Monitoring Intertidal Community Change in a Warming World

By

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Abstract

If the earth's climate is warming as predicted, the effects of this environmental change may begin to appear along a range of biological scales, including ecosystems, communities, populations and individual species. The intertidal rocky shore is a useful system for monitoring changes due to its accessibility, readily sampled organisms and well-documented ecology. Using the rocky intertidal as a model system, historical work and a modern day survey were used to detect changes in the abundance and distribution of invertebrate and algal species around the Irish coastline. Firstly, the major contributions to Irish rocky shore community ecology in the literature throughout the past 50 years were identified and assessed. One of these historical studies was then used as a baseline with which a modern day survey could be compared. Throughout the summer of 2003, a re-survey was carried out using the same semi-quantitative (*i.e.* abundance scales) methodologies as the historical survey. Results showed that after a 50-year time interval, 12 intertidal species out of the 27 re-surveyed changed significantly in abundance. These changes are discussed within the context of the species effects of climate change on the Irish coast. The methodologies used throughout the historical survey and the modern day re-survey were critically assessed with particular reference to the results obtained by different operators and the sensitivity of the methods to detecting change. During the re-survey, quantitative data were collected for two trochid species *Osilinus lineatus* and *Gibbula umbilicalis.* A detailed description and analysis of their population structure (*i.e.* size and age) and density around the Irish coastline was conducted. In particular, the population characteristics of shores at the 'edge' and 'centre' of both species distributions in Ireland were examined. The 2003 resurvey and the in-depth look at the populations of two trochid species may be used throughout future monitoring at the community and population level.

CHAPTER 1

General Introduction

1.1 Climate Change

Data collated by the International Panel on Climate Change (IPCC, 2001) suggests that the global land temperature has increased by 0.6 ± 0.2°C throughout the 20th century and is predicted to continue increasing. In Ireland, climate models have predicted a warming of the land temperature by just over 1°C by the year 2050 (Sweeney and Fealy, 2002). Changes in sea temperature lag behind those on land (for at least the last 50 years) and are expected to warm by approximately half the rate of the air (IPCC, 2001). This rise in temperature could greatly affect ecosystems, communities and populations of organisms, by causing alterations in ecosystem functioning, changes in the distribution, abundance and fitness of species, and alterations in the behaviour and morphology of biota (Parmesan *et al.*, 2000; Walther *et al.*, 2002). Predictions also suggest that sea level may rise, cloud cover may increase, ozone layer rejuvenation may be delayed leading to a possible increase in UV-light intensity, extreme events (such as storms and droughts) may increase, and the intensity of the El-Niño Southern Oscillation (ENSO) phenomenon may increase throughout the next century (IPCC, 2001). Depending on the physical and biological attributes of species' habitats, the effects of these predictions will vary. Marine habitats, particularly intertidal regions, may be most vulnerable to changes in air and sea surface temperatures, sea level rises, increases in UV-light penetration and increases in wave action due to increased storminess.

1.2 Rocky Shore Ecology

As rocky shores are found at the interface between land and sea they are exposed to physical pressures from both realms (Menge and Branch, 2001). Littoral zones support a large diversity of life, primarily marine organisms, ranging from microscopic species to macro-flora and -fauna. It is a well-studied system and as such the environmental factors affecting rocky shore organisms are well known (Stephenson and Stephenson, 1949; Southward, 1958; Connell, 1972). Intertidal regions have provided a useful model system for examining a variety of ecological issues including competition (Connell, 1961; Menge, 1976), predation (Connell, 1961; Menge, 1976) and keystone species (Paine, 1966). Despite a long and in-depth literature, some of the fundamentals of intertidal ecology are continually being questioned. The generality of zonation has been examined more closely in recent studies as research has found that consistency along shores (*i.e.* horizontal variability) is scale dependant (Benedetti-Cecchi, 2001). Although much is known about the ecology of rocky shore species, their distributions can be patchy and unpredictably variable through space and time (Underwood *et al.*, 2000). This unpredictability makes it difficult to understand fully what factors contribute to species fluctuations on rocky shores, an issue particularly relevant to broader scale studies such as climate change research.

The Irish coastline is 7,524 km long and the most dominant intertidal substrate type is rocky shore at over 40% (Neilson and Costello, 1999). Naturalists in Ireland have studied the organisms on rocky shores for centuries. However, it is only in more recent times that rocky shore populations and communities have been quantitatively researched. Although smaller-scale studies based on individual species or assemblages have enhanced our understanding of community regulation, larger scale approaches are needed to provide a basis for understanding the effect of large scale processes on the marine environment, such as pollution and climate change (Thompson *et al.*, 2002). Many rocky intertidal species have life spans of 5 to 25 years and as a result, they have the potential for long-term population stability (Lewis, 1996). The intensities of competition, grazing and predation, as well as environmental factors, however, may cause a large amount of variability at various temporal and spatial scales (Lewis, 1996). Thus long-term monitoring, incorporating these scales, is required to extract major trends in community changes (Southward, 1995). It has been shown that benthic (e.g. intertidal) communities can fluctuate naturally over scales ranging from days to decades and meters to hundreds of kilometres (Lewis, 1999). An understanding of the natural fluctuations of species in space and time can assist in distinguishing between natural changes and those caused by human disturbances.

1.3 Historical studies and Monitoring

In order to detect changes in the natural environment and to predict future developments it is essential that we know how much variation has occurred in the past (Southward and Boalch, 1994). Historical studies add much to our knowledge of rocky shore community dynamics by providing evidence for the fluctuations in population and community structure through time and, depending on the scale of the study, through space. Many recent studies have used historical research to contribute to the 'bigger picture' of a species or an assemblage's variability through time (Marawski, 1993; Beebee, 1995; Crick *et al.*, 1997; Visser *et al.*, 1998; Parmesan *et al.*, 1999; Post *et al.*, 1999; Sagarin *et al.*, 1999; Thompson and Ollason, 2001; Burrows *et al.*, 2002; Genner *et al.*, 2004). These studies utilized data collected over a number of years to draw conclusions of species changes in relation to climatic fluctuations. Examining historical data allows us to understand the natural fluctuations of species and thus allows ecologists to begin distinguishing amongst changes which may be natural and those that may be due to human influences. Understanding underlying natural patterns is important and necessary for the rational management, conservation and monitoring of marine systems in the future (Jackson, 2001).

As humans are having a detrimental effect on natural systems, it is important that monitoring programmes and ecological studies are undertaken. Large-scale monitoring of ecosystems can be costly and time consuming, and in order to reduce these problems, indicator species have been used as model or surrogate organisms for the changes undergone by an entire community (Pearson, 1994; Gladstone, 2002). However, identifying species to act as indicators can be difficult. Generally, the species chosen should fill a number of criteria including ease of sampling, taxonomic stability and well-known ecologies and distributions (Pearson, 1994; Jones and Kaly, 1996; Gladstone, 2002).

Monitoring is a basic tool for management (Jackson, 2001), and as such is essential for protecting biodiversity and defining nature reserve boundaries. Nature reserves and other natural landscapes may be vulnerable to human disturbances such as pollution, habitat loss and climate change (Halpin, 1997). Under current climate change scenarios (see above) many of the areas we are attempting to conserve may be altered. In order to facilitate in the management and conservation of natural areas and species, historical studies along with current and future monitoring research are essential.

1.4 Aims of Research

There were three main objectives during this thesis (Figure 1.1). Firstly, past studies were investigated to detect what data of value they could provide regarding the abundance and distribution of rocky shore species in Ireland. Secondly, one of these historical studies was used as a baseline for possibly detecting the effects of climate change on rocky shore communities using a modern day re-survey. Finally, the populations of two trochid species, *Osilinus lineatus* (da Costa) and *Gibbula umbilicalis* (da Costa), were studied in greater detail to provide a baseline for future changes at the population level. Therefore the aims of the research conducted throughout this thesis were to:

1) Document and investigate the historical intertidal rocky shore surveys conducted in Ireland over the past 50-years.
2) Utilize a historical study, which was identified as an important baseline survey, to examine the changes in the abundance of intertidal biota around the Irish coastline after a 50-year time interval, in the context of climate change predictions.
3) Determine the extent to which the effect of different operators could have contributed to the changes found.
4) Critically assess the methods used throughout the re-survey to determine if they are appropriate for monitoring future change in the rocky intertidal of Ireland.
5) Document and analyse the population structure of two trochid species around the Irish coast to gain an understanding of the population characteristics (*i.e.* size, density and age) and thus possibly aid in future monitoring. In particular, populations at the 'edge' and 'centre' of both species distributions in Ireland were examined for differences in population characteristics.

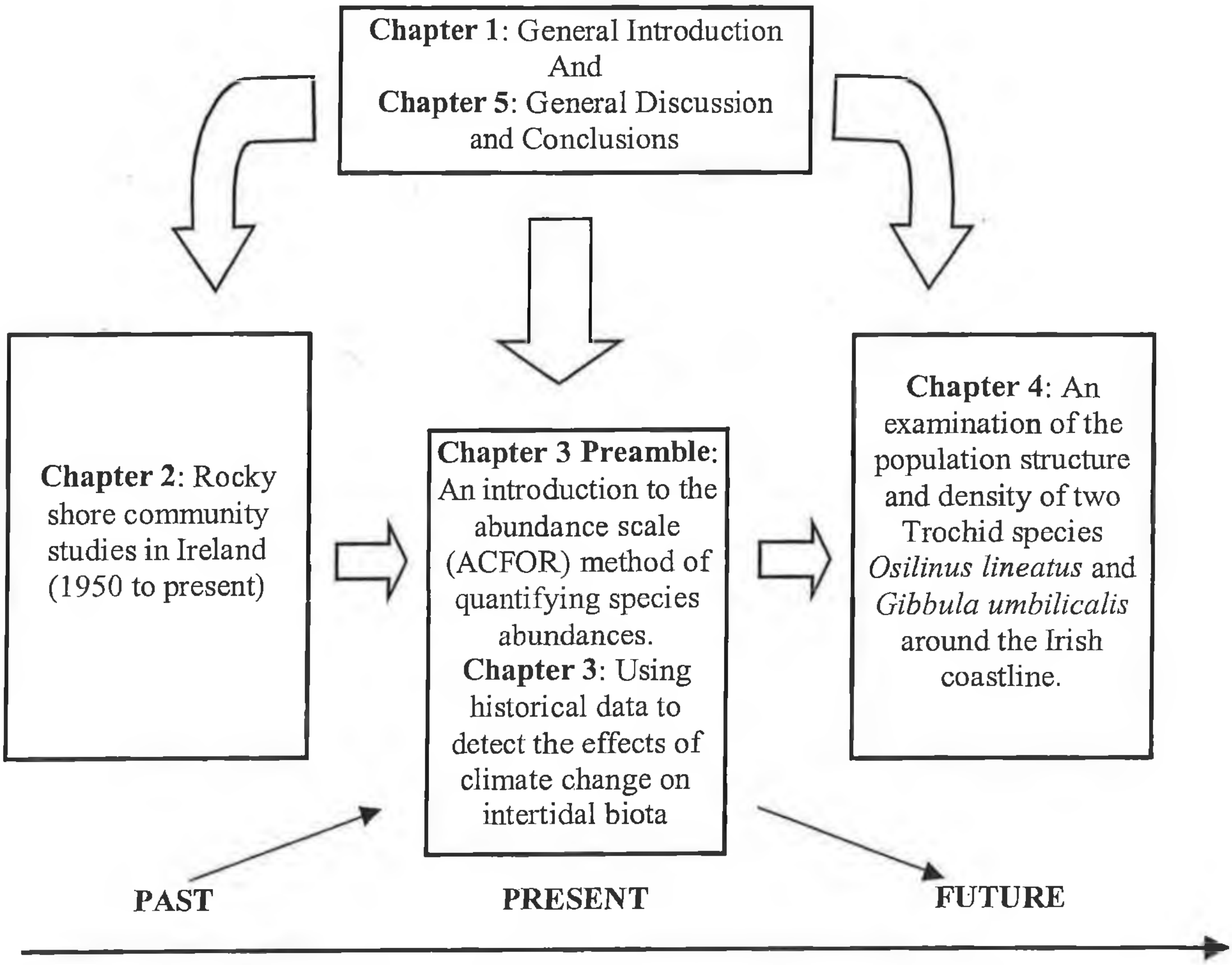


Figure1.1: Schematic diagram showing the layout and order of the five thesis chapters.

CHAPTER 2

Rocky Shore Community Surveys in Ireland (1950 to Present)

Abstract

Historical surveys of the rocky intertidal region of Ireland may provide data on the distribution and abundance of species. These data, depending on the quality, may be used during modern day analyses as a baseline for detecting change. Since the 1950's, twelve rocky shore community surveys have been undertaken in Ireland. Two of these surveys were very extensive and covered the entire coastline, while the other ten were conducted within a restricted locality or region. The surveys relied on a variety of methods involving transects, quadrats, pin-frames and sampling within undefined areas such as 'zones of most abundance'. Data were collected quantitatively and qualitatively, with the majority of surveys using semi-quantitative abundance scales. An aim, of many of the surveys, was to document the abundance of species as a baseline for future monitoring. To this end, shores were carefully documented and raw data are often present in the published works. Three of the surveys described here are re-surveys of work previously conducted, allowing for comparisons between two time periods. The methodologies used throughout each survey were critically assessed. Although each survey varied in methodologies and quality of results, they have each added to our knowledge of the rocky intertidal communities of Ireland.

2.1 Introduction

The sea has been an invaluable resource to Ireland for centuries as a primary source of food and wealth. In order for this to continue there has been a growing appreciation of the need for monitoring and conserving marine life and habitats. This has led to a recent development of action plans and assessments of marine biodiversity, which have been critical in identifying the strengths and weakness of marine research in Ireland (Costello, 2000). In particular Costello (2000) noted a lack of research and baseline data on intertidal rocky shores around Ireland.

This work is intended to be a review of the intertidal rocky shore community surveys that have been completed in Ireland (Republic and Northern) since the 1950's. There have been many surveys concentrating on the rocky intertidal zone throughout the past 50 years, however, I have chosen only those which assess the entire community (flora and fauna) or a large subset of the community present. There are twelve such works, two of which are very extensive and cover the entire coastline, and ten others that concentrate primarily within a certain locality or region (Figure 2.1 and Table 2.1). It is also important to note that 3 of these regional surveys were re-surveys of communities that had been previously examined. The first two surveys discussed (Southward and Crisp, 1954b and Picton and Costello, 1998) are those that were conducted over the Irish coastline (Republic and Northern Ireland). The third survey discussed (Wilkinson *et al.*, 1988) was regionally based and covered the Northern Ireland coastline. The final nine surveys were locally based and are listed under the geographical area in which the survey was carried out.

