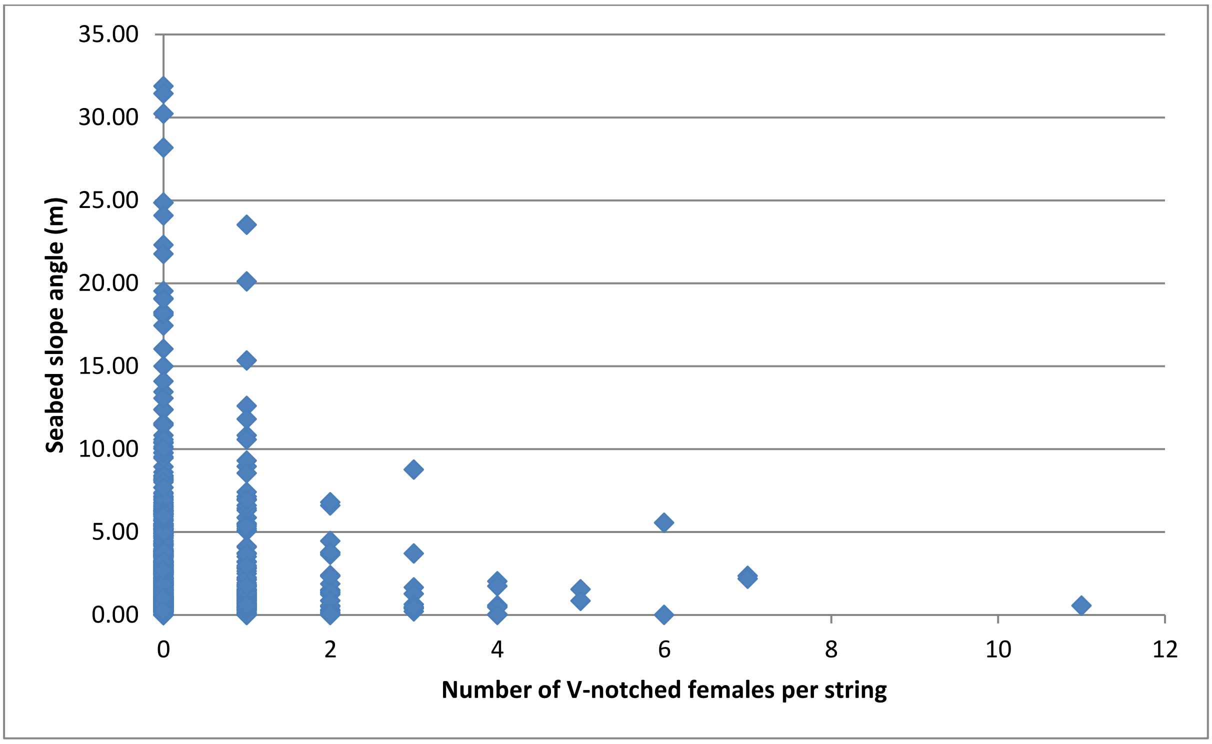


Figure 63: Number of V-notched females per string plotted against seabed slope angle.

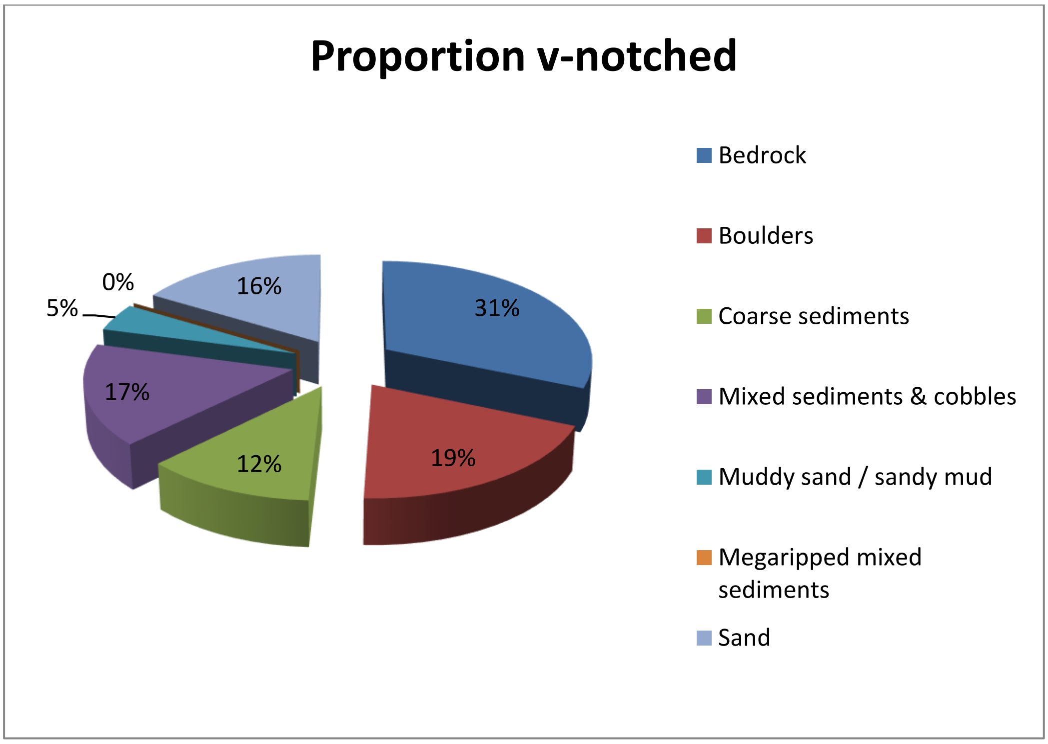


Figure 64: Proportion of V-notched lobsters caught from strings over each substratum type.

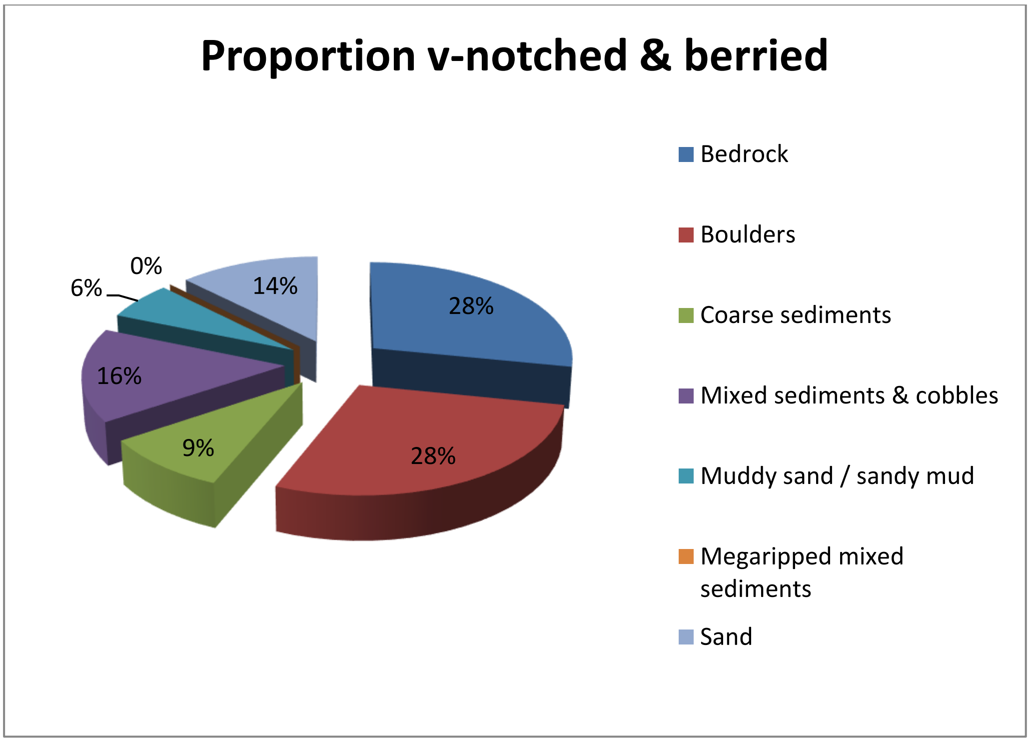


Figure 65: Proportion of V-notched and berried lobsters caught from strings over each substratum type.

4.5 Genetic Analysis

4.5.1 Sampling, data quality and summary statistics

In between 2003 and 2014 (11 years covered by the NELCO scheme, 26,777-berried lobsters were v-notched by NELCO members (average 2,231 lobsters v-notched every year). A breakdown of the number of v-notched samples per month/year is given in Table 14. Data (not shown) from interview questionnaire involving NELCO members indicates that for every 5 lobsters landed, one is v-notched and returned into the sea.

Resulting genetic data was of very good quality with 90% of the screened samples fully screened over 70% of the marker loci. Summary population genetic statistics is shown in Table 15. Nine to 23 alleles (avg. 12.5) were found to be segregating per locus with average locus observed heterozygosity ranging from 45 to 87% (71% over all loci). The polymorphic information content (PIC) per locus ranged from 0.4 to 0.9 (~0.7 over all loci). There was no evidence for departures from HWE suggesting a health stock. There was also no evidence for high incidence of null-alleles that could compromise parentage assignment.

The typing “error rate” (attributed human genotyping error, presence of “null alleles” and natural allele mutation) estimated both through empirical testing and computer driven simulations was found to be between 0.01-0.02 across all marker loci. This low error rate is similar to other error rate reported in the literature for microsatellite DNA analysis and, indeed, are considered the default setting values used in many software packages for parentage and pedigree analysis (Riester *et al*., 2009).

Table 14: Breakdown of the number of lobster v-notched by NELCO members, and used for genetic analysis, covering the period between the start of the scheme in 2003 and 2014.

Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
January				88	7	14	11			100	394		614
February			21	9		6	304		98	136	23		597
March		43	87	206		117	252		229	38			972
April		202	181	168			194		64	350			1,159
May	150	222	562	411		130	928		76		10		2,489
June	408	317	125	195	10	149	322	646	293	235	85		2,785
July	178	238	280	111	269	40	298	162	600	112	176		2,464
August	198	322	58	29	410	137	319	306	357	774	374		3,284
September	275	434	375	47	291	962	412	202	167	582	58	346	4,151
October	289	129	319	26	414	283	264	41	287	611	302	183	3,148
November	127	139	449		412	178	481	208	141	331	534	406	3,406
December	49	309	179	21	8	99		305	185	329	12	212	1,708
Total	**1,674**	**2,355**	**2,636**	**1,311**	**1,821**	**2,115**	**3,785**	**1,870**	**2,497**	**3,598**	**1,968**	**1,147**	**26,777**

Table 15: Summary population genetics statistics derived from the NELCO parental pool sample set of 2003-2004 (N=1,546) as follows: number of observed alleles per locus, observed (Hobs) and expected (Hexp) heterozygosity, locus polymorphic information content (PIC), probability of null alleles (P NULL) and statistical significance for test for departures from Hardy Weinberg Equilibrium (HWE). 'ns' – non significant.

Locus	Alleles	Hobs	Hexp	PIC	P NULL	HWE
1	9	0.641	0.654	0.608	0.006	ns
2	23	0.908	0.911	0.905	0.003	ns
3	22	0.87	0.867	0.855	0	ns
4	14	0.834	0.867	0.853	0.016	ns
5	10	0.718	0.721	0.684	0	ns
6	10	0.779	0.765	0.733	0	ns
7	15	0.828	0.826	0.803	0	ns
8	9	0.565	0.604	0.569	0.029	ns
9	7	0.44	0.456	0.401	0.018	ns
10	8	0.669	0.658	0.593	0	ns
11	10	0.536	0.541	0.438	0.004	ns
Avg.	**12.5**	**0.708**	**0.715**	**0.677**		

4.5.2 Temporal stability of genetic stock

Summary results (graphical format) for testing for temporal stability in the genetic make-up of the NELCO lobster stock during the period covered by the scheme is presented in Figure 66. Thus, a comparison of the genetic make-up of the parental poor (2003-2204) with that of samples collected over subsequent years (including those containing potential offspring) indicates good genetic stability. These findings suggest that 1) the sample sizes in each case comprise good representation of the local lobster stocks and 2) the NELCO scheme, as presently run, is not affecting the genetic make-up of the local stock.

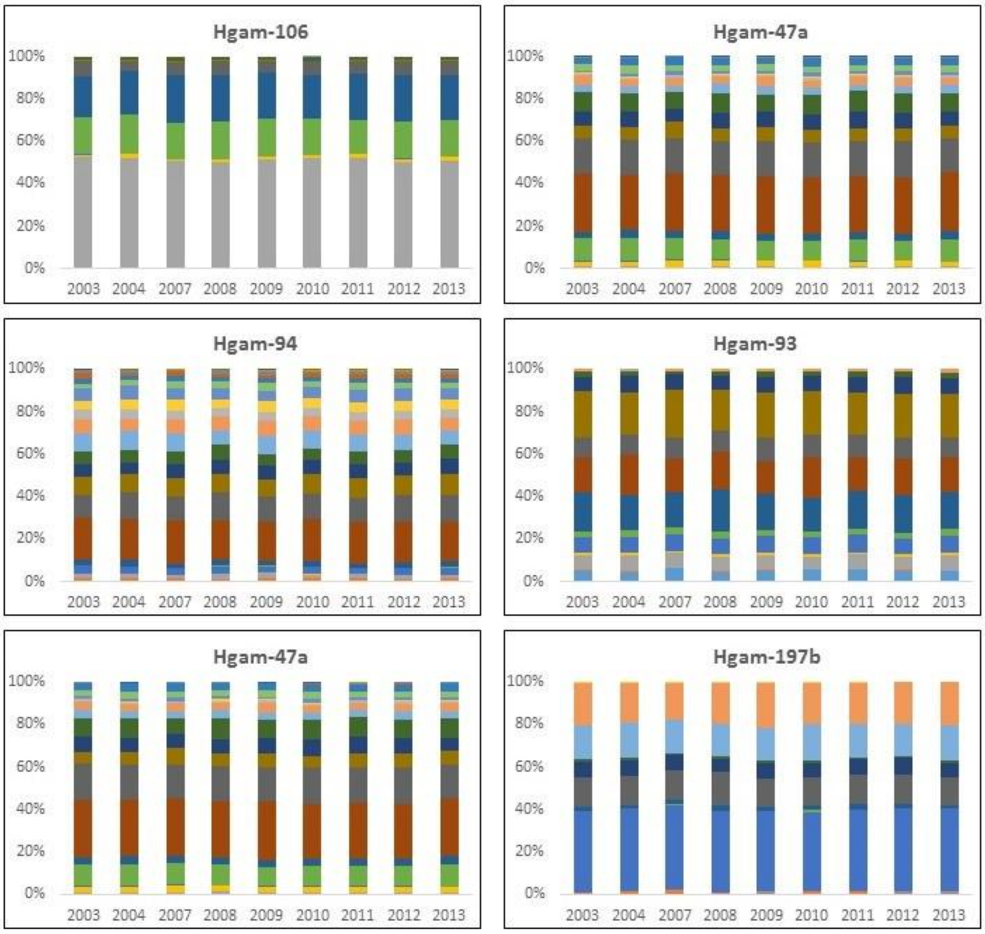


Figure 66: Allelic frequencies distribution for six randomly selected marker loci used to screen samples from the NELCO lobster v-notching scheme. In each case, allele frequencies are represented per year as a multi-colour bar. The different colours represent distinct alleles and the size proportion of the colour in each bar represents the frequency of particular alleles.

4.5.3 Assessment of markers for parentage analysis

Estimates for exclusion probabilities per locus and accumulated over loci, derived from the marker loci used in this report, for distinct scenario is provided in Table 16. While there is variation in the exclusion probabilities among individual loci/ distinct parentage scenarios, the cumulative exclusion probability for parentage assignment (irrespective of scenario considered) is higher than 0.99, clearly illustrating the usefulness of the selected marker set for lobster parentage analysis.

Table 16: Exclusion probabilities per locus and combined over loci for the following scenario: 1) the first parent known (EX 1P), 2) second parent known (EX 2P), and 3) parent pair known (EX PP). The (ID) probability of identity (i.e. probability that two randomly drawn individuals from the stock share the same genetic profile by chance) and the (IDsib) sibship i.e. "brothers"/"sisters" exclusion probability (i.e. probability of not detecting sibships).

Locus	EX 1P	EX 2P	EX PP	ID	IDsib
1	0.243	0.415	0.601	0.166	0.465
2	0.7	0.823	0.951	0.014	0.298
3	0.589	0.742	0.905	0.03	0.324
4	0.579	0.735	0.895	0.032	0.324
5	0.325	0.504	0.699	0.115	0.418
6	0.38	0.561	0.752	0.087	0.389
7	0.481	0.654	0.831	0.053	0.35
9	0.105	0.23	0.365	0.351	0.61
10	0.236	0.391	0.56	0.182	0.467
11	0.148	0.245	0.369	0.314	0.558
Combined	**0.996**	**1**	**1**	**0**	**0**

Additional evidence for the usefulness of the genetic marker set employed for lobster parentage assessment is also provided by how accurately it can be used to distinguish between genetically "related" and "unrelated" individuals. Summary results (in graphical format) of such analysis is presented in Figure 67. Queller and Goodnight (1989) relatedness estimator was calculated for each pair of lobster individuals within the parental 2003-2004 pool including offspring. Related individuals (i.e. parent-offspring, full-sibs, half-sibs), by default, invariably display high levels of genetic relatedness (i.e. positive values >0.18 in the Queller and Goonight relatedness scale) in comparison to unrelated individuals, which are characterised by low level of relatedness (<0.18 including negative values). There is a clear separation between "related" and "unrelated" group with little overlap between groups (i.e. area of uncertainty). Results suggest great potential for using this marker set for extended lobster pedigree reconstructions (i.e. identifying individuals representing extended family groups, thus greatly augmenting volume of information that can be reverted into management)

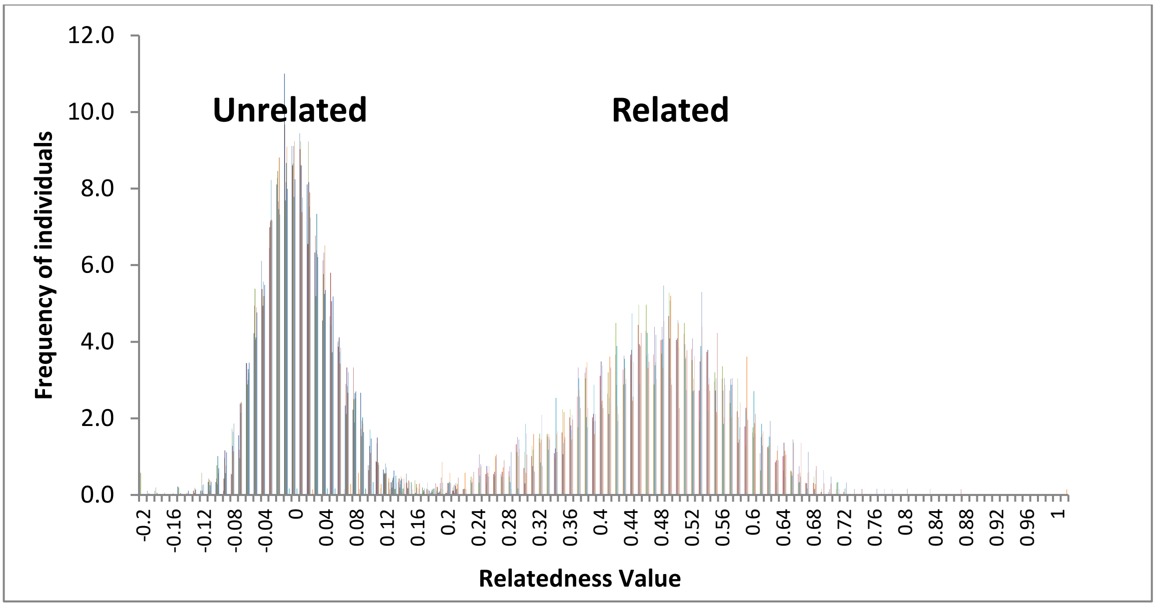


Figure 67: Frequency distribution (histogram) of relatedness coefficients estimates (Queller and Goodnight, 1989) for known lobster families (mother and offspring groups i.e. "Related") versus those from groups comprised of randomly drawn individuals (i.e. "Unrelated")

FAP analysis in *Predictive* mode for both the full complement (N=11) and selected panel (N=6) of markers confirm that the power of the marker set for parentage assignment is very high. Thus, over 99.99% and 99% of simulated samples (derived from genetic information from the parental pool 2003-1004) can be unambiguously assigned to family with 11 and 6 marker loci respectively.