2.2 Rocky Intertidal Surveys

<u>Southward and Crisp, 1954b</u>

Throughout the summers of 1950, 1952, 1953, 1958 and 1975 Professor Alan Southward and Dr. Dennis Crisp conducted a semi-quantitative survey of the Irish rocky intertidal coastline (including Northern Ireland). Overall they

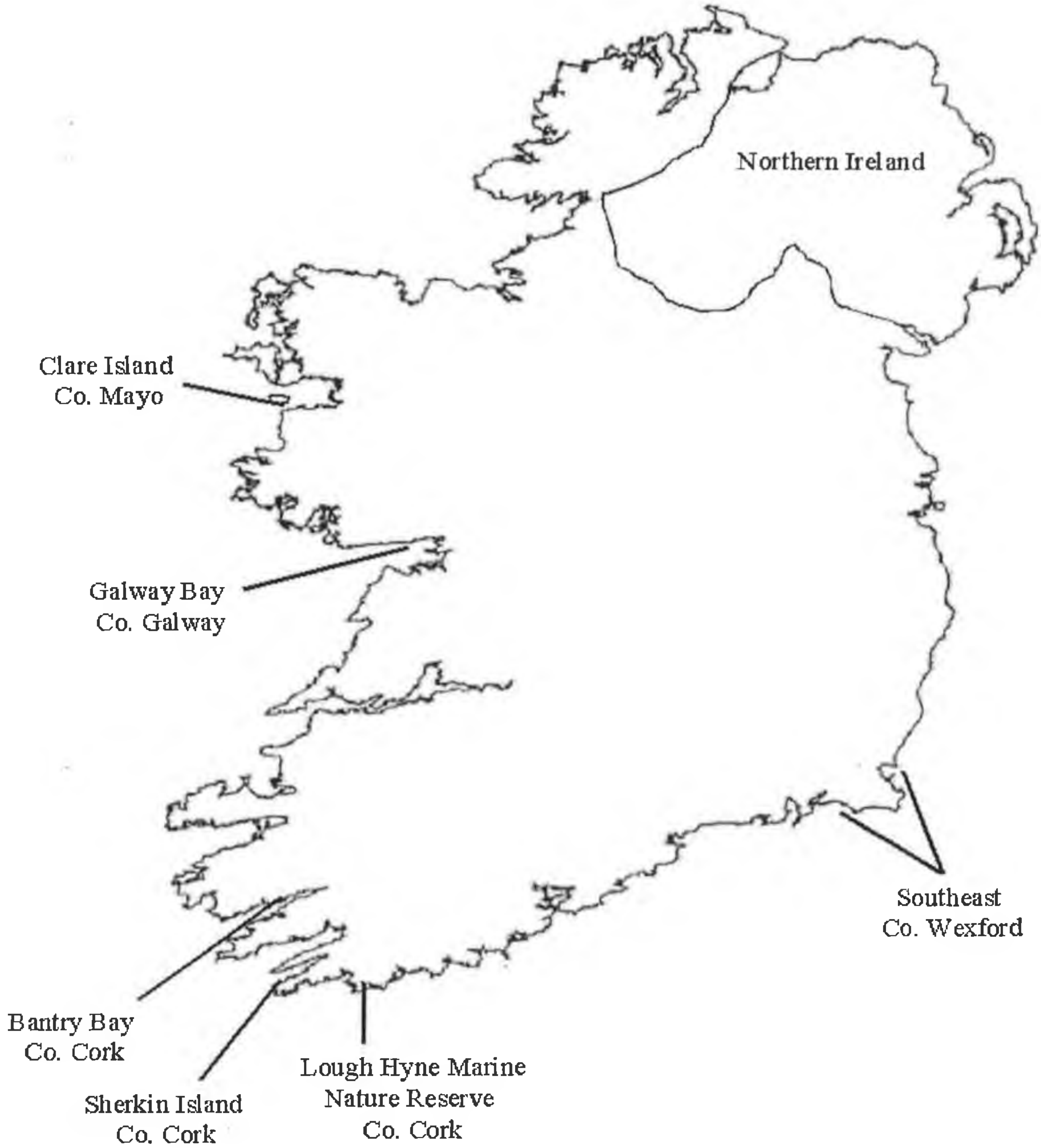


Figure 2.1: Map of Republic of Ireland and Northern Ireland showing areas where previous rocky shore community work has taken place. Note that the two surveys that covered the entire island and the one survey that covered Northern Ireland's entire coastline are not shown. Also, two surveys were conducted in Lough Hyne Marine Nature Reserve, Co. Cork and three surveys were conducted in Bantry Bay, Co. Cork.

Table 2.1: Intertidal rocky shore community (flora and fauna) surveys conducted in Ireland from 1950 to present.

Study	Location	Years	Scale Assessed	Data
Southward and Crisp, 1954b	Irish Coastline	1950, 1952, 1953, 1958, 1975	Spatial	Quantitative and Semi-quantitative
BioMar LIFE (Picton and Costello, 1998)	Irish Coastline	1992-1997	Spatial	Semi-quantitative
Wilkinson *et al*., 1988	Northern Ireland	1984-1988	Spatial	Quantitative and Semi-quantitative
Healy and McGrath, 1998	Southeast, Co. Wexford	1976-1979	Spatial and Temporal	Quantitative and Semi-quantitative
Bishop, 2003	Sherkin Island and West Co. Cork	1975-Present	Spatial and Temporal	Quantitative and Qualitative
Ryland and Nelson-Smith, 1975	Galway Bay, Co. Galway	1967-1971	Spatial	Semi-quantitative and Qualitative
Ebling *et al*., 1960	Lough Hyne, Co. Cork	1955	Spatial	Semi-quantitative and Qualitative
Little *et al*., 1992	Lough Hyne, Co. Cork	1990-1991 (Resurvey of 1955)	Spatial and Temporal	Semi-quantitative
Crapp, 1973	Bantry Bay, Co. Cork	1970-1971	Spatial	Semi-quantitative
Baker *et al*., 1981	Bantry Bay, Co. Cork	1975 (Resurvey of 1970-1971)	Spatial and Temporal	Semi-quantitative
Myers *et al*., 1980	Bantry Bay, Co. Cork	1978-1980	Spatial and Temporal	Quantitative
O'Riordan *et al*., 2002.	Clare Island, Co. Mayo	1992, 1994, 1995 (Resurvey of 1915 survey)	Temporal	Quantitative

examined 205 sites with 165 in the Republic and 40 in Northern Ireland (Alan Southward, personal communication). Twenty-five of these sites were visited more than once (17 sites in the Republic and 9 in the North), thus providing a temporal scale. The survey was initiated as an investigation into the distribution of barnacles (Southward and Crisp, 1954a) and as a result there is quantitative barnacle count data for a number of shores. Throughout the survey 42, invertebrate species and 11 algal species were sampled semi-quantitatively, although for most of the sites only subsets of these organisms were recorded. On each shore the 6-point abundance scale (abundant, common, frequent, occasional, rare and absent (ACFOR) was used to assess species abundance. The ACFOR category appropriate for each species was given by searching the area of most suitable habitat. Each species was therefore assessed within their 'zone of most abundance'. The abundance categories are based on those published in 1958 by Crisp and Southward. One major paper was published on the findings (Southward and Crisp, 1954b), however, it does not report on the entire survey and instead list 96 sites and six species. Final results document and describe the semi-quantitative abundance and distribution of the six species. In addition, environmental factors such as sea temperature, air temperature and salinity are examined to see if they may explain the distributions of the six species. No formal statistical analysis is used and all work is semi-quantitative and descriptive. Site locations were documented by recording a latitude and longitude.

Picton and Costello, 1998

Another biological survey of the Irish coastline (including Northern Ireland) was conducted from 1992 to 1997 by a number of scientists on the BioMar LIFE biotope classification project. It represented the largest survey ever carried out on the benthic marine fauna and flora of both the intertidal and subtidal habitats of Ireland (Costello, 2000). Overall, 900 sites were surveyed with 200 of these being intertidal shore sites. The intertidal sites covered all substrate types, therefore, only a subset of (*ca.*) 80 were rocky shores. The main aim of the project was to classify the marine biotopes of the coasts as a basis for describing, mapping and comparing the conservation value of inshore marine areas (Picton and Costello, 1998). While completing this task, the flora and fauna found at each site were recorded, as well as their abundance using the semi-quantitative SACFORP (*i.e.* superabundant, abundant, common, frequent, occasional, rare and present) categories. Each species encountered within a habitat was given an abundance score or, if that was not possible, species were recorded as present. The raw data collected throughout the survey can be found in an Access database on the BioMar CD (Picton and Costello, 1998). There are also printed reports of some of the key areas where BioMar conducted surveys: Bantry Bay (Emblow *et al.*, 1994), Youghal Bay (Emblow *et al.*, 1995), Mulroy Bay and Lough Swilly (Picton *et al.*, 1994) and, Kilkieran Bay and the Aran Islands (Sides *et al.*, 1994). In the end, a very large database of the abundance and distribution of intertidal and subtidal was created. Results were used to fulfil the main aim of defining marine biotopes for the entire country. To this end, multivariate analysis such as TWINSPAN and DECORANA were used to distinguish between and group together similar biotopes around the coastline. All quantifications of species abundances were semi-quantitative. The GPS location of each site was recorded so that sites could be re-located if needed.

Northern Ireland:

Wilkinson, Fuller, Telfer, Moore and Kingson, 1988

A semi-quantitative survey of the intertidal shore communities of Northern Ireland was conducted from 1984 to 1988 with the aim of assessing the conservation value of the intertidal communities along the coast. In order to determine which areas were appropriate for conservation status a structured survey was designed. The first stage involved a quick (three-four week) survey of the entire coastline. Three types of data were collected during this time: physical data (exposure, substrate type/structure, tidal range), scientific and conservation data (dominant community type, subhabitats) and human influence data (development, shore utilisation). The results from the first stage were then used to determine which sites would be most suitable for a detailed biological survey during stage two. Overall, 332 sites were visited during the first stage and out of these 200 sites were chosen for stage two (Wilkinson *et al.*, 1988). Out of these 200 sites 128 were rocky shores.

The methods used to assess the biological communities on rocky shores consisted of one 8 metre wide belt transect which was set up between low water (determined from the Admiralty Tide Tables on the day) and the top of the upper shore (Wilkinson *et al.*, 1988). Within each of these transects, the abundance of any species which was dominant and/or characteristic of the shore was recorded using an 8-point semi-quantitative abundance scale (extremely abundant, super abundant, abundant, common, frequent, occasional, rare and presence only). Quadrats were used to estimate the abundance of species with high densities, such as barnacles. A general search was undertaken outside of the transect area within any subhabitats present. Species found in these areas were only noted as present and not given an abundance score. The raw data collected throughout the survey can be found in the appendix of the Northern Ireland Littoral Survey (Wilkinson *et al.*, 1988). The data were subjected to three multivariate statistical techniques (cluster analysis, ordination and indicator species analysis) to classify sites based on species composition and physical factors. The results were used in dendrograms to show the hierarchical similarities between sites and groups of sites, thus statistically aiding in the classification of Northern Ireland shores. Also, on each shore, grid references and Lat/Long readings taken from a map are provided, as well as photographs and a shore profile.

Southeast Co. Wexford:

<u>Healy and McGrath, 1998</u>

Quantitative and semi-quantitative surveys on rocky shores in the southeast of Co. Wexford were carried out between June 1976 and August 1979. The overall aim of the survey was to document the littoral communities present in the southeast of Ireland as a baseline for monitoring human-induced change. Five rocky shores were examined, Carnsore Point, Crossfintan Point, Forlorn Point, Cahore Point and Hook Head. On shores with a relatively homogeneous rock surface, transects were used as a non-destructive method of recording species abundance and vertical distribution (Healy and McGrath, 1998). Transects extended from the lichen zone to MLWS, with fifteen stations marked at 40-cm vertical intervals (Healy and McGrath, 1998). At each station the flora and fauna were recorded within a 5-metre band using a 5-point semi-quantitative abundance scale, similar but not identical to that used by Southward and Crisp (1954b).

In order to assess the intertidal communities on shores with a more heterogeneous habitat, quantitative methods were employed (Healy and McGrath, 1998). One site, 10 meters wide and extending from the terrestrial vegetation to low water, was selected on each shore. The site was divided arbitrarily into three zones, an upper zone, a middle zone and a lower zone. Within each zone the algae and barnacles were counted using percentage cover, while the limpets were counted by throwing a $0.25m^2$ quadrat eight times. Abundance estimates for any additional species were made by counting the number of individuals collected during 5 minutes. Throughout the survey 363 taxa were identified and surveyed (Healy and McGrath, 1998). The population structures of some species (e.g. *O. lineatus* and *G. umbilicalis*) were assessed during two different years. The raw data relating to species abundance categories for each of the five rocky shores can be found within tables in the appendix of Healy and McGrath (1998). No statistical analyses were used, however, data was carefully recorded and the densities and size structures of some species are documented. The results are mainly descriptive making use of both semi-quantitative and quantitative data. Carefully taken notes and hand-drawn maps documented the sites used throughout the survey.

Sherkin Island, Co. Cork:

Bishop, 2003

In 1975 a survey of the intertidal rocky shores on Sherkin Island, Co. Cork was initiated. The aim of the survey is to document the intertidal communities present and to provide a way of monitoring changes in the rocky shore biota of West Cork (Bishop, 2003). This survey has been conducted every year since and thus provides an extensive long-term dataset. Each year, data are collected once monthly (from April to October) at 7 sites around the island (Bishop, 2003). One transect on each site, extending from low water to high shore is permanently marked (Bishop, 2003). Then, at each vertical interval of 30cm (initially done using cross-staff and pole), two $0.25\ m^2$ quadrats are placed, with one on each side of the transect (Bishop, 2003). Within each quadrat the abundance of species is recorded as either percentage cover (algae and ground cover animals such as mussels and sponges) or number per quadrat (Bishop, 2003). For the smaller species, such as barnacles and some littorinids, a further count was made within a central 10 cm x 10 cm quadrat. Volunteer marine biologists conduct each year's fieldwork and are trained in the methodology and identification of species before they begin (Bishop, 2003).

In conjunction with the monthly sampling on Sherkin Island, annual surveys using the same methodology are carried out along the coastline of West Cork. Fifty-five sites in Roaringwater Bay have been surveyed yearly since 1975, while eight sites in Dunmanus Bay have been surveyed since 1981 (Bishop, 2003). In addition, fifty-seven rocky shore sites, spanning from Baltimore to within Cork harbour, have been surveyed annually since 1995. Preliminary data, collected on Sherkin Island only, over the past 19 years (1981 to 2000) of survey work are shown in Bishop (2003). Data were collected quantitatively, however, no statistical analyses was applied to the results. Graphs are used to depict the variation in flora and fauna species through years, months and along the shores. However, it is not possible to gain raw data from the graphs because years, months and stations along the shores are combined and there is no way of separating them. Also, all barnacle and limpet species are combined so there is no distinction between species. In the appendix of Bishop (2003), there is a list of all of the species found at each of the shores, during each year of survey, on Sherkin Island. To allow for the exact location of each site and transect to be easily found detailed maps and photographs have been taken. However, the details are not included in the published work and would need to be acquired, as would the raw data, since both are archived at the Sherkin Island Marine Station.

Galway Bay, Co. Galway:

Ryland and Nelson-Smith, 1975

A semi-quantitative assessment of the fauna and flora of rocky shores in Galway Bay was carried out during the autumn months of each year between 1967-1971. This survey was an amalgamation of work collected by students during five years of fieldtrips to Galway Bay, and the main aim was simply to document the species present. In total, six rocky intertidal shores were studied. On each shore, a transect survey extending from low water to extreme high water was conducted. Ten stations were marked along the transect at 60 cm vertical intervals using a cross staff and pole. At each station, the area inspected extended for 3.3 m to each side of the marker and halfway (vertically) to the next marker above and below (Ryland and Nelson-Smith, 1975). Within this zone the abundance of 33 species was assessed using the semi-quantitative abundance scales derived by Crisp and Southward (1958). Any other species found within the transect boundaries was identified and used to compile a list of species which in the end amounted to over 400. Descriptive methods, such as kite diagrams, were used to show the change in species abundances along shores. If the raw data was needed, it was recorded throughout the kite diagrams and could be easily attained. The name of each site was the only information recorded regarding site locations.

Lough Hyne Marine Nature Reserve, Co. Cork:

Ebling, Sleigh, Sloane and Kitching, 1960

During July 1955 and September 1958, observations on 48 intertidal species, both flora and fauna, were made at 33 sites throughout Lough Hyne, Barloge Creek and the immediate outside coast (Ebling *et al.*, 1960). The two aims of the survey were to study species distributions in relation to wave action and to create a baseline study that could be used to detect changes in the future. Each site was horizontally 10 meters long, within which a search of the entire intertidal and shallow sublittoral area was made. Each species found was recorded using either a four-point abundance scale or presence/absence. The population density of some barnacle and gastropod species was recorded by conducting counts to estimate the number of animals per unit area. Overall, the distribution and abundance of 48 species was documented. Some species were recorded semi-quantitatively while others were noted as present or absent only. Results were descriptive and maps were used to determine whether species were distributed in accordance with physical factors, such as exposure. The raw data collected throughout the survey is not listed, however, it could be attained from the maps in Ebling *et al.* (1960). To allow for sites to be relocated photographs and maps were used for documentation.

Little, Morritt and Stirling, 1992

A re-survey of Ebling *et al.* (1960) was conducted during September 1990 and July 1991 (Little *et al.*, 1992). The aim was to begin a monitoring programme of the intertidal zone within Lough Hyne and to compare the differences between 1955 and 1990-91 (Little *et al.*, 1992). The methods of Ebling *et al.* (1960) were followed as closely as possible, however, not all of the 33 sites were re-surveyed. For some species, the abundance categories used by Ebling *et al.* (1960) were modified for use during the re-survey (Little *et al.*, 1992). In September 1990, 20 sites were re-surveyed and then in July 1991, 18 of those 20 sites were surveyed again. This was done so that any differences in season could be determined. A non-parametric sign test was used to determine if there had been any significant change in the abundance of species during the one-year time period and after 35 years. Results showed that, from September 1990 to July 1991, the abundance of six species had changed significantly. Overall, after 35 years, 25 species were assessed for changes. Of these 15 showed no change, while three increased significantly and seven decreased significantly (Little *et al.*, 1992).

Bantry Bay, Co. Cork:

Crapp, 1973

In 1970 and 1971, a semi-quantitative survey was carried out at 40 sites within Bantry Bay, Co. Cork (Crapp, 1973). The aim of the survey was to document the marine communities of the bay and to create a baseline that would allow for the detection of pollution effects (Crapp, 1973). At each site, one transect was arbitrarily chosen which extended from mean low water spring tides to the top of the supralittoral zone (Crapp, 1973). Along the transect, at every 30 cm, vertically determined by cross-staff and pole, the abundances of the 68 macro-fauna and flora were determined within a 10 metre wide band. Each species was assessed using the semi-quantitative abundance categories based on a modified version of those created by Crisp and Southward (1958) (Crapp, 1973). Results were descriptive and kite diagrams were used to represent the abundance of species at each of the sites. To aid in future surveys, the raw data was sent to University College Cork for archiving. Careful notes on the description and location of sites were taken but transect locations were not permanently marked.

Baker *et al.*, 1981

During the summer of 1975, a re-survey of Crapp (1973) was begun in response to two oil spills that happened within Bantry Bay during, October 1974 and January 1975 (Baker *et al.*, 1981). The same sites and methods were employed to ensure that the re-survey could be compared to previous work. In some cases there were difficulties in locating the original transects, therefore, some of the sites surveyed may not have been identical to those surveyed by Crapp. Overall, the semi-quantitative abundances of nearly 60 intertidal plant and animal species were estimated (Baker *et al.*, 1981) using the same 8-point abundance categories as Crapp (1973). Kite-diagrams were superimposed onto those created by Crapp (1973) to determine if there had been any changes to the zonation and abundance of species. The authors reported that many changes had occurred in species abundances after the 3-year interval, however, these changes could not be consistently related to the pollution episodes (Baker *et al.*, 1981).

Myers, Cross and Southgate, 1980

Following on from the work conducted during 1970, 1971 and 1975, another survey was initiated in Bantry Bay during 1978-1980 (Myers *et al.*, 1978). The aims of the survey were to create a baseline for future monitoring and to investigate aspects of the ecology of rocky intertidal communities (Myers *et al.*, 1980). This survey intended to build on previous work by including sublittoral habitats and surveying the shores monthly as opposed to the 'once off' protocol used previously. Five sites were used for continuous sampling, four in Bantry Bay and one in the neighbouring Dunmanus Bay. At each site a transect was established and stations were located at 30cm vertical intervals extending from the lichen zone to MLWS (Myers *et al.*, 1978). Then, at each 30cm station, a permanent 50cm x 50cm quadrat was marked. These quadrats were examined monthly and the species (flora and fauna) were recorded using percentage cover or counts. The abundance and density of barnacle species was assessed within randomly placed quadrats. A study investigating the re-colonisation of 42 cleared $0.25m^2$ areas was also carried out. The survey ran for 26 months and therefore allowed for analysis of the differences between months, seasons and years. The fluctuations in species abundances on each of the five shores are shown graphically with months on the x-axis and either percentage cover or number per quadrat on the y-axis. Thus, raw data could be extracted from the graphs if necessary. No statistical tests were used throughout the survey, however the average density and standard deviation of barnacle species is included in Myers *et al.*, (1980). Quadrats along transects were permanently marked using paints and nails while photographs were taken on every visit.

Clare Island, Co. Mayo:

O'Riordan, Myers, McGrath, Delaney, Cussen and Cronin, 2002

From July 1992 through April 1995 an extensive survey was undertaken on the intertidal region of Clare Island, Co. Mayo (Myers, 2002). This survey was based on an initial survey conducted at the beginning of the century (1909-1911) and therefore represented a partial re-survey of the area. The original survey was a qualitative presence/absence study that involved, amongst many other disciplines, a survey of the marine communities (flora and fauna) (Praeger, 1915; Myers, 2002). The work on rocky shores involved a search and record method where every area including the microhabitats such as the undersides of boulders, rock pools and algal holdfasts were cleaned out and analysed (Southern, 1915). Due to the original survey's methods being entirely quantitative, of their time, and often destructive the recent re-survey decided to adopt a new methodology.

Overall a number of studies were undertaken (Myers, 2002), however only one looked at the entire community in detail. This survey took place on Lackacanny shore, an extremely exposed site approximately 27 meters long (O'Riordan *et al.*, 2002). The main aim of the survey was to document the abundance and zonation of flora and fauna on one of the most exposed sites in the British Isles (O'Riordan *et al.*, 2002). Surveys were conducted on five occasions July 1992, August 1992, October 1992, May 1994 and April 1995. The methods used involved the use of a 50cm x 50cm grid quadrat with eighty-one cross-wires (O'Riordan *et al.*, 2002). Five quadrats were placed randomly within each of four biological zones extending from low water to the lichen zone. Each taxon under a cross-wire was counted and recorded. In some cases this was done in the field and in others photography was used to analyse the quadrat in the lab. A cross calibration exercise, using a non-parametric Wilcoxon matched paired analysis, was undertaken to ensure that there was no significant difference between those quadrats assessed in the field and those in the lab. Results show the mean and standard deviation of the percentage cover for each taxon recorded during the survey. Throughout fieldwork, most flora and fauna were identified to species, however, in the tables shown in O'Riordan *et al.* (2002) some species are combined into groups (e.g. limpets, winkles and barnacles).

2.3 Discussion

Overall, eleven surveys out of the twelve examined species abundances within space. Six of these surveys also included a temporal component. The one remaining survey (O'Riordan *et al.*, 2002) examined temporal variation only, by examining one shore over a number of years. The amount of space covered by the surveys and the time scales on which they were sampled vary for each survey. Some surveys covered the entire coastline, others were regional, some were local and one survey focused on one shore only. Similarly, the amount of time each survey was conducted varied. Some surveys were "once-off" while others, have been conducted over 25 consecutive years or were re-surveys of previous surveys.

Nine of the surveys used semi-quantitative abundance scales to assess species abundances (Table 2.1). Three of these surveys incorporated a mix of quantitative and semi-quantitative methods (Southward and Crisp, 1954b; Healy and McGrath, 1998; Wilkinson *et al.*, 1988). Two surveys used both semi-quantitative and qualitative methods (Ebling *et al.*, 1960; Ryland and Nelson-Smith, 1975). The other four surveys relied on semi-quantitative methods only (Crapp, 1973; Baker *et al.*, 1981; Little *et al.*, 1992; Picton and Costello, 1998). Most of the abundance scale categories were based on variations of the same scale. Ebling *et al.* (1960) and the Little *et al.* (1992) used a 4-point scale with categories based on percentage cover (flora) or numbers per area (fauna). Although, for some species, abundance was represented in a highly subjective way, by attributing categories based on few, few but widespread and plentiful. Southward and Crisp (1954b), Ryland and Nelson-Smith (1975) and Healy and McGrath (1998) used a 6-point ACFOR scale (abundant, common, frequent, occasional, rare and absent). Picton and Costello (1998) used a 7-point scale that included a superabundant and a present category. Crapp (1973), Baker *et al.* (1981) and Wilkinson *et al.* (1988) used an 8-point scale which included an extremely abundant category above superabundant. When categories were added to the 6-point ACFOR scale, if species were assessed as percentage cover all of the categories changed in definition. However, if species were assessed using numbers per area, then instead of the scale being open ended at abundant the scale continued on with increasing densities representing extremely and super abundant.

Unlike quantitative methods, abundance scales allow a large spatial area and a large number of species to be surveyed quickly and probably for this reason it may have become a popular methodology for intertidal community work in Ireland. However, there are also negative aspects to using abundance scales. Many of the surveys mentioned future monitoring as an aim. However, as the abundance scales are semi-quantitative, they do not lend themselves easily to modern analytical techniques. The analyses used by the semi-quantitative surveys centered on descriptive methods, which may not be robust enough to draw good conclusions about changes in communities. Three of the surveys, which used semi-quantitative data, did use statistical techniques (Wilkinson *et al.*, 1988; Little *et al.*, 1992; Picton and Costello, 1998). Wilkinson *et al.* (1988) and Picton and Costello (1998) used the multivariate statistics of ordination and cluster analysis to identify similarities between the biological and physical components of the communities recorded. The other survey to use statistical techniques was a re-survey (Little *et al.*, 1992). This re-survey used a non-parametric statistical test to distinguish amongst the changes of species from two time periods. However, as it is only two time periods, there is no measure of the fluctuations undergone by species through time.

Three surveys did not employ the use of semi-quantitative abundance scales and instead used fully quantitative methods (Myers *et al.*, 1980; O'Riordan *et al.*, 2002; Bishop, 2003). Each of the three surveys was aimed at monitoring species fluctuations through time, and thus all involved a temporal component. Quadrats and pin-frames were used to quantify species numbers on shores. Two of these surveys used permanently marked quadrats, Myers *et al.* (1978) and the Sherkin Island survey (Bishop, 2003). A short fall of using the same quadrat every sampling period (*i.e.* months or years) is that species are examined within the same specific area every time. Therefore, the fluctuations in the abundance of species within fixed quadrats may not represent the fluctuations of species on the shore. For instance, if a species reduces its abundance within the quadrat it is possible that directly next to the quadrat the species is in the same abundance as recorded previously. The use of permanent quadrats is not recommended in more modern ecological studies, representing how these two surveys are of their time. The third survey used randomly placed pin-frame quadrats to assess species (flora and fauna) percentage cover. By randomly placing quadrats they accounted for the variability that may be occurring across the shore. However, by using percentage cover there is no record of the density of species on the shore.

A common aim amongst many of the surveys was their possible use in future monitoring programs. Nearly all of the surveys (except Ryland and Nelson-Smith, 1975) have documented the location of sites with notes, maps or photography and some have even permanently marked transects and quadrats (e.g. Myers *et al.*, 1978; Bishop, 2003). This documentation allows for the possibility of pinpointing the exact location of sites. Three of the surveys have already been used during re-surveys (Baker *et al.*, 1981; Little *et al.*, 1992; O'Riordan *et al.*, 2002) and two of these specifically monitored for species changes (Baker *et al.*, 1981; Little *et al.*, 1992). In Bantry Bay and Lough Hyne Marine Nature reserve re-surveys showed that many of the species experienced changes in abundance. However, as the original surveys were based on descriptive (i.e. kite diagrams and maps) methods drawing robust conclusions' regarding species changes was difficult. Baker *et al.* (1981) assessed changes in species abundances by taking kite diagrams from the re-survey and superimposing them over kite diagrams from the original survey. They concluded that there had been many changes to the zonation and abundance of species after a four year time period. It is possible, however, that the results referring to changes in the zonation of species on the shore may be due to sampling methodologies. Transects were conducted from MLWS to the supralittoral zone. The original survey by Crapp (1973) did not permanently mark transects. Thus, if the re-survey began their transect at a different location or height on the shore, it would have been nearly impossible for the identical zonation patterns to appear between surveys. A more appropriate method would have been to analyze the differences between species abundances without the use of kite-diagrams. The re-survey of the rocky intertidal of Lough Hyne conducted by Little *et al.* (1992) made use of non-parametric statistics to assess changes in species abundances through time. These methods were more appropriate than those used by Baker *et al.* (1981).

The only survey, which has used long-term monitoring to make observations of species abundances continually through space and time, is the Sherkin Island survey. Data has been collected every year for nearly thirty years, allowing a large dataset on species fluctuations to accumulate (Bishop, 2003). The raw data is impressive, however, there are some negative aspects to the Sherkin Island survey. Firstly, data collected by volunteers has been shown to vary between individuals (Foster-Smith and Evans, 2003). Although the careful training of volunteers solved the problems of using different people collecting data each year, there is no way to standardize results amongst individuals. This also has important implications for re-surveys, as different people are often carrying out the original survey and the re-survey. Surveys have often commented on the differences between individuals (Baker *et al.*, 1981; Healy and McGrath, 1998; Burrows *et al.*, 2002). However, to date no survey has yet quantified the differences between individuals. Another, negative aspect of the Sherkin Island survey is that the four intertidal barnacle species, common to Irish shores, are combined into one group. Research has shown that barnacle species in Britain fluctuate through time, with one species increasing in abundance during cold temperature periods and two species increasing in abundance during warm temperature periods (Southward, 1991). By combining these species into one group, there is no measure of the variability between the species through time.

In conclusion, although the quality of results has varied, each survey has contributed to the knowledge of rocky shore communities in Ireland. Some of these surveys may be useful for this reason alone. However, some of them are proving useful as historical work is being used in modern analyses (See Chapter 3). It is important that rocky shore surveys, focusing on community dynamics, continue in Ireland because they are essential to understanding the fluctuations and natural variations of biota. This knowledge could allow us to distinguish between natural fluctuations and the affects of over-exploitation, pollution, and possibly climate change on species.

Raw data from the Southward and Crisp (1954b) survey, the Healy and McGrath (1998) survey, the Crapp (1973) survey and the Myers *et al.* (1978) survey are being archived and will be kept at University College Cork and the library of the Marine Biological Association of the United Kingdom in Plymouth.

PREAMBLE TO CHAPTER 3

An Introduction to the Abundance Scale (ACFOR) Method of Quantifying Species Abundances

Ecologists have devised many methods for quantifying patterns in nature each of which falls along a gradient of qualitative to fully quantitative. The abundance scale method, or ACFOR as it is commonly called, is used to collect semi-quantitative data on species abundances and distributions. ACFOR stands for abundant, common, frequent, occasional, and rare, each of which represent a category along the abundance scale. The pioneers of this methodology in marine biology were Dennis Crisp and Alan Southward (Crisp and Southward, 1958).