4.5.4 Parentage analysis

The results of both *FAP* analysis (*Assignment* mode) assuming 2 and 3 allele mismatches (genotyping error rate of ~0.01) are summarised in Tables 17.A and 17.B. The offspring of lobsters v-notched in 2003-2004 start to appear in the fishery (as berried females) in relatively small numbers (between 1% and 6% of berried lobsters) in 2007 (four years after hatching). Numbers increase substantially to peak in 2009 (between 14% and 42% of berried lobsters), six years after hatching, and level out between 9%-10% and 30%-34% from 2010 to 2013. The overall estimated contribution of the NELCO v-notching scheme to the local lobster fishery ranges between 9% and 33%. In practical terms, this means that in between from 2007-2013, 9% to 33% of all lobster landed by NELCO originate from the v-notching scheme. The results of *FRANZ* analysis are similar to those generated by *FAP* and for simplicity they are now shown.

Tables 17.A and 17.B. Summary statistics for *FAP* analysis (*Assignment* mode) assuming 2 and e allele mismatches (error rate of allele calls of ~0.01). Results are displayed by year and include: 1) number of v-notched lobsters (NELCO scheme); 2) number of lobsters assigning to the 2003-2004 parental pool; 3) DARD recorded landings (metric tons); 4) estimated number of lobsters based on DARD recorded landings (converted from weight landings); 5) estimated number of lobsters derived from the NELCO scheme (i.e. offspring of families comprising the 2003-2004 parental pool); 6) estimated contribution (weight in metric tons) derived from the NELCO scheme; and 7) % contribution of NELCO V-notching scheme to the local lobster fishery. In each case, totals are also provided.

A)

Calendar Year	Sampled:- V-notched berried per year	FAP assignment - 2bp mismatch	DARD recorded Landings - NELCO (tons)	Estimated No. of lobsters based on DARD landings	Estimated No. of lobsters derived from NELCO V-notching scheme	Estimated weight (tons) - NELCO scheme contribution	% contribution of NELCO v-notching scheme to fishery
2007	1,821	13	31	48,129	333	0.2	1%
2008	2,144	200	29	46,494	4,334	2.7	9%
2009	3,786	536	27	45,257	6,404	3.9	14%
2010	1,871	189	40	72,874	7,343	4.0	10%
2011	2,497	228	33	55,970	5,102	3.0	9%
2012	3,598	316	44	76,859	6,753	3.9	9%
2013	1,969	195	45	77,195	7,626	4.4	10%
2007-2013	17,686	1,675	249	422,778	37,895	22.2	9%

B)

Calendar Year	Sampled:- V-notched berried per year	FAP assignment - 3bp mismatch	DARD recorded Landings - NELCO (tons)	Estimated No. of lobsters based on DARD landings	Estimated No. of lobsters derived from NELCO V-notching scheme	Estimated weight (tons) - NELCO scheme contribution	% contribution of NELCO v-notching scheme to fishery
2007	1,821	101	31	48,129	2,662	1.7	6%
2008	2,144	818	29	46,494	17,731	11.1	38%
2009	3,786	1582	27	45,257	18,911	11.5	42%
2010	1,871	636	40	72,874	24,768	13.5	34%
2011	2,497	831	33	55,970	18,623	11.1	33%
2012	3,598	1089	44	76,859	23,256	13.4	30%
2013	1,969	662	45	77,195	25,939	15.1	34%
2007-2013	17,686	5,717	249	422,778	131,889	77.3	33%

It is also important to note that the relative contribution (%) of NELCO v-notching scheme to the fishery each year has to be considered as a function of the sample numbers. Thus, the apparent peak in 2009 is relative to higher number of lobsters v-notched in that particular year. In fact, the absolute number of lobster linked to the NELCO scheme each (e.g. "*Estimated No. of lobsters derived from the NELCO v-notching scheme*" in Table 17.A and 17B) start to peak around 2009 and 2010 (i.e. 6,404 - 7,343 Table X.A and 18,911 – 24,768 Table 17.B) and have remained more or less stable until the present but with a noticeable positive trend. See the summaries (in graphical format) of the impact/contribution of the NELCO v-notching scheme is further presented in Figures 68 and 69 for illustration.

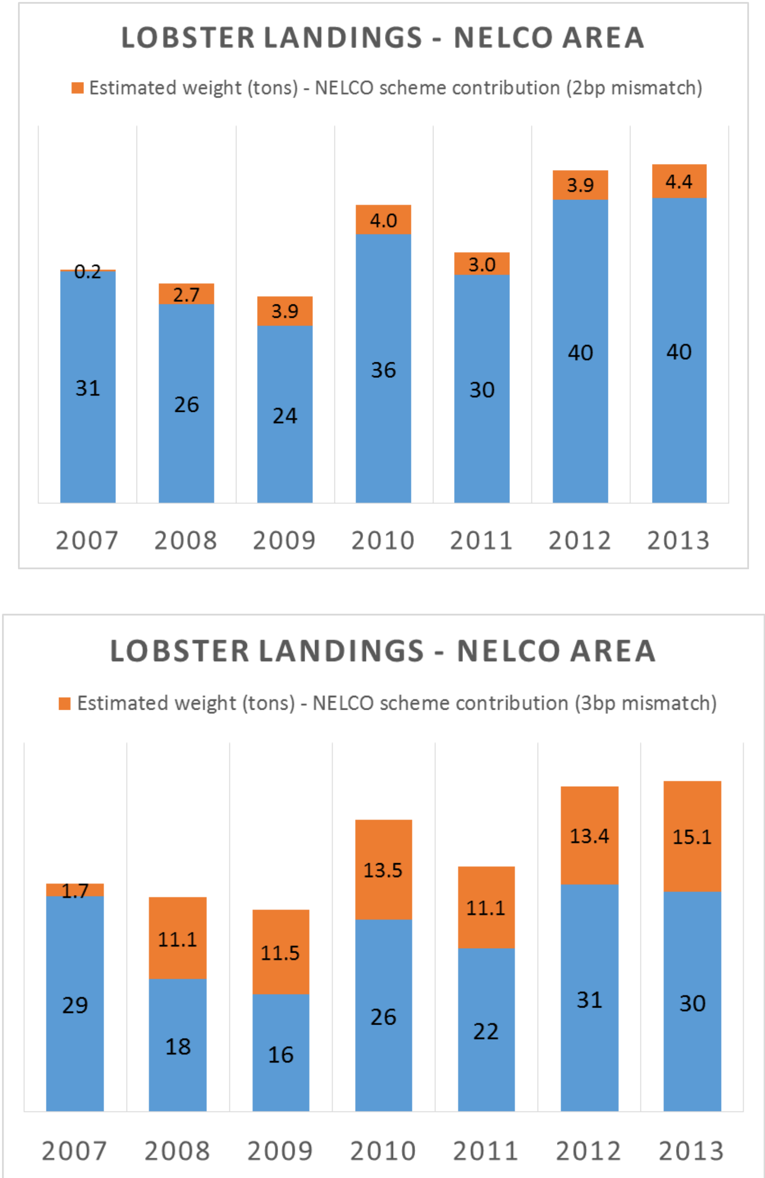


Figure 68. Lobster landings (in metric tons) in area covered by NELCO v-notching scheme.

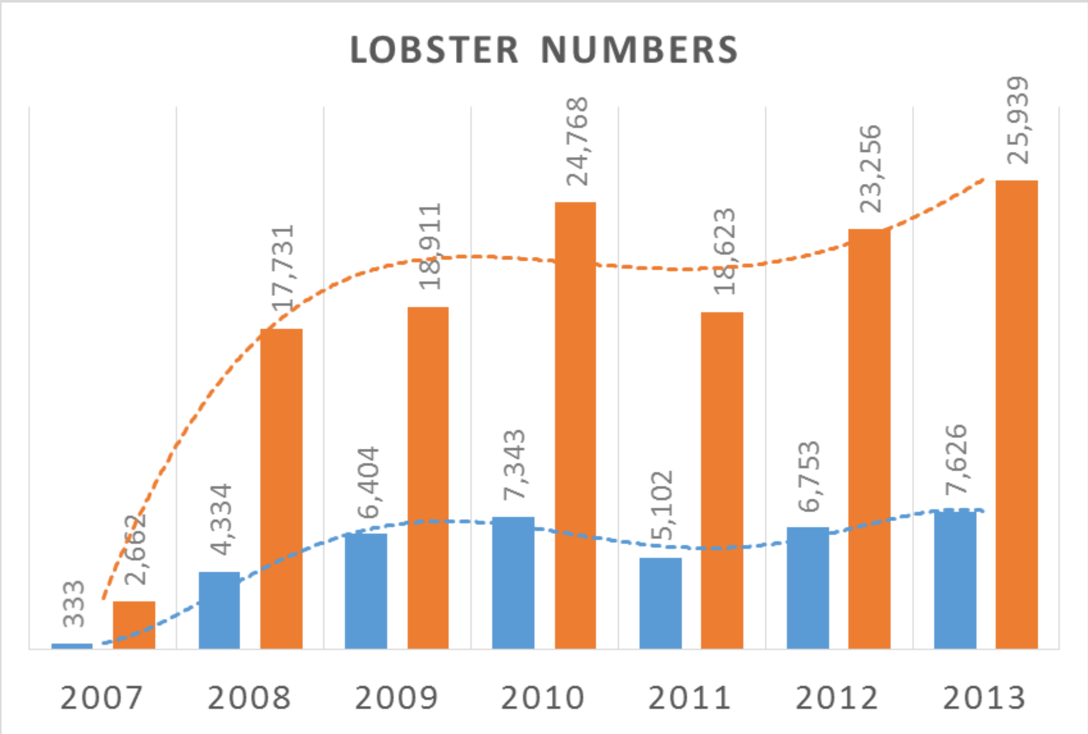


Figure 69: Estimated number of lobsters recruited into the fishery (i.e. berried females) resulting from the NELCO v-notching scheme, assuming 2 (blue) and 3 (red) allele mismatches.