The ACFOR method was essentially a modification of a plant ecology protocol, which was devised twenty years previously. Braun-Blanquet (1932) devised a method for quantifying plant communities using a semi-quantitative 6-point scale based on percentage cover (*i.e.* + represents less than 1% cover, 1 represents 1-5% cover, 2 represents 6-25% cover, 3 represents 26-50% cover, 4 represents 51-75% cover and 5 represents 76-100% cover). The methodology was used to classify plant communities rapidly based on their biological structure within a given area such that plant associations could be identified. The abundance scales of Crisp and Southward (1958) are also based on a 6-point scale (abundant, common, frequent, occasional, rare and absent). However, modifications were made for quantifying intertidal fauna (Figure 3.1). Throughout its use on rocky shores some scientists expanded the number of categories to 7 or 8 (Raffaelli and Hawkins, 1996), adding superabundant and extremely abundant categories (Crapp, 1973; Baker *et al.*, 1981; Wilkinson *et al.*, 1988; Picton and Costello, 1998). For some species, especially those assessed on a percentage cover scale (e.g. plants and mussels), in order to add categories above 'abundant' the category 'width' was decreased. Thus, any amount of cover over 30% was assessed as 'abundant' on the 6-point scale (Figure 3.1), whereas, using an 8-point scale cover from 30-60% was assessed as 'abundant' (Crapp, 1973; Baker *et al.*, 1981). The changes made to the definition of a category when adding categories above abundant was not consistent for each species. For instance, new categories for some molluscs (e.g. limpets, periwinkles and dogwhelks) were added directly to the top of the original abundance scale with 'abundant' on the 6-point scale being anything over 50 per m^{-2} and 'abundant' on the 8-point scale being 50-100 per m^{-2}.

Species	Abundance Category				
	A	C	F	O	R
Barnacles					
Chthamalus stellatus, Chthamalus montagui, Semibalanus balanoides, Elminius modestus	More than 1 per cm^2; rocks well covered	0.1-1.0 per cm^2; up to 1/3 of rock space covered	0.01-0.1 per cm^2; individuals never more than 10cm apart	0.0001-0.01 per cm^2; few within 10cm of each other	Less than 1 per m^2; only a few found in 30 min searching
Balanus perforatus	Over 0.1 per cm^2; close groups on most vertical faces, often up to MTL	0.01 to 0.1 per cm^2; adjacent groups, not always above LWN	Less than 0.01 per cm^2; adjacent in crevices	Less than 0.01 per cm^2; rarely adjacent even in crevices	Only a few found in 30 min searching
Limpets					
Patella vulgata, Patella depressa, Patella aspera	Over 50 per m^2 or more than 50% of limpets at certain levels	10-50 per m^2, 10% to 50% at certain levels	1 to 10 per m^2, 1% to 10% at certain levels	Less than 1 per m^2 on average, less than 1% of population	Only a few found in 30 min searching
Topshells					
Osilinus lineatus, Gibbula umbilicalis, Gibbula pennanti	Exceeding 10 per m^2 generally	1-10 per m^2, sometimes very locally over 10 per m^2	Less than 1 per m^2, locally sometimes more	Always less than 1 per m^2	Only a few found in 30 min searching
Periwinkles					
Littorina saxatilis agg., Littorina obtusata/mariae Melaraphe neritoides	Over 1.0 per cm^2 at HW, extending down the midlittoral zone	0.1-1.0 per cm^2, mainly in the supralittoral fringe	Less than 0.1 per cm^2, in crevices		Only a few found in 30 min searching
Littorina littorea	More than 50 per m^2	10 – 50 per m^2	1 – 10 per m^2		Only a few found in 30 min searching
Anemones					
Actinia equina, Actinia fragracea, Anemonia viridis, Bunodactis verrucosa	Many in almost every pool and damp place	Groups in pools and damp places	Isolated specimens in few pools		A small number, usually under 10, found after 30 min searching
Algae					
	>30%	5-30%	<5%	Scattered individuals	Few plants 30 min search

Figure 3.1: Abundance scales derived by Crisp and Southward (1958).

The ACFOR methodology is applicable to both flora and fauna on rocky shores. However, it is restricted to conspicuous species. The areas used in the definitions of each category were devised according to the size of the animal (ranging from <1cm^2 for barnacles to >1m^2 for sea anemones) or plant. Using this methodology, most faunal species are assessed as number per area whereas flora species and *Mytilus* spp. are assessed as percentage cover. For the majority of species, each of the ACFOR categories is defined on a logarithmic scale so that there is an order of magnitude difference between each level of the scale from rare to abundant. It is important to repeat however, that the precise definition of each category is dependant on the groups of organisms being quantified. Thus, the method has lent itself particularly well to intertidal communities because Crisp and Southward were able to assign specific ACFOR values to various groups of organisms (based on size/mobility). For example, the criteria for assigning an ACFOR category for barnacles are very different to those for algal species (See Crisp and Southward, 1958; Figure 3.1).

Two general methods of using abundance scales on rocky shores have been developed. The first involves a fixed transect on which stations are marked at various vertical height intervals using levelling equipment. At each station an area is designated on both sides of the transect, within which species abundances are assessed using ACFOR. This method allows the zonation patterns on the shore to be quantified. The second method requires no fixed transect, and instead requires that the entire shore be searched for each species. The species is then assessed within its 'zone of most abundance'. This method involves an initial investigation of the shore to locate the area where the species is most abundant and the ACFOR category is then assigned from this specific area. The outcome is that for each shore, one abundance score for each species is allocated, thus no measurement of the change in abundance of a species at different levels along the shore is provided.

As with all methods there are positives and negatives to using ACFOR in rocky shore ecology. A major advantage to using this method is the number of shores that can be assessed in a short space of time over a large geographical range. It is also readily used on rocky shores of varying physical attributes (e.g. heterogeneity and exposure). In addition, because there are only 6 categories (7 or 8 in some instances) and each has a quantitative description, different operators should be able to attribute categories accurately. However, because each species may be assessed in an undefined area ('zone of most abundance' in some cases) it can be subjective and in practice results can vary amongst operators (Baker *et al.*, 1981; Foster-Smith and Evans, 2003 and Chapter 3). This variation amongst operators is most important for re-surveys and studies conducted over a long period, such as the Sherkin Island survey (Chapter 2), where different volunteers or operators are used to quantify species abundances every year. Another difficulty amongst operators can be the interpretation of each category along the abundance scale (Foster-Smith and Evans, 2003), which can become especially critical when species are near the limits (upper or lower) of one category. This leads to individuals making a subjective decision on whether to go up, down (depending on end of scale) or stay within the category. Essentially, because there is no measure of within shore variability, each shore becomes a replicate within a large spatial scale. Therefore, the method lends itself to more robust analyses when there are many shores surveyed over large spatial scales (greater than regional).

In Chapter 3, the historical rocky intertidal studies conducted by Southward and Crisp during the 1950's were used as a baseline with which to assess changes in species distributions after a 50-year time period. The methodologies used during the 1950's surveys were based on the logarithmic ACFOR scale and therefore in order to remain comparable were used throughout the 2003 re-survey. The usefulness and suitability of the ACFOR scale is discussed in greater detail in Chapter 3.

CHAPTER 3

Using Historical Data to Detect the Effects of Climate Change on Intertidal Biota

Abstract

I have used a historical data set collected by Professor Alan Southward and Professor Dennis Crisp during the 1950's as a baseline for possibly detecting change in the rocky intertidal of Ireland. In 2003, abundance scale (ACFOR) data were collected for an assemblage of 27 species using the same methodologies and sites as the 1950's surveys. Quantitative data were also collected for both *Semibalanus balanoides* and *Chthamalus spp.* for a subset of 16 of these shores. Comparison of the ACFOR data between the 1950's and 2003 showed statistically significant changes in 12 of the 27 species surveyed. Overall, two species increased significantly in abundance while ten decreased in abundance. The reasons for the changes to species abundances were assessed in context of human induced effects, such as climate change and operator error. The effects of different operators allocating abundance scale categories were considerable and may have accounted for the significant change detected in 3 out of the 12 species. Quantitative barnacle count data were tested against ACFOR data to determine how sensitive semi-quantitative scales are to detecting change. Parametric analysis on the quantitative data showed that *Chthamalus* spp. increased and *Semibalanus balanoides* showed no change after a 50-year time period. In contrast, non-parametric analysis on the abundance scale data indicated that there had been no change in the abundance of either taxon after 50 years. The problems associated with using ACFOR scales were shown to be 'operator error' and the sensitivity of semi-quantitative data at detecting significant change.

3.1 Introduction

In recent years, studies demonstrating the possible effects of climate change on organisms have become more prevalent within the scientific literature (Parmesan and Yohe, 2003; Root *et al.*, 2003). These data span terrestrial, freshwater and marine ecosystems and range from the tropics to the poles (Hughes, 2000; Wuethrich, 2000; Walther *et al.*, 2002). Throughout the past century the average global surface temperature (the average of near surface land temperature and sea surface temperature) has increased by approximately 0.6°C and is predicted to continue increasing during the next 100 years by 1.2 to 3.5°C (Intergovernmental Panel on Climate Change [IPCC], 2001). Although the overall mean temperature is increasing, it is believed that different regions will experience different climatic variations in relation to temperature and precipitation (Walther *et al.*, 2002). Knowledge of the direct effects of these rapid climate changes on biota is essential for future monitoring, conservation and reliable management decisions.

Climate change can affect species by causing changes to phenology and physiology (Inouye *et al.*, 2000; Réale *et al.*, 2003; Sims *et al.*, 2004), abundance and distribution limits (Barry *et al.*, 1995; Parmesan, 1996; Thomas and Lennon, 1999), and community structure and functioning (Post *et al.*, 1999; Pounds *et al.*, 1999; Walther, 2002; Genner *et al.*, 2004). In some cases, climate change may even cause extinction in species that are unable to adapt or respond to fluctuations in their physical environment (Grabherr *et al.*, 1994; Thomas, *et al.*, 2004). As climate becomes more variable the frequency, intensity and duration of extreme events such as heat waves, cold 'snaps', droughts and tropical storms are predicted to increase (IPCC, 2001). Therefore, it is difficult to determine whether changes to species are caused by a series of extreme events or are a response to a gradual shift of mean climate (Easterling *et al.*, 2000).

Due to Ireland's location in the northeast Atlantic (52° to 55°N), it receives warm water from the North Atlantic Drift allowing air and sea temperatures to be mild compared to other countries within the same latitude. This combination of northern latitude and mild temperature allow both northern (cold adapted) boreal species and southern (warm adapted) Lusitanian species to coexist. Some of these northern and southern species reach the edge of their geographical distribution at or close to Ireland (Lewis, 1964). It is possibly these species at the edge of their range which are most likely to respond to fluctuations in physical factors such as climate by changing in abundance (Lewis, 1996; Harrison *et al.*, 2001b). The intertidal is a good system for monitoring geographical change because it is well studied and the ecologies of species are well-known, the organisms are restricted to a narrow strip of shoreline habitat and therefore are easily tractable (Sagarin and Gaines, 2002), many of the species are mostly sessile or sedentary (Menge and Branch, 2001) and long-term monitoring is made easy by their accessibility and visibility (Lewis, 1996). In addition, because it is the interface between land and sea, the intertidal experiences environmental pressures from both realms. As a consequence, fluctuations in temperature of both land and sea affect intertidal biota. Thus, although intertidal organisms are useful for monitoring geographical change, predicting the effects of climate change on the intertidal may not be as straightforward as for fully terrestrial or fully marine species. If climate change is having an effect, the biota of intertidal regions may be most affected by sea level rise, increases in both seawater temperature and air temperature, increases in ultra-violet light penetration, and increases in storminess and wave action (Harrison *et al.*, 2001a).

Essentially there are two types of data that are useful for investigating the biological effects of climate change on biota: time series and baseline. Time series data (collected over a number of consecutive years) has been used to show the effect of climate change on a wide range of organisms, including plants (Bradley *et al.*, 1999), insects (Parmesan *et al.* 1999), amphibians (Beebee, 1995; Visser *et al.*, 1998), birds (Crick *et al.*, 1997, Inouye *et al.*, 2000), mammals (Post *et al.*, 1997; Post *et al.*, 1999), fish (Genner *et al.*, 2004) and marine zooplankton (Southward *et al.*, 1995). However, collecting data over a series of years is time consuming, costly and often not possible, thus there is not a large amount of long-term time series data in the ecological literature. Baseline data sets (once-off studies), on the other hand, are more prevalent in the literature because for these studies, continued finances or effort are not required. Research using baseline studies has discerned population responses to climate change, such as fluctuations in abundance and distribution limits (Parmesan, 1996; Sagarin *et al.*, 1999). The positive and negative aspects of using historical baseline data as a way to study the biological effects of climate change have not yet been explored in the literature.

This study utilized a historical baseline as a method for determining whether the abundance of intertidal organisms around the Irish coastline have been influenced by climate change. On the hypothesis that there has been a warming trend in global temperatures, we would expect southern (warm adapted) species to increase in abundance and possibly extend beyond their current northern range limits while northern (cold adapted) species would experience declines in abundance and possible local extinctions at their southern range limits (Sagarin *et al.*, 1999). Climate change acts over large scales and therefore changes due to climate would be expected to happen over similar scales. However, neither the speed at which these changes are occurring or the amount of species change that can be directly attributed to climate effects are known.

I used a previous intertidal dataset, collected by Professor Alan Southward and Professor Dennis Crisp (Southward and Crisp, 1954b), as a baseline to detect changes in the geographical distribution of biota. My aims were to: (1) investigate changes in the abundance of intertidal organisms around the Irish coast after a 50-year time interval; (2) assess whether any of these changes is consistent climate change scenarios; (3) to determine the proportion of variability in abundance data attributable to operator differences; and (4) to determine whether the abundance scale (ACFOR) is an appropriate method for showing change in intertidal systems.

3.2 Materials and Methods

Retrieval of Historical Data and Selection of Re-Survey Sites

In October 2002, a trip was made to Plymouth, UK to meet with Professor Alan Southward. The aim of the meeting was to discuss his methodology and to pinpoint as accurately as possible (using grid references and memory) the location of each site studied during the 1950's survey. To facilitate this task, a set of 1:50,000 scale Discovery Series Ordinance Survey maps for the Irish coastline were used. Professor Southward also provided a Microsoft Excel database in which he had transferred all of his and Professor Crisp's notebook data.

During the 1950's survey, 205 sites were surveyed around the Irish coastline by assessing the abundance of 53 intertidal invertebrate and algal species (for a full description of Southward and Crisps work see Chapter 2). However, many of those sites were only surveyed for a subset of the species. For comparison, 27 species which were recorded on a regular basis, out of the original 53, were used throughout the re-survey. As each of the selected 27 species was not sampled on every shore during the 1950's survey only those sites with at least 15 species recorded were chosen. In the end, 63 sites were chosen for re-survey (Figure 3.2 and Table 3.1).

Study Area and Methodology

The re-survey was conducted in collaboration with a research group from Plymouth, who simultaneously re-sampled throughout the UK. In order to ensure that the methodology used by each team was comparable, two separate 'training' days were completed. During these days the protocol and identification of species were rigorously standardised.

All 63 sites, incorporating the entire island of Ireland, were sampled between March and November 2003. At each site, 55 intertidal species (or genus in the case of species which could not be identified to species level i.e. *Cystoseira* spp., *Mytilus* spp.) were quantified (Appendix I). If present, their abundance was recorded using the logarithmic ACFOR (abundant, common, frequent, occasional, rare) categories. The abundance scales used were those devised by Alan Southward and Dennis Crisp during the early 1950's and published in 1958 (Crisp and Southward, 1958; See Figure 3.1 in Chapter 3 preamble). The list of 55 species included the 27 species sampled by Southward and Crisp in 1950, and 28 others that represent possible indicator species for climate change or exotics which have been introduced to Irish waters.