Overall, results suggest that recruitment from the 2003-2004 parental pool has been staggered over a number of years. To further investigate this trend, the individual contribution of female lobsters from different CL size classes was examined. The results are summarised in Figure 70. There is clear bias in recruitment pattern of offspring from larger versus smaller females. In particular, results suggest the larger females recruit later to the fishery in comparison to smaller females. While this could be partially explained by the distinct grow rates of lobsters, it is also possible that this differential pattern is linked to moulting frequency with larger females moulting less frequently in comparison to smaller females.

An additional interesting observation was that a number of the v-notched lobster were caught over multiple years around the same geographical location (Figure 71). While the majority of these, were observed twice, other were observed 3, 4, 5 and up to 9 times from 2003 to 2014. This clearly indicates that many of the v-notched lobster continue to contribute to the local stock for 10 to 15 years or more.

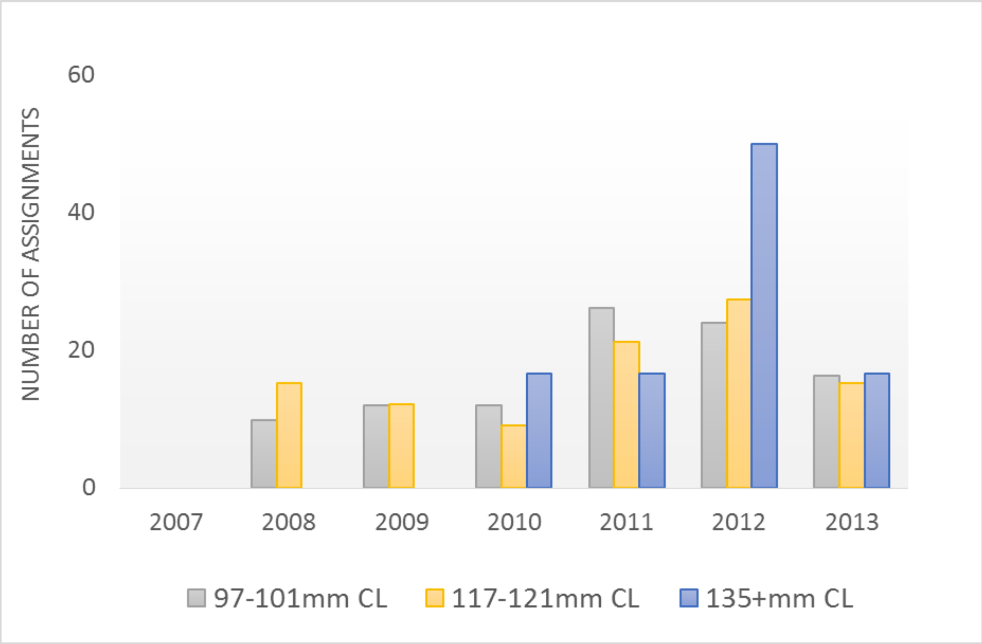


Figure 70: Number of individual assignments per year to the 2003-2004 parental pool as a function of the female's size (CL).

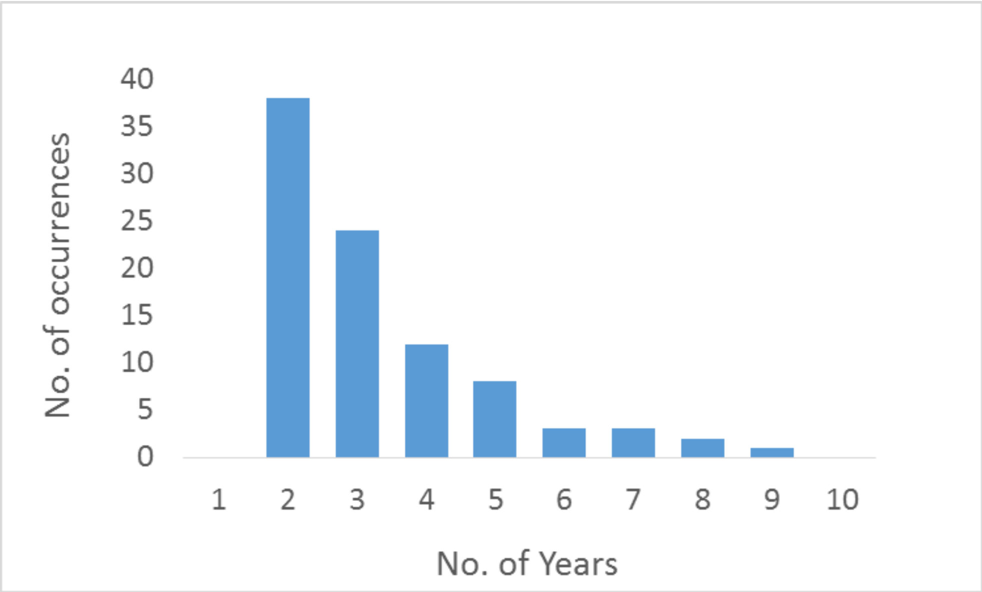


Figure 71: Summary of the number of instances versus number of years that a fraction of the v-notched lobster females remain in the fishery within the NELCO fishing range (Outer Ards and County Down Coast).

4.5.5 Family variance in individual assignment (difference performance of large versus smaller females)

Results from parentage assignment also indicate that almost one third of the families contributing offspring to local stock had more than one recruiting offspring (i.e. more than one offspring recruiting to the stock as a berried lobster (Figure 72). Further analysis examining the correlation between female size and contribution to recruitment clearly indicates a positive correlation. Indeed, it is interesting to note that the families with the most offspring assigning (e.g. 4 families with responsible for 10+ offspring recruiting to the stock in subsequent years) are comprised of larger females with CL ranging from 105 to 120 mm.

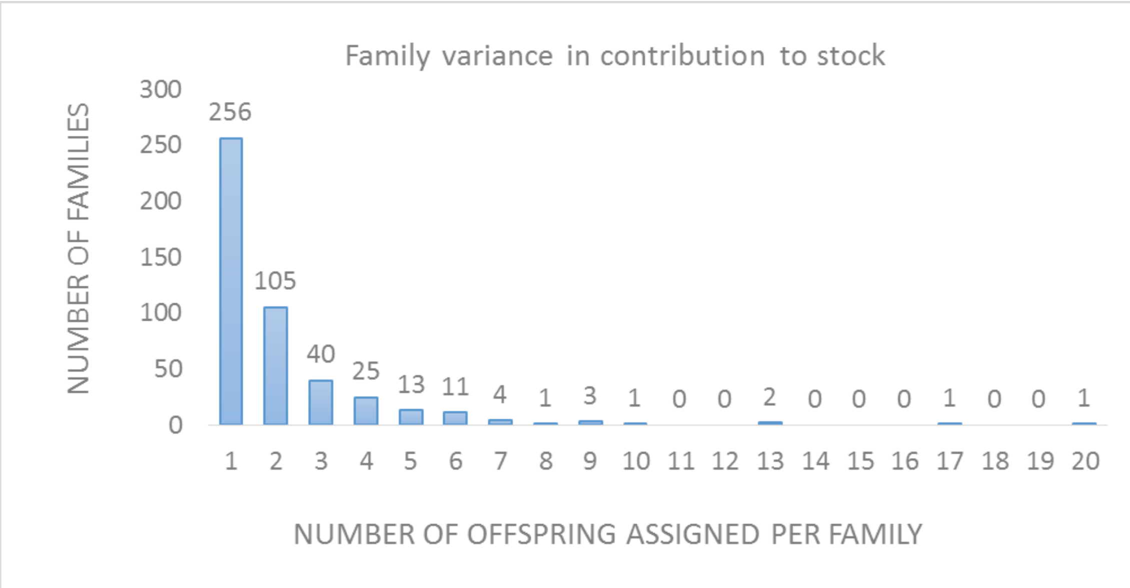


Figure 72: Summary results illustrating the observed variance in the number of offspring assigning to individual families of the 2003- 2004 parental pool.

4.5.6 Larval dispersal and adult recruitment patterns

Comparison of the geographic location of lobsters comprising the 2003-2004 parental pool against the location of lobster caught in the fishery from 2007 onwards assigning to the parental pool allows for an indirect assessment of larval dispersal (i.e. how far an offspring go?). Thus, genetic tagging (through family assignment) offers a viable procedure to track offspring from "fertilised egg" to adulthood. Summary results of individual assignment as a function of geographic location of "mothers" and putative "assigned" offspring are displayed in Figures 73. Overall, 81% of the lobsters caught into the County Down area assign to females also caught into this area during 2003 and 2004. This pattern is not consistent as only 24% of the lobsters caught in the Outer-Ards area assign to females also caught in this area during 2003 and 2004 (Figure 73). For those individuals assigning to females in other areas, results suggest the existence of a biased movement northwards.

The NELCO 2003-2004 parental pool line was also used to verify the origin of individual lobster caught outside the NELCO fishing area. Considering the extended larval pelagic stage of lobsters, it is reasonable to assume that at least a fraction of produced offspring will disperse further than the area covered by the parents as a function of prevailing oceanic currents. In here, adult lobsters caught in the NCLFA area were tested against NELCO 2003-2004 parental pool. Results from parental assignment analysis indicate that 9% of the NCLFA lobsters caught in the Antrim and North Coast of Northern Ireland during 2013 and 2014 can be traced back to the NELCO parental pool. Interestingly, the majority of those assignments are linked to putative parents from the most southern part of the NELCO range (e.g. Carlingford Lough, Dundrum Bay area). Thus, while most recruitment seems to be local, at least a fraction of offspring experience medium/long dispersal pattern. For instance, a berried lobster captured in 2013 from the Rathlin Island fishing area assign (i.e. is the offspring) of a 2003 mother caught at St. Johns Point/Minerstown, County down, a location some over 100 km away.

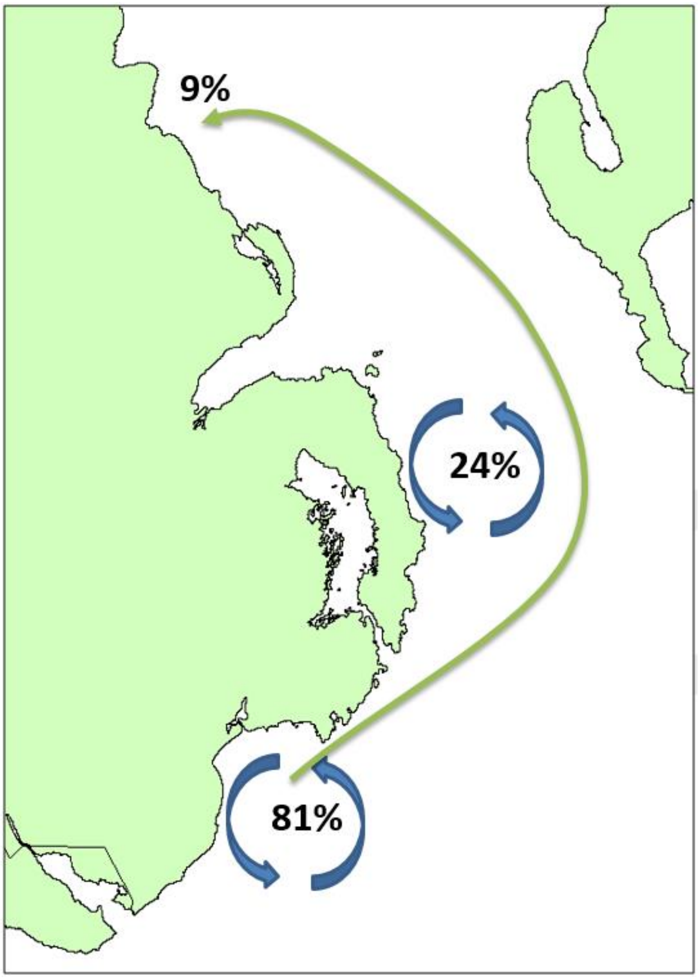


Figure 73: Local recruitment patterns of the NELCO lobster stocks and their percentage assignment rates to the genetic parental baseline (blue arrows) and percentage of lobster caught in the NCLFA area that assign to the NELCO 2003-2004 parental pool.

5. Discussion

Whilst only a small proportion of the total UK landings, the Northern Ireland lobster fishery is important to the Northern Ireland fishing sector, worth an estimated £1 million first sale value in 2014. Whilst the County Down coastline has the highest total landings of lobsters, it is the North Coast and Antrim which shows the highest CPUE. Between 1965 and 1973 the CPUE for Northern Ireland (assumed to be LPUE (Landings per Unit Effort)), decreased from 13.1kg per 100 lobster pots, to 7.0, recovering to 10.1 in 1972 (Watson, 1974). In 1974 Watson reported a higher CPUE in the North coast in comparison to that on the East Coast (all fishing south of 55ºN, at 8.9kg per 100 pots and 5.9kg per 100 pots respectively. This current study also showed a higher CPUE on the North coast.

During this investigation, the average CPUE was 40.6kg per 100 pots with the LPUE averaging at 10.6kg per 100 pots. Whilst this is on par with the historic records the total landings have increased massively from mean landings between 1954 and 1973 of 17 tonnes, to over 100 tonnes in 2014. As the CPUE is similar, even with an increase in landings and effort, the lobster fishery today can be viewed as being in a better condition.

The highest landings of lobsters occur during the summer months, when there are more fishermen targeting lobsters. There is also an increase in landings around Christmas time when the market demand and value per kilo increases. The highest CPUE noted during this study is also between July and September. The tagging study reported peak returns during the summer months. While this could be due to the increased effort on the fishery, it may also be linked to the increased movement of the lobsters during this period. The increased movement of lobsters means that there is an increased likelihood that they will find and enter a pot. This would, therefore, explain the increased catch per unit effort at this time. This increased movement of lobster can be linked to the increase in water temperature during the summer months. Bowlby *et al*. (2007), found that movements of the American lobster decreased by a factor of ten during the cold months of December to April. Being ectothermic lobsters cannot physiologically move as quick when they are colder.

The smallest lobster recorded during this study was 45mm with only small numbers of lobsters less than 70mm being observed. Similar studies have found that smaller lobsters tend not to be captured in the pots. Studies using divers have also reported minimal numbers of small lobsters. This invariably leads to a gap in knowledge from the postlarval lobsters to the size at which they begin appearing in pots.

The length frequency of lobsters captured during this study was reported. Lovewell and Addison, 1986, highlighted the fact that different types of pot retain different size of animals In Northern Ireland there is quite a variation in the types of pot used including soft eye, hard eye, parlour and American pots. In addition, more fishermen are including escape panels in their pots to allow smaller animals to escape thus reducing their sorting time, bait and making a fishing trip overall more time efficient. This, therefore, has to be kept in mind when examining the results.

Strangford Lough lobsters were shown to be larger than elsewhere around the coast. No escape gaps, which would allow smaller lobsters to escape and, thus, skew the length frequency, were present on any of the pots surveyed in Strangford Lough. Growth rates reported through the tagging scheme indicate that the increase in carapace length at moult is largest for lobsters in the Lough. Indeed whilst around the coast the overall percentage of lobsters landed, which are above the MLS is low, it is highest in Strangford Lough with almost 50% of lobsters in the Lough being of a landable size. Addison and Lovewell (1985), and Bannister and Lovewell (1985), suggested that larger lobsters will be present in areas with more suitable habitat. For example, the bigger size of Whitby and Bridlington lobsters in comparison to Norfolk lobsters was suggested to be linked to the presence of large boulders in the Whitby and Bridlington areas. Strangford Lough is a very complex habitat with large areas of boulder fields which provide a good habitat for lobsters.

The length frequency of lobsters was found to be skewed by the presence of large female lobsters, which cause a significant difference in the lengths of males versus females. In a study of the American lobster by Pugh *et al.* 2013, it explained that if the length frequency of a stock is skewed, particularly in the larger size classes, this could prevent the larger females from finding a suitable male to mate with. Not only may it not be possible for the smaller male to physically mate with the lobster, but these smaller males contribute smaller spermatophores. As the fecundity of female lobsters increases with size, this could mean that the limited sperm produced by the smaller males may not be sufficient to fertilise the entire clutch of a large female. Whilst there was no evidence of multiple paternity of egg clutches in this study, it could explain the multiple paternity reported in other investigations. In Northern Ireland, in terms of the larger lobsters, there is selective removal of males as the larger females tend to be protected by a v-notch. In the current study an estimated 30% of lobsters greater than 100mm in length were berried. Therefore it could be that there are insufficient large males available to successfully mate with these females. Considering that larger females are more fecund and tend to result in a larger number of surviving offspring, future v-notching schemes should contemplate the protection of a percentage of males to ensure large females will still be able to contribute to the fishing stock.

Tully *et al*. (2001) reported the fecundity of lobsters in Ireland related to carapace length. He estimated that a lobster of 100mm carapace length would produce some 9,000 eggs as opposed to a 90mm lobster, which would produce some 6,455 eggs. Moland *et al.* (2010), reported findings from their study investigating the influence of maternal size on offspring for the European lobster. They found that egg size increased significantly with the size of the mother. Egg size was found to be linked with larval size with bigger eggs producing bigger and potentially fitter larvae. Thus, it could be assumed that the larger larvae produced by larger females have an increased chance of survival. This hypothesis is supported by the genetic data, which clearly shows a correlation between female size and contribution to recruitment as measured by number of individuals assigning to large females during parentage analysis. Also, larger females produced more consistent sized eggs in comparison to the variable sized eggs produced by smaller lobsters. Taking this evidence on board it is important that larger females are retained in the stock for breeding and again that their breeding potential is met with the presence of larger males.

Estrella and McKiernan (1989) noted, in Massachusetts, that there was a smaller ratio of male American lobster in catches (38-42%) in comparison to females. They hypothesised that this was due to morphological differences in the carapace of male and female lobsters. Females tend to have a wider abdomen to hold eggs and with the width of the animal affecting the ability to escape from a pot, a higher proportion of males can potentially escape over the number of female escapees. This study found no such difference in the overall sex ratio of the lobsters caught.