Two operators, Dr. Anne Marie Power and myself, sampled all 63 sites. Sites were sampled at low water during spring tides to allow for an adequate estimate of lower shore species abundances. Each site was located using both the data documented during the 1950's, including the latitude and longitude of each

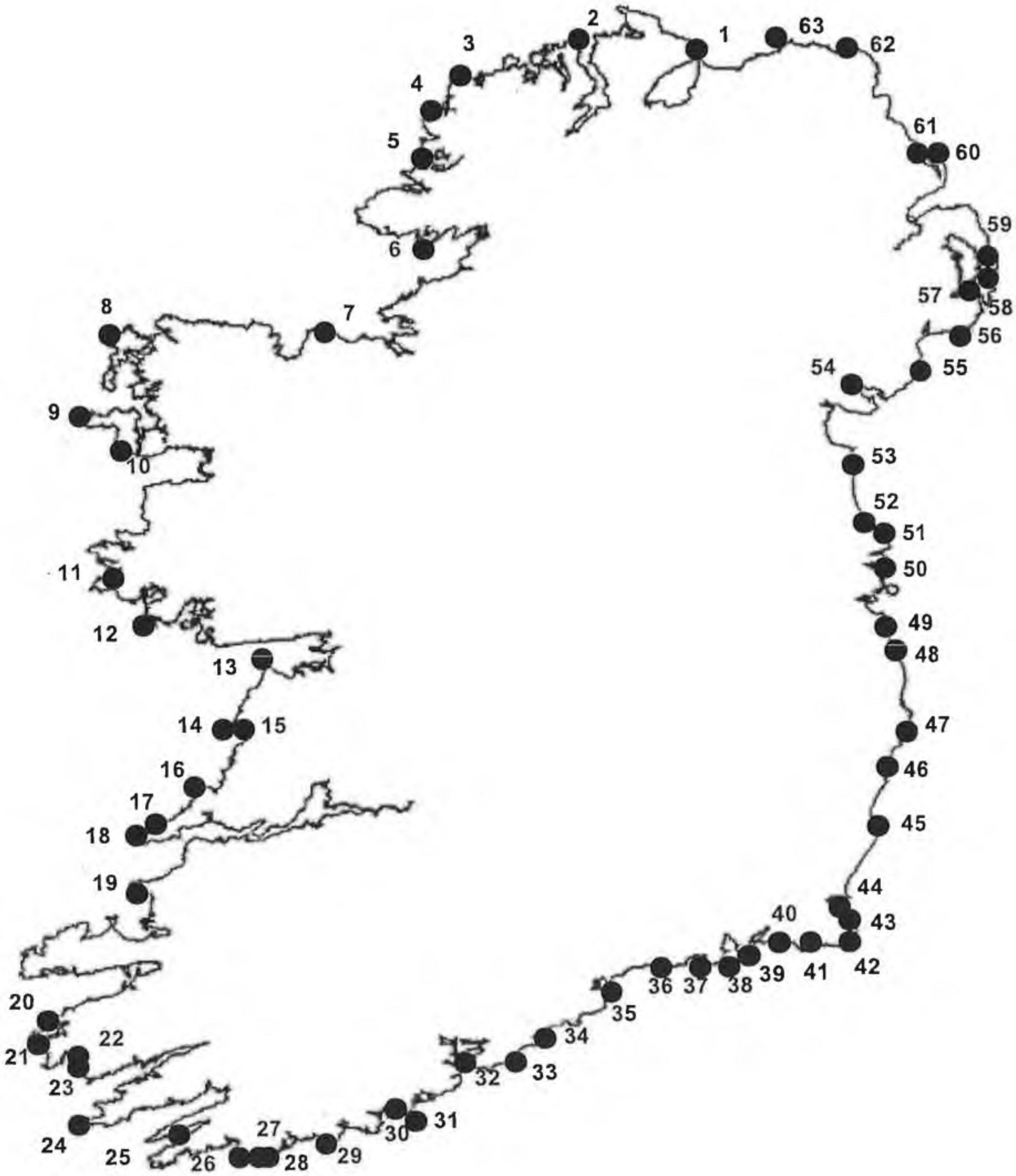


Figure 3.2: Map of Ireland showing the 63 sites re-surveyed during 2003.

Table 3.1: The names and locations in latitude/longitude (using dGPS) of the 63 sites sampled throughout the re-survey. Numbers correspond to Figure 3.2.

	Latitude	Longitude	Site Name and County
1	N55 17.65	W007 07.708	Culdaff, nr Dunmore Hd, Co. Donegal
2	N55 16.678	W007 38.197	Fanad Head, Co. Donegal
3	N55 09.065	W008 17.901	Bloody Foreland, N+S, Co. Donegal
4	N55 02.168	W008 23.077	Rinnalea Pt, Co. Donegal
5	N54 55.942	W008 26.823	Maghery-Termon, Co. Donegal
6	N54 34.063	W008 27.745	St. Johns Point, Co. Donegal
7	N54 17.494	W008 57.136	Easky, east of quay, Co. Sligo
8	N54 15.409	W010 04.857	Termoncarragh, Co. Mayo
9	N53 58.371	W010 07.944	Dooagh Achill Island, Co. Mayo
10	N53 52.556	W009 57.991	Cloghmore Achill Sound, Co. Mayo
11	N53 27.523	W010 02.594	Mannin Bay, Clifden, Co. Galway
12	N53 24.228	W010 06.999	Bunowen Point, Co. Galway
13	N53 09.264	W009 15.847	Black Head, Co. Clare
14	N52 55.898	W009 28.415	Cangregga, Co. Clare
15	N52 56.074	W009 25.753	Furreera, Co. Clare
16	N52 44.698	W009 31.892	Doonbeg, Co. Clare
17	N52 39.418	W009 43.334	Castle Point, Co. Clare
18	N52 35.110	W009 52.365	Moneen, Loop Head, Co. Clare
19	N52 23.795	W009 54.668	Kerry Head, Southside, Co. Kerry
20	N51 56.680	W010 16.610	Lough Kay, Doulus Bay, Co. Kerry
21	N51 53.027	W010 23. 618	Portmagee Channel, Opposite Bray Head, Co. Kerry
22	N51 45.626	W010 08.528	Abbey Island, Derrynane, Co. Kerry
23	N51 46.259	W010 01.253	Daniels Island, Near Whitestrand, Co. Kerry
24	N51 36.209	W010 02.679	Whiteball Head Bay, Co. Cork
25	N51 47.613	W008 11.726	Gyleen, Co. Cork
26	N51 29.883	W009 17.157	Tranabo Pier, Co. Cork
27	N51 29.007	W009 14.100	Toe Head, Co. Cork
28	N51 29.055	W009 14.479	Toe Head Bay, Co. Cork
29	N51 31.774	W008 57.266	Galley Head, Co. Cork
30	N51 37.426	W008 33.656	Ringalurisky Point, Co. Cork
31	N51 36.346	W008 32.046	Old Head of Kinsale,Co. Cork
32	N51 29.585	W009 42.262	Goleen, Co. Cork
33	N51 49.605	W008 00.049	Ballycotton, Co. Cork
34	N51 53.105	W007 51.976	Knockadoon Head, Co. Cork
35	N52 03.284	W007 32.439	Helvick Head, Co. Cork
36	N52 08.315	W007 22.245	Bunmahon, Co. Waterford
37	N52 07.749	W007 06.210	Brownstown Head, Co. Waterford
38	N52 07.439	W006 55.871	Hook Head, Co. Wexford
39	N52 10.491	W006 50.233	Baginbun Head, Co. Wexford
40	N52 12.875	W006 43.843	Cullenstown Reef to West, Co. Wexford
41	N52 10.379	W006 35.630	Forlorn Point/Crossfarnoge, Co. Wexford
42	N52 10.427	W006 21.938	Carnsore Point,Co. Wexford
43	N52 14.439	W006 18.821	Greenore Point, Co. Wexford
44	N52 14.722	W006 19.487	Rosslare Harbour, Waddingsland Point, Co. Wexford
45	N52 34.111	W006 11.993	Cahore Point, Co. Wexford
46	N52 44.229	W006 08.607	Kilmichael Point, Co. Wexford
47	N52 55.744	W006.01.328	Ardmore Point, Co. Wicklow
48	N53 08.900	W006 03.712	Greystones, Co. Wicklow
49	N53 11.791	W006 05.300	Bray, Co. Wicklow
50	N53 35.141	W006 06.202	Skerries, Co. Dublin
51	N53 27.100	W006 08.472	Malahide Coast, Co. Dublin
52	N53 36.974	W006 10.991	Balbriggan, Co. Dublin
53	N53 47.847	W006 13.223	Port Oriel, Clougherhead, Co. Louth
54	N54 05.901	W006 12.600	Rosstrevor, Co. Down
55	N54 06.264	W005 53.784	Annalong, Co. Down
56	N54 13.719	W005 39.145	St. Johns Point, Co. Down
57	N54 20.182	W005 32.465	Kilclief, Co. Down
58	N54 23.233	W005 27.533	Kearney Pt, Co. Down
59	N54 29.399	W005 26.123	Townhead, across from Burial Island, Co. Down
60	N54 50.904	W005 43.678	Portmuck, Co. Antrim
61	N54 52.134	W005 48.801	Larne, on the Glenarm A2 coastal Rd., Co. Antrim
62	N55 12.652	W006 11.670	Marconi's Cottage, Co. Antrim
63	N55 12.746	W006 39.475	Portrush, Co. Antrim

site, and the data gained through conversation with Alan Southward. Once found, two GPS readings were taken for each site, one at the access point (dGPS) and another at the centre of the shore being sampled. Digital photographs were taken to show the approach and the general view of each site. Once this initial assessment was completed, the shore was sampled for each of the 55 species with abundance categories for all species being assigned within their 'zone of most abundance'. This meant that each species was recorded as an abundance category within the locality in which the species was most abundant. Any species not located was recorded as absent. On average, both operators spent an hour searching and recording abundances on each shore. Notes were kept in individual notebooks and at the end of each survey the abundance scales allocated were discussed and a consensus was recorded. This procedure ensured standardised results for each site between observers, especially in the case of rare species, which may have been recorded as absent by one of the observers and not the other. Overall, species were given an abundance score after two hours of sampling effort and if a species was not found during that time it was recorded as absent.

Once the semi-quantitative ACFOR survey was completed, quantitative data on barnacle species were collected. Counts were conducted within three replicate, randomly placed (5x5) cm or (5x2) cm quadrats (depending on barnacle density) at lower, middle and high barnacle zone levels. The barnacle zone was defined as the area of shore where barnacle density ranges from a cover of 50 to 100%. More specifically the lower zone was just above the lowest part of the shore where barnacles could be found. The middle zone was defined as the middle of the belt where barnacles could be found; and the upper zone the highest area on the shores where barnacle cover ranged from 50 to 100%. When time was limited, digital photographs were taken for analysis in the laboratory. An archive of digital photographs was created of quadrats at each shore level.

A sub-sample of eight shores was used to determine the amount of variability due to operator differences. The difference recorded on these shores was then used as a calibrator for differences between the 1950's and 2003 surveys. Four of the eight shores were used to quantify the differences between individuals (AMP and myself), who were trained together, sampling at the same time and within the same space. The other four shores were used to provide an estimation of error due to teams (UK and Irish), which had already standardised the protocol and methodology. Fieldwork between teams was conducted in Northern Ireland and involved each team surveying the same shores on consecutive days. Each team had to independently locate shores using the information provided from the 1950's survey.

<u>Data Analysis</u>

During data collection, *Chthamalus stellatus* (Poli) and *Chthamalus montagui* Southward were identified and assessed separately, however, throughout all of the analyses they were combined as *Chthamalus* spp. because the two species were not separated at the time of the initial baseline survey. Species were grouped as northern, southern or broadly distributed to reflect their geographical range distribution. Northern species were those whose geographical range extended from the Arctic Circle south to northern Portugal. Southern species extended from North Africa to north as far as Scotland. Broadly distributed species had ranges extending from Norway to North Africa or the Mediterranean (Hayward *et al.*, 1996; Gibson *et al.*, 2001; *MarLIN*, 2001).

The abundance scale (ACFOR) data are based on categories, and therefore they could only be analysed using non-parametric statistical tests. The paired Wilcoxon signed ranks test was used to examine differences amongst the 27 species recorded both 'then' (1950's) and 'now' (2003). Only shores where the species was recorded during both the 1950's and 2003 surveys were used during analysis. This was because a search for every species on each shore during the 1950's survey was not conducted, resulting in differences in the number of observations for each species. Data for the Wilcoxon signed ranks test, involved changing the ACFOR categories as follows: abundant to 5, common to 4, frequent to 3, occasional to 2, rare to 1 and absent to 0.

Multivariate analysis was performed on the available data to compare the overall assemblages on shores between the 1950's and 2003. Data from the 1950's were incomplete (*i.e.* certain species were not examined in the 1950's survey and so could not be compared with the data collected in 2003) and therefore only 11 species and 24 sites could be included in the data matrix. Multi-dimensional scaling and an analysis of similarity test (ANOSIM) were conducted to examine differences between groups of samples ('then' and 'now'). Both were carried out using the PRIMER program (Plymouth Marine Laboratory). ANOSIM produces a test statistic between 0 and 1 with 0 being indistinguishable groups of samples and 1 being completely distinguishable groups (Clarke and Gorley, 2001).

The percentage error when allocating abundance categories was quantified between individual operators and teams of operators. The operator error percentage was then used as a surrogate for the amount of difference you would expect when any two individuals or teams allocated abundance categories. Any species that showed a significant change was measured against this error to make sure that any differences found were not due to individuals or teams.

Univariate parametric paired t-tests were used to analyse the quantitative *Chthamalus* spp. and *Semibalanus balanoides* counts. All counts were standardised to $1cm^2$ for ease of comparison. The abundance of *Chthamalus* spp. and *S. balanoides* at each height was presented as the mean and standard deviation of three replicate quadrats. Data from counts collected during the 1950's were averaged *in-situ* for each shore height, thus no standard deviation could be calculated for all of the past shores. To allow for a comparison between the quantitative and semi-quantitative data, the counts for each of the three barnacle zones were averaged for an overall abundance for each shore. More specifically this was calculated as the mean of the abundance at each of three heights within the barnacle zone (high, mid and low). The count data was converted to abundance categories and tested using the non-parametric Wilcoxon signed ranks test. Each quantitative count was changed to an abundance category and then to a corresponding value from 0-5, with 0 representing absent and 5 representing abundant, as before.

In total, 16 shores that were sampled during both the 1950's and 2003 were used throughout the quantitative and semi-quantitative barnacle analysis (Appendix II). The Anderson-Darling test was used to test for normality and Levene's test was used to ensure that the two samples had equal variances. If the data did not meet all of the assumptions they were log $(x + 0.01)$ or square root transformed.

3.3 Results

Species differences through 50 years

The null hypothesis that there has been no change in species (semi-quantitative) abundance between the 'then' and 'now' surveys was tested by comparing the frequencies of abundance scores shown in Table 3.2. Overall, 12 of the 27 species showed a significant change in their abundance. In terms of each species geographical distribution, five northern species *Alaria esculenta* (L.), *Balanus crenatus* Bruguière, *Laminaria hyperborea* (Gunnerus) Foslie, *Laminaria saccharina* (L.) Lamouroux, *Littorina littorea* (L.), one southern species *Paracentrotus lividus* (Lamarck), and four broadly distributed species *Calliostoma zizyyphinum* (L.), *Gibbula cineraria* (L.), *Codium* spp., *Melarhaphe neritoides* (L.) showed a significant decrease in abundance from the 1950's to 2003. In contrast, one northern species *Semibalanus balanoides* (L.) and one introduced species, *Elminius modestus* Darwin, showed an increase in abundance. Overall, 15 species showed no significant change in abundance from the 1950's to 2003. Six were northern species (*Ascophyllum nodosum* (L.) Le Jolis, *Chondrus crispus* Stackhouse, *Halidrys siliquosa* (L.) Lyngbye, *Himanthalia elongata* (L.) Gray, *Mastocarpus stellatus* (Stackhouse) Guiry and *Nucella lapillus* (L.)) eight were southern species (*Anemonia viridis* (Forskål), *Bifurcaria bifurcata* Ross, *Chthamalus* spp., *Cystoseira* spp., *Gibbula umbilicalis* (da Costa), *Osilinus lineatus* (da Costa), *Patella ulyssiponensis* Gmelin, *Sabellaria alveolata* (L.)) and one (*Mytilus* spp.) was a broadly distributed taxon. Some of the possible factors contributing to the change in the abundance of the 12 species are listed in Table 3.3 and are examined further throughout the results and the discussion.

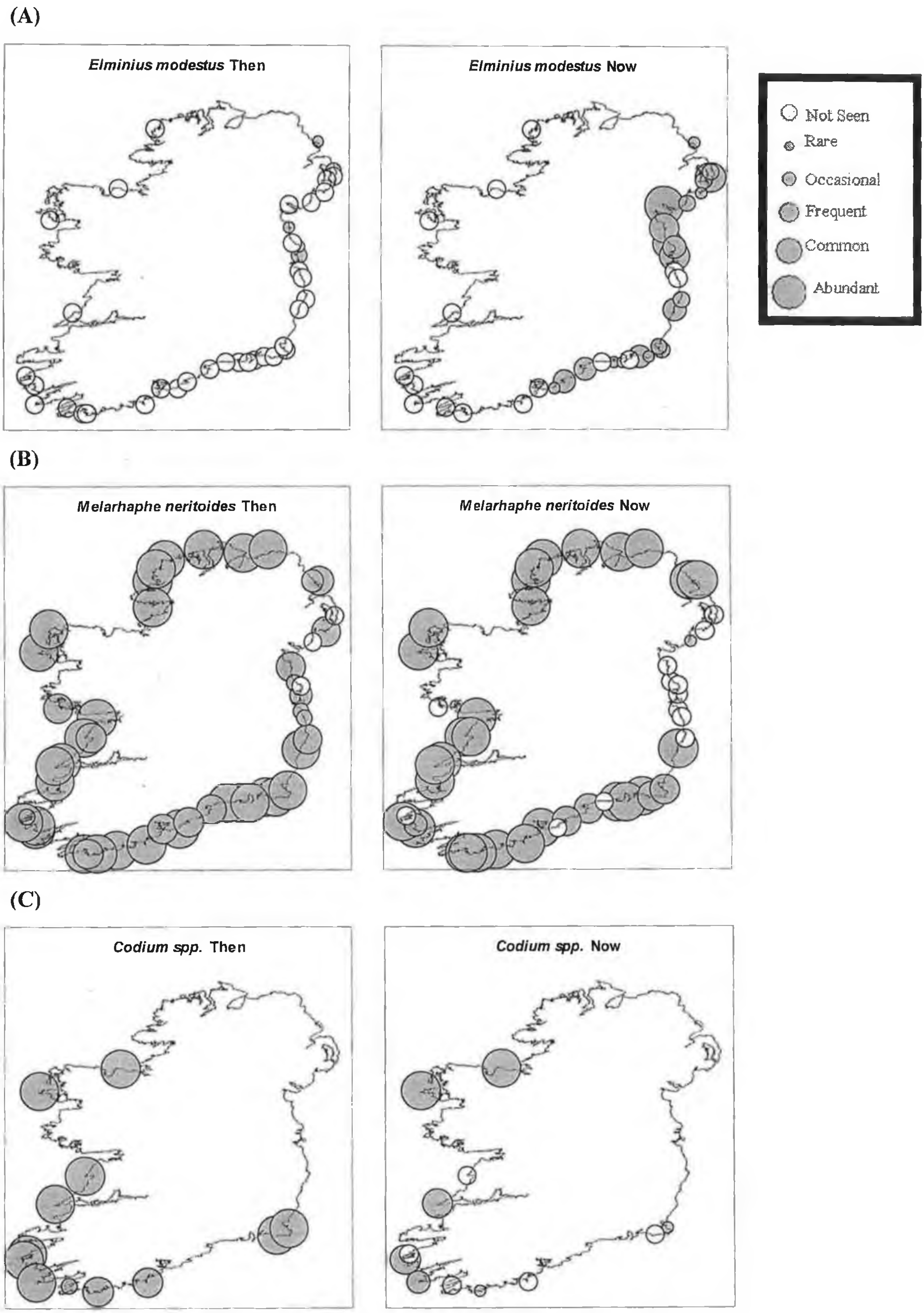
Changes in species abundances are shown in Figure 3.3 (A-L). Four of the species showed a clear geographical pattern of change. The introduced barnacle species *E. modestus* (Figure 3.3A) showed an overall increase especially along the east coast. The broadly distributed *Codium* spp. experienced a significant decrease along the south and southwestern coastline (Figure 3.3B). *Melarhaphe neritoides*, also a broadly distributed species, showed a significant decrease predominantly along the east coast (Figure 3.3C). *Paracentrotus lividus*, a southern species, decreased significantly along the west coast (Figure 3.3D) and

Table 3.2: The frequency of each abundance category for all 27 species, which were surveyed during the 1950's (then) and 2003 (now). 2003 frequencies are shown inside parenthesis in bold. Although the 2003 re-survey estimated the abundance of all 27 species at 63 sites, only those sites were the species was recorded in the 1950's were used during calculations. *Chthamalus montagui* and *Chthamalus stellatus* are listed combined as *Chthamalus* spp. because they were not separated as two species until after the 1950's survey. The asterisks represent a significant change in abundance using the non-parametric Wilcoxon signed ranks test (* P<0.05, ** P<0.01, *** P<0.005, **** P<0.001).

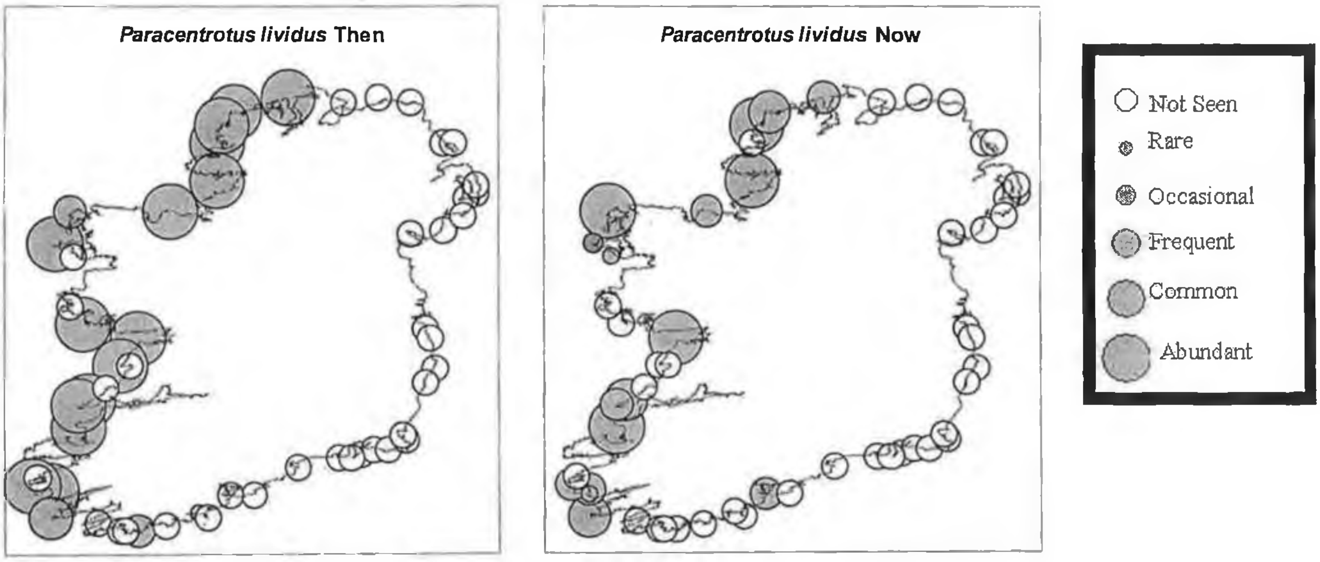
	Abundant	Common	Frequent	Occasional	Rare	Absent	Total Sites Recorded	Geographic Distribution	Change in Abundance
Alaria esculenta	16 **(10)**	7 **(1)**	2 **(1)**	4 **(5)**	1 **(4)**	16 **(25)**	46	North	Decrease***
Ascophyllum nodosum	5 **(8)**	8 **(5)**	1 **(1)**	4 **(0)**	1 **(0)**	1 **(6)**	20	North	
Balanus crenatus	2 **(0)**	8 **(0)**	0 **(0)**	3 **(0)**	0 **(0)**	3 **(16)**	16	North	Decrease****
Chondrus crispus	8 **(9)**	9 **(5)**	0 **(3)**	2 **(1)**	2 **(3)**	1 **(1)**	22	North	
Halidrys siliquosa	20 **(18)**	9 **(0)**	0 **(2)**	4 **(5)**	0 **(5)**	10 **(13)**	43	North	
Himanthalia elongata	19 **(24)**	11 **(1)**	3 **(0)**	5 **(2)**	0 **(0)**	15 **(26)**	53	North	
Laminaria hyperborea	7 **(1)**	5 **(1)**	1 **(0)**	2 **(1)**	0 **(1)**	0 **(11)**	15	North	Decrease***
Laminaria saccharina	10 **(2)**	11 **(6)**	3 **(1)**	4 **(6)**	0 **(2)**	0 **(11)**	28	North	Decrease****
Littorina littorea	27 **(15)**	8 **(12)**	1 **(7)**	0 **(0)**	0 **(1)**	1 **(2)**	37	North	Decrease***
Mastocarpus stellatus	11 **(16)**	13 **(0)**	0 **(3)**	2 **(4)**	1 **(1)**	0 **(3)**	27	North	
Nucella lapillus	27 **(27)**	11 **(7)**	1 **(4)**	2 **(2)**	0 **(2)**	1 **(0)**	42	North	
Semibalanus balanoides	30 **(42)**	15 **(8)**	4 **(2)**	2 **(1)**	1 **(2)**	5 **(2)**	57	North	Increase*
Anemonia viridis	8 **(11)**	3 **(5)**	3 **(4)**	5 **(1)**	5 **(9)**	32 **(26)**	56	South	
Bifurcaria bifurcata	5 **(7)**	1 **(0)**	2 **(0)**	1 **(0)**	1 **(0)**	28 **(31)**	38	South	
Chthamalus spp.	44 **(48)**	11 **(5)**	3 **(4)**	2 **(0)**	1 **(2)**	1 **(3)**	62	South	
Cystoseira spp.	4 **(3)**	3 **(1)**	0 **(0)**	3 **(2)**	0 **(0)**	24 **(28)**	34	South	
Gibbula umbilicalis	28 **(28)**	10 **(10)**	2 **(6)**	4 **(0)**	3 **(6)**	8 **(5)**	55	South	
Osilinus lineatus	18 **(15)**	6 **(6)**	3 **(2)**	5 **(2)**	1 **(9)**	17 **(16)**	50	South	
Paracentrotus lividus	16 **(5)**	1 **(3)**	2 **(6)**	0 **(1)**	1 **(2)**	35 **(38)**	55	South	Decrease**
Patella ulyssiponensis	23 **(15)**	6 **(9)**	3 **(10)**	6 **(2)**	1 **(1)**	0 **(2)**	39	South	
Sabellaria alveolata	4 **(5)**	3 **(1)**	2 **(0)**	4 **(1)**	0 **(0)**	15 **(21)**	28	South	
Calliostoma zizyphinum	1 **(0)**	0 **(0)**	1 **(0)**	7 **(0)**	0 **(6)**	6 **(9)**	15	Broadly distributed	Decrease*
Codium spp.	9 **(2)**	2 **(1)**	0 **(1)**	1 **(1)**	0 **(0)**	0 **(7)**	12	Broadly distributed	Decrease***
Gibbula cineraria	13 **(4)**	19 **(8)**	1 **(6)**	3 **(9)**	0 **(7)**	5 **(7)**	41	Broadly distributed	Decrease****
Melarhaphe neritoides	29 **(30)**	10 **(4)**	2 **(1)**	4 **(0)**	0 **(1)**	3 **(12)**	48	Broadly distributed	Decrease**
Mytilus spp.	28 **(31)**	4 **(3)**	2 **(3)**	10 **(7)**	0 **(3)**	5 **(2)**	49	Broadly distributed	
Elminius modestus	0 **(1)**	0 **(4)**	0 **(5)**	2 **(6)**	3 **(7)**	33 **(15)**	38	Introduced	Increase****

Table 3.3: Possible factors contributing to the change in species abundances. See discussion (Section 3.4) for further explanation.