Berried lobsters started appearing in the catch at 70mm. This is slightly smaller than the figure of 75mm, which is commonly used as the figure for when lobsters start carrying eggs. In the Firth of Forth and the Hebrides the onset of sexual maturity was 82mm and 87mm respectively (Lizarraga-Cubedo, *et al.* 2003). In the Irish lobster Tully (2004) reported that size at maturity (the size at which 50% of female lobsters are mature and capable of spawning) varied from 92-96mm meaning the 87mm MLS only allows approximately 15% of the lobsters to spawn prior to being fished.

Bennett and Brown (1979) indicated that one of the main problems arising when examining stocks of crustacean such as lobsters is the issue of discontinuous growth through moulting and the lack of aging ability. This leads to a difficulty in determining if the modes of a size frequency distribution relate to an age class (i.e. yearly) or a moult class. The use of tags, which are retained through moulting can begin to answer these questions. In recent years tag-recapture programmes have been successfully used around the UK to gain information on the movement of lobsters and the determination of breeding grounds. In this study streamer tags were used as a fast cheap way of tagging lobsters to monitor growth and movement. However, some of the sources of error in tagging studies include the loss of tags, movement of lobsters outside of the fishing grounds, loss of legibility of tag numbers and the under-reporting of recaptured tagged lobsters by fishermen. In this study we got a return in tags of around 9%. This is similar to other tagging studies such as the Cornwall Sea Fisheries Committee 2007-2009 tagging programme, which achieved an overall recapture rate of 9.9% (Cornwall Sea Fisheries Committee, 2010). However, as the tags are retained throughout moult it is hoped that tag returns will continue to be reported by fishermen after this report. Genetic tagging offers a complementary useful approach to assess lobster movement, in particular, when using in combination with parentage assignment analysis.

In this study the analysis on the movement of lobsters showed that the majority of animals were territorial and did not move far from where they were initially tagged. This has been reported by other tagging studies across the UK. Hepper and Coombs, 1965 reported that 86% of lobsters tagged off the Yorkshire coast were recaptured within 2 miles of the point of release. On the South coast of England, 95% of recaptured tagged lobsters had moved less than 3.8km from their initial release site (Smith *et al.* 2001). There was only a weak correlation between the days between captures and the distances moved by the lobsters. This would indicate that it is not time that is limiting their movement but that they are “choosing” to stay in a particular area.

A small number of lobsters did move larger distances. Along the Antrim and Outer Ards coasts there was significant southerly movement by several lobsters. Indeed four lobsters tagged on Antrim coast were recaptured along the Outer Ards coast with two of these lobsters having moved almost 50km from where they were initially tagged. As no fisherman fishes in both locations, it is likely that this is actual movement and not lobsters which have been caught to land and then returned when the tag is noticed.

The largest distance moved was by a male lobster which was tagged in Portstewart and moved 105km to Tory Island, Donegal. These large distances travelled, whilst not common, have been reported in other studies. On the South coast of England lobsters have been reported moving up to 104km in 148 days (Cornwall Sea Fisheries Committee, 2010).

Though the majority of movement reported was along the coastline in County Down several lobsters reported offshore movement of 9-10km. Whilst it has been suggested that the European lobster does not carry out the seasonal migrations inshore and offshore as documented for the American lobster, it would appear that some of our lobsters so indeed move between the inshore and offshore fishing areas. Hepper and Coombs, 1965, reported findings of a tagging study carried out in Yorkshire which showed that some lobsters which were released inshore were caught offshore during the winter indicating some interchange but no evidence of large-scale migrations.

There was no reported difference between the distance travelled by male and female lobsters. *Smith et al*, 2001, also found that, for the European lobster, the distance moved did not differ significantly between male and female lobsters. This lack of difference has also been reported for the American lobster (Bowlby *et al*, 2007). Whilst Agnalt *et al*. 2007, found that berried females travel shorter distances, remaining close to the site at which they are released, lack of recaptures of berried lobsters means that no conclusion can be made from this study on the movement of berried lobsters. In concurrence with Smith *et al*. 2001 there was no correlation between the distance which lobsters moved and the carapace length.

The tagging study also provided estimates on growth of lobsters. Growth at moult averaged around a 13% increase in body size. This is in line with the range of 10_15% which has previously been accepted for the European lobster. In the Isles of Scilly increase in carapace length for males and females was reported at 13.4% and 13.1% change in body size (Kelly-Fletcher and Holt, 2015). Although not significant, in this study male lobsters were found to have a higher growth at moult than females which was most notable for lobsters greater than 80mm. Smaller growth has previously been reported for females (Hepper, 1978; Phillips *et al*. 1980; Schmalenbach *et al*. 2011; Wahle *et al.* 2013). This is explained by the increased energy expenditure at maturity of females in producing and carrying the egg brood. The time between moults may also be increased for both species but in particular for females. The onset of maturity also explains the reduced growth at moult with increasing carapace length (the larger the animal the more energy is diverted to reproduction and away from growth).

The data collected support the documented habitat preferences of lobsters for rocky areas, and also their need for nearby sedimentary habitats, with generally around 50% of lobsters being caught on bedrock or boulder habitats, with the next largest proportion found on mixed substratum with cobbles, and then sands. Upon closer examination of the abundance of lobsters caught in areas where high resolution habitats maps are available, it is clear that higher abundances are found in very heterogeneous areas, particularly where a mosaic of sedimentary and reef habitats are found at fairly short scales. This concurs with the findings of other researchers (e.g. Galparsoro *et al.,* 2008, and Geraldi *et al.,* 2009).

The importance of scale should be emphasised when evaluating the habitat preferences of lobster populations in Northern Ireland. The bathymetric digital elevation model used in this study is of a broad scale resolution ($25m^2$), and although some patterns could be shown between slope angles, terrain ruggedness etc. and lobster abundances, these may not hold true as these data are based on such a broad scale. Where data permit, it would be useful to examine finer scale habitat preferences, for example in areas with higher resolution bathymetric data. The lobster abundance data used have been derived from commercial pot fisheries, which may have their choice of string locations driven not only by potentially suitable lobster habitat but also by practicalities such as proximity to ports, safe working water depths and sea conditions etc. This will inevitably mean that sampling will not estimate lobster abundances in other potentially suitable habitat further offshore, for example, which may skew the habitat preference results. However, where estimates of suitable habitat which is also available to commercial fisheries is required, the datasets gathered in this project are very valuable and further information could still be gleaned using more local scale habitat and environmental data.

The results of the genetics analysis not only confirm those derived from more traditional methods (e.g. dispersal) but also substantially add and provide novel information that can be easily translated into management strategy. Thus, this study provides, for the first time, novel evidence in support of v-notching as a viable and natural management strategy to ensure the long-term sustainability of lobster stocks. Prior to this study, methods used to assess the impact of the v-notching scheme were based on mark-recapture, as well as recording increased landings and/or higher number of undersize lobsters (e.g. Tully, 2004). While useful, these methods do not provide a direct measure linking v-notched lobsters with recruitment. The genetic approach used in this study provides a direct measure of the v-notching program.

The current v-notching scheme run by NELCO has involved the v-notching of some 2,000 berried females, on a yearly basis, since its implementation in 2003. Considering that v-notches will remain on a lobster for 2 to 4 years (depending on the lobster size) the number of v-notched lobsters in the NELCO area, even accounting for natural mortality and loss of v-notches through moulting by a fraction of the lobsters (in particular the smaller lobsters), is likely to be relatively large. Indeed, estimates, based on the observer trips indicate that some 47% of the berried lobsters in the NELCO area are currently protected through v-notching. Considering that some 9% to 33% of these v-notched lobsters are actively contributing to stock recruitment, the value of these lobsters is considerable. Indeed, it is important to note that the estimates (at both ends) are likely to be conservative because of the very stringent parameters used in the parentage analysis. At the higher end, the contribution of v-notched lobster over time could reach well over 50%.

Recruitment is staggered over time, reflecting both variance in performance of lobsters of different size classes (i.e. offspring of larger lobsters tend to take longer to recruit but are more abundant in numbers) and differential grow rates. Any cohort year will be comprised of lobsters of different length classes/ages. Also, many v-notched lobsters are likely to continue to contribute to the lobster for many years; hence a classical recruitment curve where one generation is replaced by the next is unlikely to be achieved for lobsters.

Considering the extended pelagic phase of lobster larvae (2-3 weeks) it was thought that larvae would potentially settle down far from the site of their parents depending on prevailing oceanic currents and wind. The results of this investigation challenges this view. Thus, while some dispersal is clearly happening, most recruitment appears to be local. Thus, larvae are probably able to determine where to go. Most likely this involves vertical movement into the water column thus escaping dispersal by surface currents. Since lobster depend on rocky sheltered substrate, it is reasonable to assume at least some form of selection against dispersal to potentially “unfavourable” habitats.

Over the past 3-4 years, NELCO members have been reporting on an increasing number of undersized lobsters in their pots. Based on the results reported in this study, we can state with reasonable high confidence that this increase is indeed linked with the NELCO v-notching scheme. While, we have no equivalent data (i.e. parental genetic profile) from the NCLFA area, it is reasonable to assume that their v-notching scheme is working similarly to the NELCO scheme. The main difference is in procedure. Since the beginning of the NELCO scheme, lobsters have been v-notched locally and returned to the sea immediately, thus minimising stress associated with caging and transport. While, the effect of this procedure has not been fully assessed, given results presented in here, it would be reasonable to adopt v-notching procedure as currently carried out by NELCO.

6. Recommendations

I. This study has provided unambiguous and novel evidence indicating that V-notching is indeed a viable and very effective management strategy to the ensure long-term sustainability of lobster stocks. For the NELCO v-notching scheme, the contribution (in term of stock recruitment) is currently between 9% and 33% (conservative estimations) and is likely to increase over the next few years, assuming that the scheme will continue. Genetic tagging offers a number of advantages over other more traditional tagging methods. In addition to providing a mechanism to monitor the health of lobster stocks, it also informs on dispersal and connectivity. Thus, genetic tagging should be considered as a tool to be routinely used to assess the stock. Recent advances in molecular biology and technology means that screening costs have been greatly reduced. Given the value of the generated data, the cost/benefit ratio is well worth.