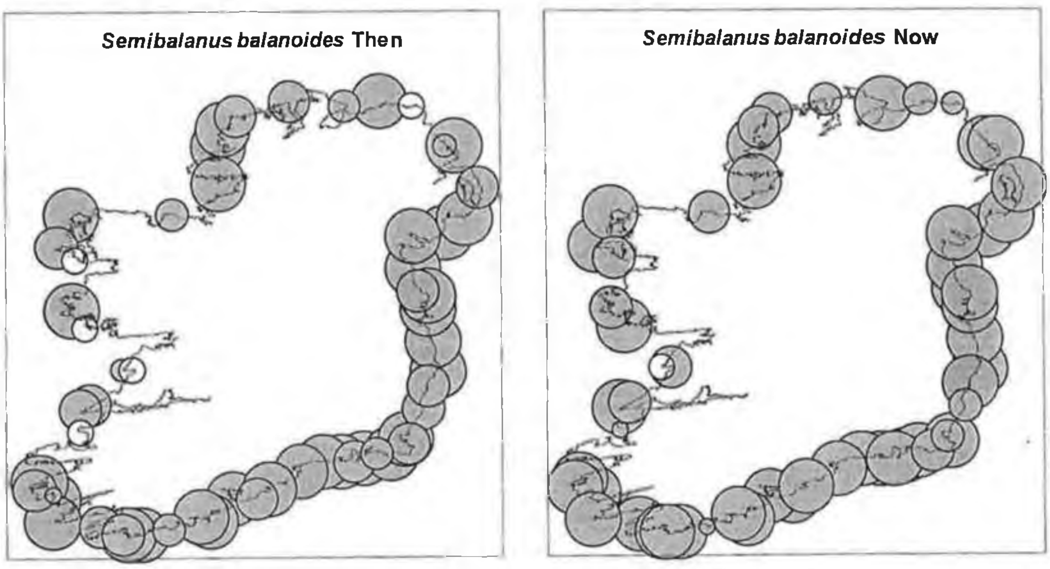
Species	Geographical Distribution	Significant change	Possible Contributing Factor
Alaria esculenta	Northern	Decrease	Climate Change (UV light) or sampling difficulties
Laminaria saccharina	Northern	Decrease	Climate Change (UV light) or sampling difficulties
Laminaria hyperborea	Northern	Decrease	Climate Change or sampling difficulties
Semibalanus balanoides	Northern	Increase	Operator error
Balanus crenatus	Northern	Decrease	Climate Change or sampling difficulties
Littorina littorea	Northern	Decrease	Over-exploitation
Paracentrotus lividus	Southern	Decrease	Over-exploitation
Melarhaphe neritoides	Broadly distributed	Decrease	Operator error
Gibbula cineraria	Broadly distributed	Decrease	Depletion of food source or sampling difficulties
Calliostoma zizyphinum	Broadly distributed	Decrease	Depletion of food source or sampling difficulties
Codium spp.	Mix of Southern/Introduced	Decrease	Identification difficulties
Elminius modestus	Introduced	Increase	Operator error


(A)
Elminius modestus Then
Elminius modestus Now
Not Seen
Rare
Occasional
Frequent
Common
Abundant
(B)
Melarhaphe neritoides Then
Melarhaphe neritoides Now
(C)
Codium spp. Then
Codium spp. Now

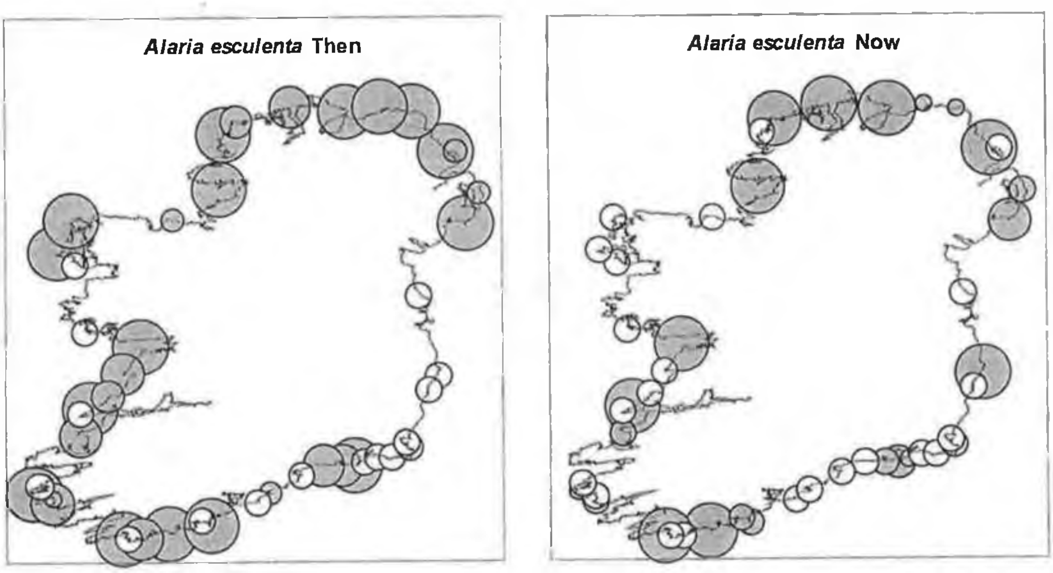
(D)


Paracentrotus lividus Then
Paracentrotus lividus Now
Not Seen
Rare
Occasional
Frequent
Common
Abundant

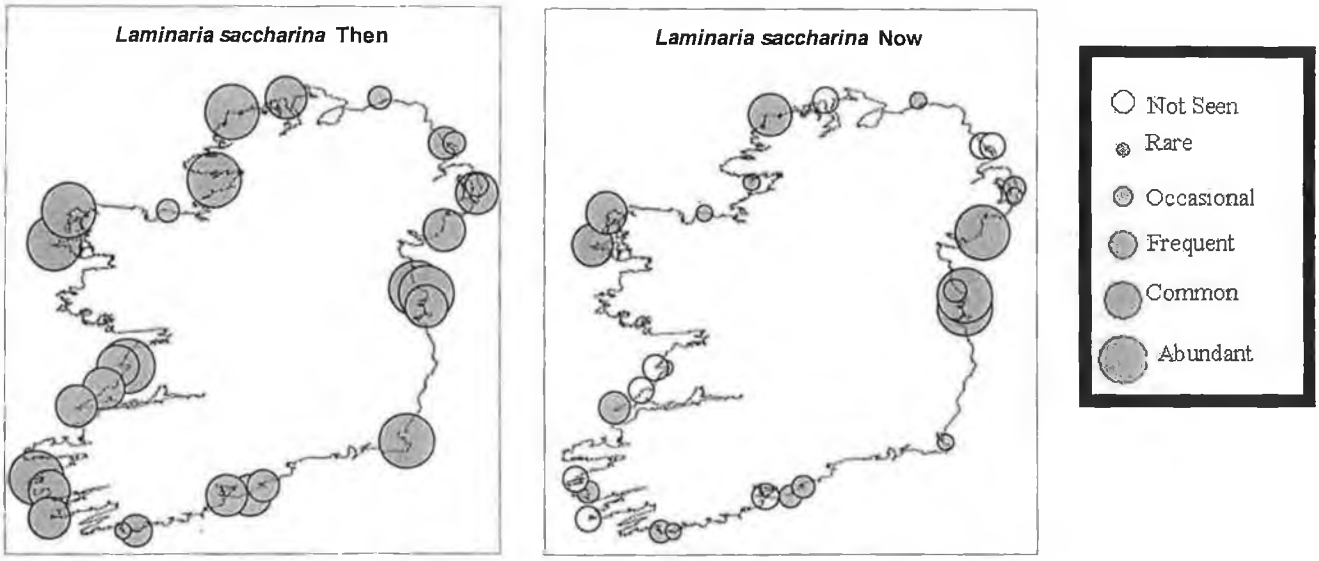
(E)


Semibalanus balanoides Then
Semibalanus balanoides Now

(F)

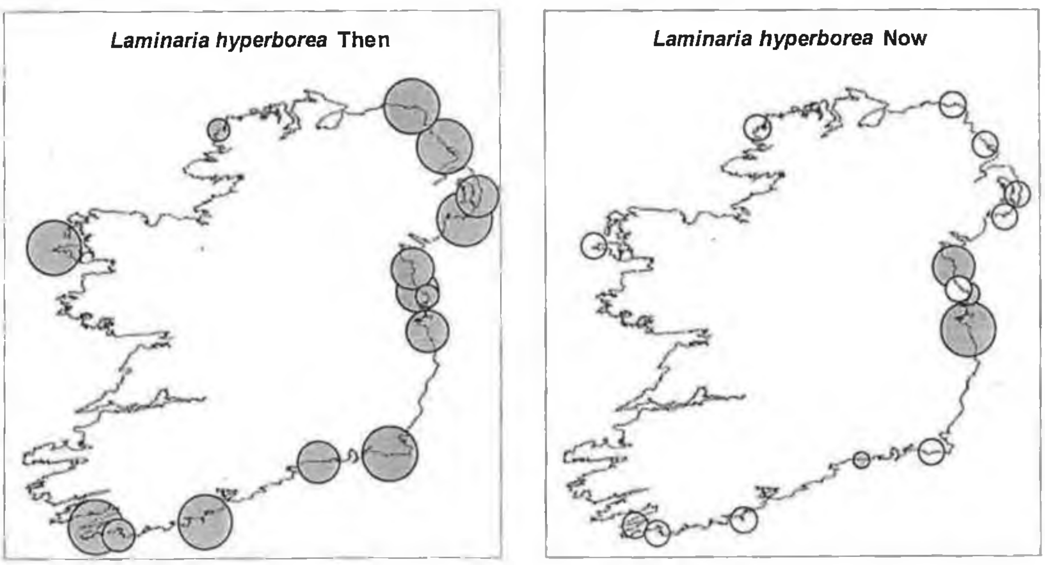

Alaria esculenta Then
Alaria esculenta Now

(G)



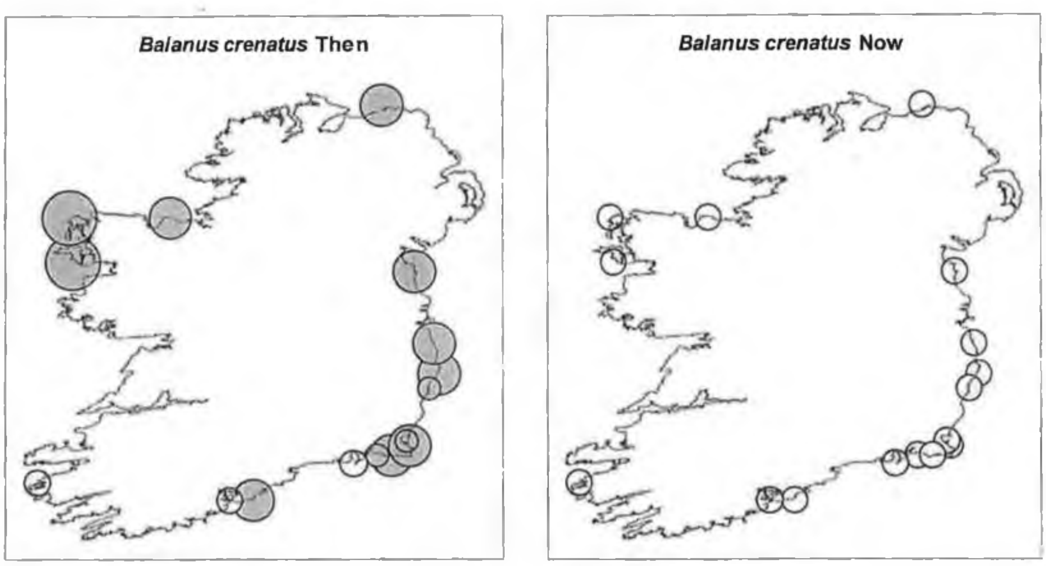
Laminaria saccharina Then
Laminaria saccharina Now
Not Seen
Rare
Occasional
Frequent
Common
Abundant

(H)



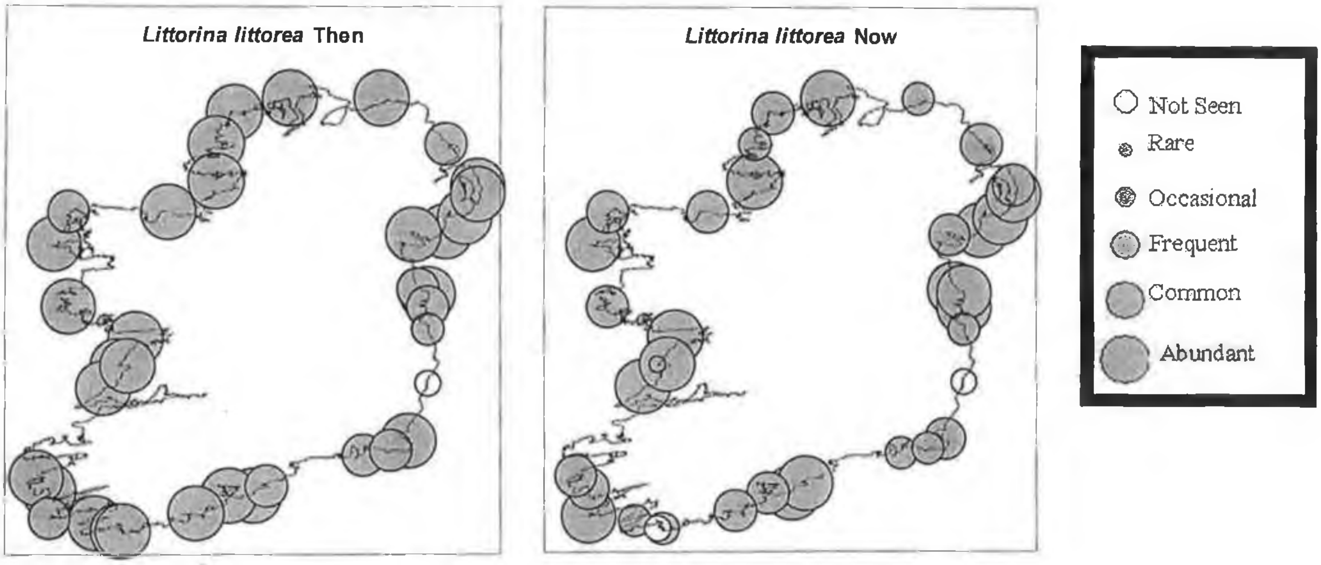
Laminaria hyperborea Then
Laminaria hyperborea Now

(I)

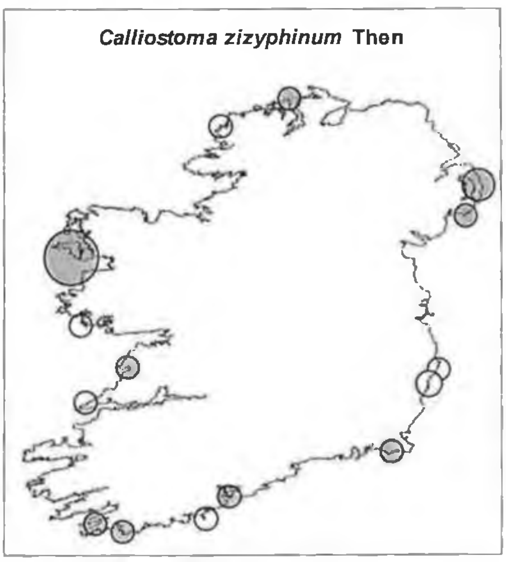


Balanus crenatus Then
Balanus crenatus Now

(J)



(K)



(L)

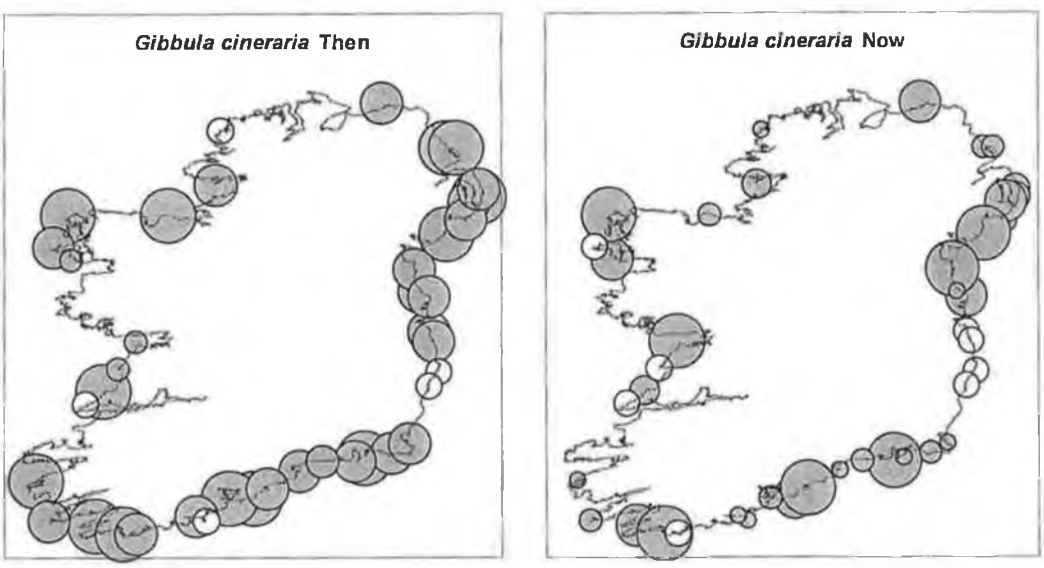


Figure 3.3 (A-L): The distribution (based only on sites that were sampled during both 'then' and 'now') and abundance of species during the 1950's (then) and 2003 (now).

the other seven species showed significant changes but in no clear geographical pattern. The northern species *S. balanoides* (Figure 3.3E) showed an overall increase while the other northern species *A. esculenta* (Figure 3.3F), *L. saccharina* (Figure 3.3G), *L. hyperborea* (Figure 3.3H), *B. crenatus* (Figure 3.3I) and *L. littorea* (Figure 3.3J) showed decreases over the entire coastline. The two broadly distributed species *C. zizyphinum* (Figure 3.3K) and *G. cineraria* (Figure 3.3L) also showed decreases over the entire coastline.