II. The NELCO v-notching scheme has been running for over 11 years, and it should be supported for years to come. It is, as clearly summarised in the results session, a very unique scheme where management is directly linked to research. The cost of the scheme, in terms of grant aid to NELCO members is justified in terms of the benefit of the scheme. The numbers of lobster v-notched per year are reasonable. There is no need for genotyping 2,000 samples/year. Genetic screening should be carried out every 2/3 years on a subset of samples to ensure there are no changes in the stock structure.

III. Additional research is still required to model number of lobsters that should be v-notched to ensure stock sustainability.

IV. Whilst we now have landings and effort data available for all pot fisherman who have a shellfish licence there is a big gap in the knowledge of how much effort is being placed on the stocks by recreational fisherman. Several of the IFCA's operate a scheme whereby all pots must be labelled with a tag. Any pot not correctly labelled is lifted by enforcement officers. They have different colours of tags for commercial pots and recreational pots. Anyone who wishes to fish recreationally has to apply for tags through the IFCA. Whilst the recreational fisherman does not have to provide landings data, this scheme allows the IFCA's to monitor the number of recreational pot fisherman around their district. It also means they have contact details for all people who are hauling pots to allow for full communication. Indeed during the tagging programme, whilst I contacted all commercial pot fishermen I had no method of directly reaching recreational potters (though we did get several returns by hobby fishermen who had searched the tag details on the internet and found out how to return the details).

V. The lobster tagging scheme received returns of recaptured lobsters of just below 9%. Whilst this tallies with other studies it could be higher by providing a small reward for each tag return

VI. A lot of information is contained on landings and effort data. However, as with human nature there is room for input errors and misreading on handwriting. Whilst there is mixed feeling between fishermen about the use of an electronic log sheet, it is recommended that a system is offered to fisherman as an alternative to the current paper forms. This will reduce any handwriting issues and will free more time up for the enforcement officers. It will also be much easier to keep a check on submissions. Indeed this could be offered to recreational fishermen as well who may be willing to provide information on their catches.

VII. Whilst data can be collected by observers they cannot be everywhere and indeed some fishermen do not want an observer on board either from a safety perspective or for other reasons. A form of inshore monitoring system would provide the full extent of the fishery, monitoring temporal and spatial changes as fishermen change target species, fish different ground etc.

VIII. As an important next step in the lobster fishery management, the datasets gathered in this project along with high resolution habitat data derived from multibeam sonar should be used to predict suitable lobster habitat in areas where lobster abundances are currently unknown. This could be used to evaluate the extent and distribution of lobster habitat within the inshore zone, such that availability of this habitat to the pot fishing industry can be assessed and this can contribute to marine spatial planning and management within the coastal zone. This is particularly important in terms of ongoing developments in the coastal zones, whether marine renewables, pipelines and cables or designation of Marine Protected Areas (e.g. Special Areas of Conservation, Marine Conservation Zones), for which the existing uses and value of fishery resource areas must be properly evaluated.

7. References

Addison, J. T. and Lovewell, S. R. J. (1985). "Pot selectivity and the size composition of catches of lobster (*Homarus gammarus* L.) and crab (*Cancer pagurus* L.) on the East coast of England." International Council for the Exploration of the Sea; Shellfish Committee **CM 1985/K: 35**.

Adey, J.M., Atkinson, R.J.A., Smith, I.P., Tuck, I.D. Taylor, A.C. (2006) “The environmental impact of the *Nephrops* creel fishery”*.* Final report to Scottish Natural Heritage 168pp.

Agnalt, A. L., Kristiansen, T.S., Jorstad, K.E. (2007) "Growth, reproductive cycle and movement of berried European lobsters (*Homarus gammarus*) in a local stock of southwestern Norway." ICES Journal of Marine Science **64(2):** 288-297

Agnalt, A. L., E. Farestveit, K. Gundersen, K. E. Jorstad, and T. S. Kristiansen (2009). Population characteristics of the world's northernmost stocks of European lobster (*Homarus gammarus*) in Tysfjord and Nordfolda, northern Norway. New Zealand Journal of Marine and Freshwater Research **43**:47-57.

Bannister, R. C. A. and Lovewell, S. R. J. (1985). "Sampling the size composition of catches of the Lobster (*Homarus gammarus* L.) on the East Coast of England." International Council for the Exploration of the Sea; Shellfish Committee **CM 1985/K:36**.

Bannister, R. C. A. and Addison, J. T. (1995). "Investigating space and time variation in catches of lobster (*Homarus gammarus* (L.)) in a local fishery on the east coast of England." ICES Marine Science Symposium **199**: 334-348.

Bannister (2011) Review of lobster v-notching, cited in, Poseidon (2011) Northern Ireland brown crab strategy. Final report to Northern Ireland Fish Producers Organisation (NIFPO) 102pp.

Bennett, D. B. and Brown, C. G. (1979). "The problems of pot immersion time in recording and analysing catch-effort data from trap fishery." Rapports et proces verbaux des reunions/ Conseil permanent international pour l'exploration de la mer **195**: 186-189.

Bennett, D. B., and Lovewell, S. R. J. (1977). The effects of pot immersion time on catches of lobsters Homarus gammarus (L) in the Welsh coast fishery., Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research.

Bowlby, H. D., Hanson, J. M. and Hutchings, J. A. (2007). Resident and dispersal behaviour among individuals within a population of American lobster *Homarus americanus*. Marine Ecology Progress Series **331**:207-218.

Cheng, J. H. and Chang, E. S. (1993). "Determinants of postmoult size in the American lobster (Homarus americanus). I. D13 is the critical stage." Canadian Journal of Fisheries and Aquatic Sciences **50**: 2106-2111.

Clements, A. and Service, M. (2015a). *In prep.* Bathymetric and Habitat Map for Strangford Lough (Special Area of Conservation and Marine Conservation Zone), Northern Ireland. Report to Department of the Environment (NI).

Clements, A. and Service, M. (2015b). *In prep.* Bathymetric and Habitat Map for Dundrum Bay (Special Area of Conservation and offshore), Northern Ireland. Report to Department of the Environment (NI).

Clements, A., Plets, R., and Quinn, R. (2010). Habitat Mapping of the Skerries/Causeway Proposed Marine SAC. Report for Northern Ireland Environment Agency. University of Ulster.

Cobb, J. S. and Castro, K. M. (2006) *Homarus* Species, in Lobsters: Biology, Management, Aquaculture and Fisheries (ed B. F. Phillips), Blackwell Publishing Ltd, Oxford, UK. doi: 10.1002/9780470995969.ch9

Comeau, M. and Savoie, F. (2001). "Growth increment and moult frequency of the American lobster (Homarus americanus) in the southwestern Gulf of St. Laurence." Journal of Crustacean Biology **21**(4): 923-936.

Cooper, R.A. and Uzmann, J.R. (1980) Ecology of juvenile and adult Homarus, In: Cobb, J.L. and Phillips, B.F. (1980b)The biology and management of lobsters, Volume II Ecology and Management. Academic Press

Cornwall Sea Fisheries Committee (2010). Annual reasearch and monitoring report, 2009. Research Report**: R201001**.

Dybern, B. I., Jacobson, L. and Hallback, H. (1967). On the habitat behaviour of the lobster (*Homarus vulgaris*) in Swedish waters. International Council for the Exploration of the Sea; Shellfish Committee **C.M. 1967/K:3**.

Eno, N.C., MacDonald, D.S., Kinnear, J.A.M, Amos, C.S., Chapman, C.J., Clark, R.A., Bunker, F.St P.D., and Munro, C. (2001) “Effects of crustacean traps on benthic fauna”. ICES Journal of Marine Science **58**: 11-20.

Estrella, B. T., and McKiernan, D.J. (1989). Catch-per-unit-effort and biological parameters from the Massachusetts coastal lobster (Homarus americanus) resource: description and trends. NOAA Technical Report **NMFS 81**.

Factor, J. R. (ed.) (1995) Biology of the American Lobster *Homarus americanus*. Academic Press, San Diego.

Ferguson, A. *et al*. (2002). Genetic diversity in the European lobster (*Homarus gammarus*): population structure and impacts of stock enhancement (http://www.qub.ac.uk/bb-old/prodohl/GEL/gel.html).

Galparsoro, I., A. Borja, J. Bald, P. Liria, and G. Chust. 2009. Predicting suitable habitat for the European lobster (*Homarus gammarus*), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche Factor Analysis. Ecological Modelling **2009**.

Geraldi, N. R., R. A. Wahle, and M. Dunnington. 2009. Habitat effects on American lobster (*Homarus americanus*) movement and density: insights from georeferenced trap arrays, seabed mapping, and tagging. Can. J. Fish. Aquat. Sci 66:460-470.

Gibson, F. A. (1967). "Growth rate and age in Irish lobsters together with references to ovigerous females." International Council for the Exploration of the Sea; Shellfish and Benthos Committee **C.M. 1967/K:4**.

Gibson, R., Hextall, B. and Rogers, A. (2001) “Photographic guide to sea and shore life of Britain and North-west Europe”. Oxford University Press.

Hepper, B. T. and Coombs, R. F. (1965). "Provisional results of a lobster-tagging experiment off the coast of Yorkshire." International Council for the Exploration of the Sea; Shellfish Committee **C.M. 1965/M. 95**.

Hepper, B. T. (1970). "The growth at moulting of lobsters, Homarus velgaris Milne-Edwards, in the Menai Straits, North Wales." International Council for the Exploration of the Sea Shellfish and Benthos Committee, *C.M.1970/K:10*.

Hepper, B. T. (1978). Population dynamics of the lobster *Homarus gammarus* (L) of the coasts of England. Ministry of Agriculture Fisheries and Food, Directorate of Fisheries Research, Lowestoft

Holt, T.J., Rees, E.I., Hawkins, S.J., and Seed, R. (1998) "Biogenic Reefs (volume IX). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs". Scottish Association for Marine Science (UK Marine SACs Project) 170pp.

Jennings, S., Kaiser, M.J. and Reynolds, J.D. (2001) Marine Fisheries Ecology. Blackwell publishing.

Jones, O. and Wang, J. (2009) COLONY: a program for parentage and sibship inference from multilocus genotype data. *Molecular Ecology Resources* 10: 551–555.

Keenan, K., McGinnity, P., Cross, T. F., Crozier, W. W., Prodöhl, P. A. (2013), diveRsity: An R package for the estimation and exploration of population genetics parameters and their associated errors. *Methods in Ecology and Evolution* 4: 782–788. doi: 10.1111/2041-210X.12067

Kilada, R. and Acuna, E. (2015). "Direct age determination by growth band counts of three commercially important species in Chile." Fisheries Research **170**: 134-143.

Kilada, R., Sainte-Marie, B., Rochette, R., Davis, N., Vanier, C., and Campana, S. (2012). Direct determination of age in shrimps, crabs, and lobsters. Can. J. Fish. Aquat. Sci **69**:1728-1733.

Kinnear, J.A.M., Barkel, P.J., Mojsiewicz, W.R., Chapman, C.J., Holbrow, A.J., Barnes, C., and Greathead, C.F.F. (1996) "Effects of Nephrops creels on the Environment". SOAEFD Marine Laboratory, Aberdeen.

Kelly-Fletcher, D and Holt, D (2015) Interim report on the Isles of Scilly IFCA Shellfish Tagging Project Publication Number: IOS IFCA 2015/01

Konovalov, D. A, *et al*. (2004). KINGROUP: a program for pedigree relationship reconstruction and kin group assignments using genetic markers. *Molecular Ecology* 4:779-782.

Lawrence, S., Cowie, L. and Milliken, K. (2015). A new source of bait. Quay Issues.

Linnane, A., Mazzoni, D. and Mercer, J. (2000) 'A long-term mesocosm study on the settlement and survival of juvenile European lobster *Homarus gammarus* L. in four natural substrata', *Journal of Experimental Marine Biology and Ecology* 249, pp. 51-64.

Lizarraga-Cubedo, H. A., I. Tuck, N. Bailey, G. J. Pierce, and J. A. M. Kinnear. (2003). Comparisons of size at maturity and fecundity of two Scottish populations of the European lobster, Homarus gammarus. Fisheries Research **65**:137-152.

Loo, L. O., Baden, S. P. and Ulmestrand, M. (1993). Suspension feeding in adult *Nephrops norvegicus* (L.) and *Homarus gammarus* (L.) (Decopoda). Netherlands Journal of Sea Research **31**:291-297.

Lovewell, S. R. J. and Addison, J. T. (1986). "Further pot selectivity experiments in the fisheries for lobster and crab on the east coast of England." International Council for the Exploration of the Sea; Shellfish Committee **C.M. 1986/K:7**.

McCandless, D. and Stockdale, L. (2004) 'Lobster 'v-notching' final report', North Eastern Sea Fisheries Committee.

Mitchell, A.J. and Service, M. (2004). Northern Ireland Nearshore Subtidal Habitat Mapping Project. Report to the Environment and Heritage Service and the Department of Agriculture and Rural Development.

Moland, E., Moland-Olsen, E. and Stenseth, N. C.. (2010). Maternal influences on offspring size variation and viability in wild European lobster *Homarus gammarus*. Marine Ecology Progress Series **400**:165-173.

OSPAR Commission (2009) “Background Document for *Modiolus modiolus* beds”. Biodiversity series. 28pp.

Phillips, B.B., Cobb, J.S. and George, R.W. General Biology In; The biology and management of lobsters, Volume I Physiology and Behaviour (1980). Academic Press

Prodöhl, P. A., Jørstad, K. E., Triantafyllidis., A., Katsares, V. and Triantaphyllidis, C. (2006). European lobster – *Homarus gammarus*. In: Geneimpact Final Scientific Report **(**http://www.imr.no/genimpact/filarkiv/2007/07/european_lobster.pdf/en**)**

Pugh, T. L., Goldstein, J. S., Lavalli, K. L., Clancy, M. and Watson III, W. H. (2013). At-sea determination of female American lobsters (*Homarus americanus*) mating activity: Patterns vs. expectations. Fisheries Research **147**:327-337.

Richards, P. R. and Wickens, J. F. (1979). Lobster culture research. M. o. A. F. a. Food. Lowestoft. Laboratory Leaflet **No.47**.

Rousset, F., 2008. Genepop'007: a complete reimplementation of the Genepop software for Windows and Linux*. Molecular Ecology Resources* 8: 103-106.

Schmalenbach, I., Mehrtens, F. Janke, M. and Buchholz, F. (2011). A mark-recapture study of hatchery-reared juvenile European lobsters, *Homarus gammarus*, released at the rocky island of Helgoland (German Bight, North Sea) from 2000 to 2009. Fisheries Research **108**:22-30.

Sheehy, D. (1976) Utilization of artificial shelters by the American lobster, *Homarus americanus*. Journal of the Fisheries Research Board of Canada **33**: 1615-1622

Sheehy, M. R. J., Shelton, P. M. J., Wickins, J. F., Belchier, M. and Gaten, E. (1996) Ageing the European lobster, *Homarus gammarus,* by the lipofuscin in its eyestalk ganglia. Marine Ecology Progress Series **143**:99-111.

Sheehy, M. R. J., Bannister, R. C. A., Wickins, J. F. & Shelton, P. M. J. (1999) New perspectives on the growth and longevity of the European lobster (*Homarus gammarus*). *Canadian Journal of Fisheries and Aquatic Sciences* 56, 1904–15.

Shellfish and Benthos Committee (1974). Report of the meeting of the ad hoc group for the study of the European lobster (Homarus gammarus), Dublin 12-14 March. International Council for the Exploration of the Seas. **C.M. 1974/K:3**.

Skog, M. (2009). "Male but not female olfaction is crucial for intermoult mating in European lobsters (Homarus gammarus L.)." Chemical Senses **34**: 159-169.

Smith, I. P., Jensen, A. C., Collins, K. J. and Mattey, E. L. (2001). Movement of wild European lobsters *Homarus gammarus* in natural habitat. Marine Ecology Progress Series **222**:177-186.

Taylor, H (1975) “The Lobster: its life cycle”. Sterling Publishing Co.

Taggart, J. B. (2007), FAP: an exclusion-based parental assignment program with enhanced predictive functions. *Molecular Ecology Notes*, 7: 412–415. doi: 10.1111/j.1471-8286.2006.01616.x

Telsnig, J. D. (2014). Final report: An assessment of the impact of v-notching European lobsters in the Northumberland district., Newcastle University. MSc in International Marine Environmental Consultancy**:** 25.

Tully, O. (2001). "Impact of the v-notch technical conservation measure on reproductive potential in a lobster, (*Homarus gammarus* L.), fishery in Ireland." Marine and Freshwater Research **52**(8): 1551-1558.

Tully, O., Roantree, V., and Robinson, M. (2001). Maturity, fecundity and reproductive potential of the European Lobster (*Homarus gammarus*) in Ireland. Journal of the Marine Biological Association of the United Kingdom **81**:61-68.

Tully, O. (2004). Integration of biology and management in lobster fisheries. The biology and management of clawed lobster (Homarus gammarus L.) in Europe. O. Tully, Bord Iascaigh Mhara. Fisheries Resource Series **No 2**.

Waddy, S. L., Aiken, D. E. & Kleijn, D. P. V de. (1995) Control of growth and reproduction In: J. R.Factor (Ed.) Biology of the American Lobster *Homarus americanus* Academic Press, San Diego.

Wahle, R. A., Incze, L. S. & Fogarty, M. J. (2004) First projections of American lobster fishery recruitment using a settlement index and variable growth. *Bulletin of Marine Science* 74, 101–14.

Wahle, R.A., Castro, K.M., Tully, O. and Cobb, J.S. (2013) Chapter 8, Homarus In: (ed. B. Philips) Lobsters Biology, Management, Aquaculture and Fisheries. Second Edition. Wiley Blackwell.

Watson, P. S. (1974). "The Northern Ireland lobster fishery 1954-1973." International Council for the Exploration of the Sea; Shellfish and Benthos Committee **C.M.1974/K:19**.

Watson, W. H., Golet, W., Scopel, D. and Jury, S. (2009). Use of ultrasonic telemetry to determine the area of bait influence and trapping area of American lobster, *Homarus americanus*, traps. New Zealand Journal of Marine and Freshwater Research **43**:411-418.

Welby, P. R. (2014). Crab and lobster stock assessment research report 2014., Eastern Inshore Fisheries and Conservation Authority.**:** 49.

Wright, D. J., Lundblad, E. R., Larkin, E. M., Rinehart, R. W., Murphy, J., Cary-Kothera, L. and Draganov, K. (2005). ArcGIS Benthic Terrain Modeler, Corvallis, Oregon, Oregon State University, Davey Jones Locker Seafloor Mapping/Marine GIS Laboratory and NOAA Coastal Services Centre. Accessible online at: http://www.csc.noaa.gov/products/btm/ .

Wright, D.J., Pendleton, M., Boulware, J., Walbridge, S., Gerlt, B., Eslinger, D., Sampson, D., and Huntley, E. (2012). ArcGIS Benthic Terrain Modeller (BTM), v. 3.0, Environmental Systems Research Institute, NOAA Coastal Services Centre, Massachusetts Office of Coastal Zone Management. Available online at http://esriurl.com/5754.