Multi-dimensional scaling (MDS with stress = 0.15) showed that there was no distinct separation between 'then' and 'now' assemblages for the 24 shores used in this analysis (Figure 3.4). An ANOSIM test confirmed the lack of separation between the groups of samples (1950's vs. 2003), indicating that the two groups were indistinguishable (test statistic; global R = 0, P = 0.64).

Operator Error

While using the ACFOR categories to assess species abundances, operators and teams tended to differ most often when allocating the abundant, common and absent categories, whereas operators were more consistent when assigning the frequent, occasional and rare categories (Figures 3.5A and 3.5B). When two operators were on the same shore at the same time, they attributed a differing abundance category to species 18.88% of the time (Table 3.4, shores 1 through 4). 3.57% of the total was due to differences of more than one category. The highest discrepancy amongst operators when allocating ACFOR categories occurred between teams (of two operators each) with 24.18% (Table 3.4, shores 5 through 8). 16.75% of the total were due to changes of more than 1 category.

It was important to determine whether the 12 species, which showed a significant change in abundance from the 1950's to 2003, were affected by operator error. Each of the 12 species was assessed for the number of times an abundance score was attributed differently by one or more categories from 'then' to 'now' (Table 3.5). The scale of change observed in three species, *E. modestus*, *M. neritoides* and *S. balanoides*, was less than the percentage difference between teams of operators at the level of two or more abundance categories. Thus the significant change in abundance shown during analysis for these three species may be due to operator error. The other eight species did not fall within the range

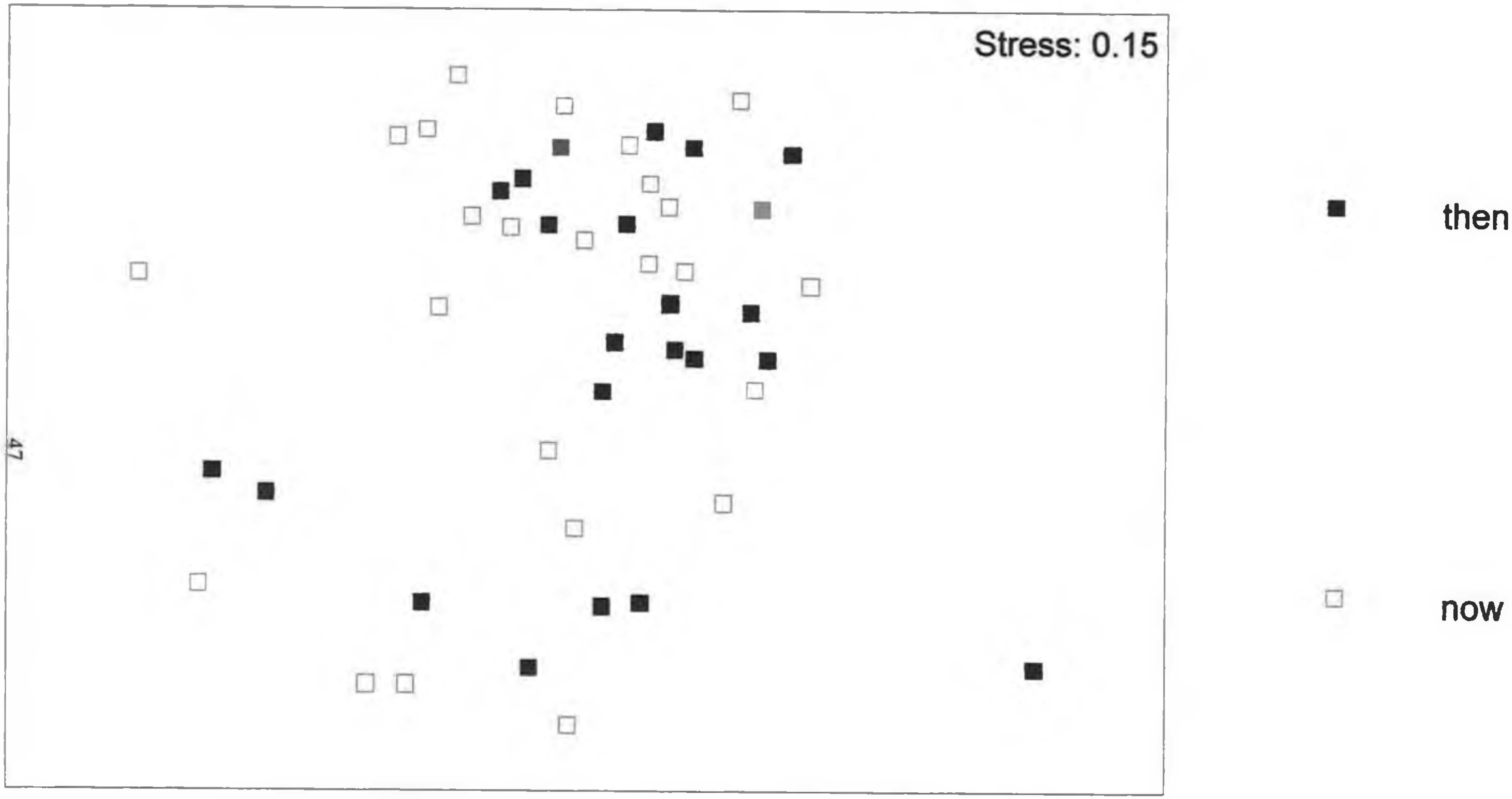


Figure 3.4: Multivariate comparison of communities from the 1950's (then) and 2003 (now) using multi-dimensional scaling (MDS). Scatter plot derived from a data matrix consisting of the abundances of 11 species (11 rows) recorded at 24 sites from the 1950's along with the same 24 sites from 2003 (48 columns). Black boxes represent sites from the 1950's while white boxes represent sites from 2003.

(A) (B)

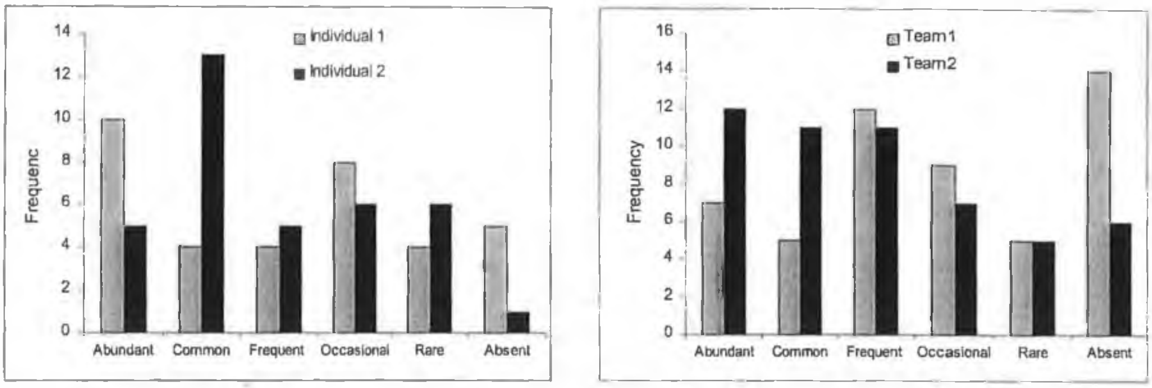


Figure 3.5: Operator error differences in the frequency of abundance categories allocated between (A) two individuals at four shores within the same space and time and (B) two teams, of two individuals each, at four shores within the same space on consecutive days.

Table 3.4: Number and percentage differences in allocating an ACFOR category. Shores 1 to 4 are shores, which were sampled by individuals sampling within the same space and time. Shores 5 to 8 are shores sampled by teams sampling the same space on consecutive days. The standard deviation is also shown.

Shore	Number Different	Differences of >1 category	Number of species per site	Percentage Different	Percent due to >1 category
1	8	2	49	16.33	4.08
2	11	2	49	22.45	4.08
3	8	3	49	16.33	6.12
4	10	0	49	20.41	0.00
Mean	**9** +/- 1.5	**2** +/- 1.25	**49**	**18.88** +/- 3.1	**3.57** +/- 2.6
5	8	5	54	14.81	9.26
6	12	9	53	22.64	16.98
7	15	12	54	27.78	22.22
8	17	10	54	31.48	18.52
Mean	**13** +/- 3.9	**9** +/- 2.9	**54** +/- 0.5	**24.18** +/- 7.2	**16.75** +/- 5.45

Table 3.5: Listed are the twelve species that showed a significant change in abundance from the 1950's to 2003. The number and percentage of times an ACFOR category differed, overall and by more than 1 category, from the 1950's to 2003 are listed. The three species in bold are those that fall within the percentage and standard deviation of mean team operator error (22.22%) when allocating categories of more than one magnitude of difference.

Species Name	Shores Recorded	Number of Differences	Differences of > 1 category	Percentage Different	Percent due to > 1 category
Alaria esculenta	15	12	12	80.00	80.00
Balanus crenatus	12	10	8	83.33	66.67
Calliostoma zizyphinum	28	26	17	92.86	60.71
Codium spp.	47	25	21	53.19	44.68
Elminius modestus	**57**	**30**	**12**	**52.63**	**21.05***
Gibbula cineraria	16	13	10	81.25	62.50
Laminaria hyperborea	38	21	15	55.26	39.47
Laminaria saccharina	41	33	21	80.49	51.22
Littorina littorea	15	10	5	66.67	33.33
Melarhaphe neritoides	**48**	**20**	**7**	**41.67**	**14.58***
Paracentrotus lividus	37	22	16	59.46	43.24
Semibalanus balanoides	**55**	17	4	**30.91**	**7.27***

of error due to operator, however, the significance level of the change shown by these species may have been increased due to the effects of operator error.

Barnacle quantitative vs. semi-quantitative

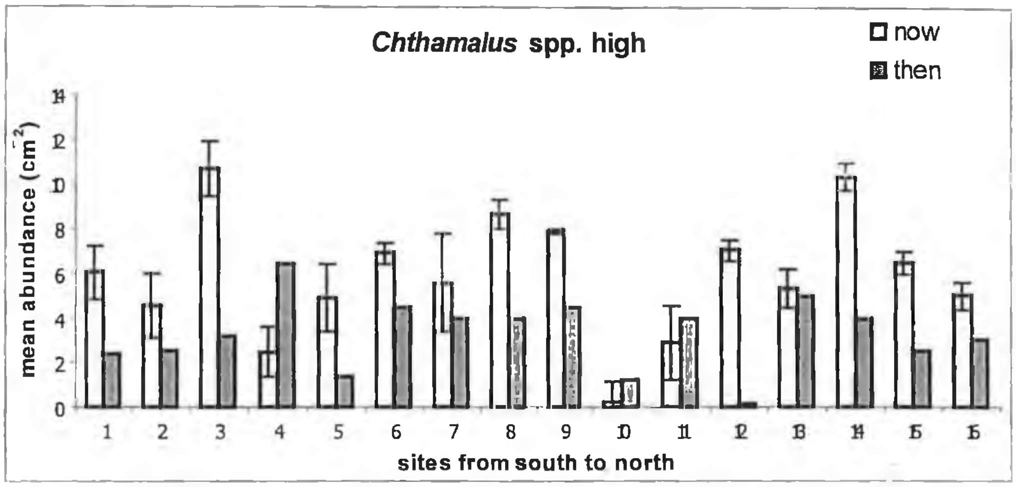
Parametric analysis on the quantitative barnacle data has shown that *Chthamalus* spp. increased significantly in abundance within the high barnacle zone only (paired $t = 3.473$, d.f. = 15, $P<0.005$, Figure 3.6A), while showing no significant change within the mid zone (paired $t = 1.402$, d.f. = 15, $P>0.05$, Figure 3.6B) or the lower zone (paired $t = 1.978$, d.f. = 15, $P>0.05$, Figure 3.6C). *S. balanoides* showed no significant change in abundance within the high barnacle zone (paired $t = -0.942$, d.f. = 15, $P>0.05$, Figure 3.6D), the mid zone (paired $t = -0.257$, d.f. = 15, $P>0.05$, Figure 3.6E) or the lower zone (paired $t = -0.881$, d.f. = 15, $P>0.05$, Figure 3.6F).

Analysis of the quantitative mean abundance has shown that *Chthamalus* spp. (Figure 3.7A) significantly increased across 16 shores from the 1950's to 2003 (paired $t = 3.225$, d.f. = 15, $P<0.01$), whereas *S. balanoides* (Figure 3.7B) showed no significant change in mean abundance from then to now (paired $t = -1.647$, d.f. = 15, $P>0.05$). These results differed from those obtained when analysing the abundance scale (ACFOR) data for both taxa (Table 3.6). Once the quantitative count data were converted to an ACFOR score and value, non-parametric analysis showed no significant difference in the abundance of either *Chthamalus* spp. ($Z = -1.414$, $P>0.05$) or *S. balanoides* ($Z = -1.098$, $P>0.05$).

3.4 Discussion

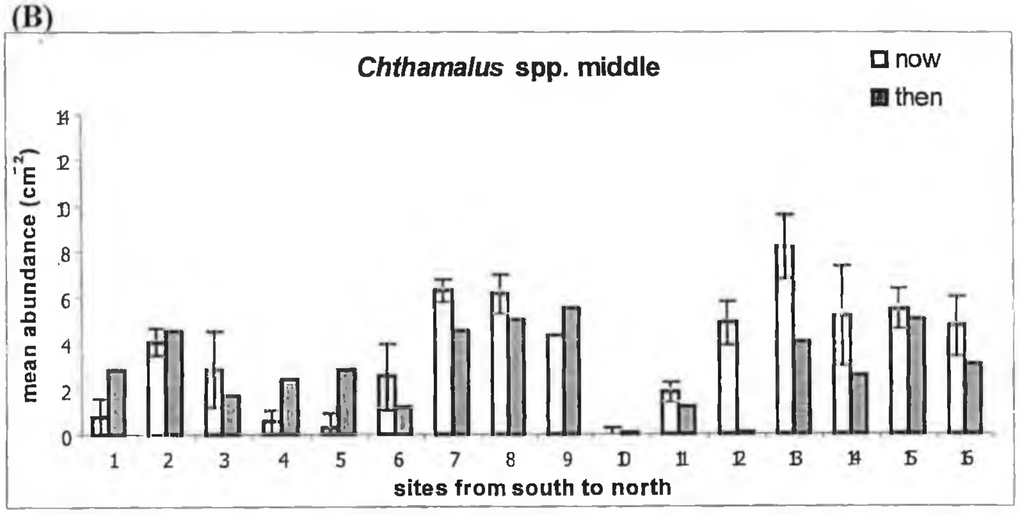
This analysis of intertidal species abundances, using ACFOR data, has shown a significant change in 12 out of 27 species. There are a number of possible reasons why some of these species have changed in abundance (Table 3.3). Although there are contributing factors which might be directly or indirectly accountable for the significant changes in the abundance of 12 species it would be wrong to assume that none of the changes are due to natural fluctuations. It was not possible to draw robust conclusions about species fluctuations and climate change because there were only two data points spanning 50 years. Long-term trends in species abundances may be obscured by short-term fluctuations (Lesica

(A)



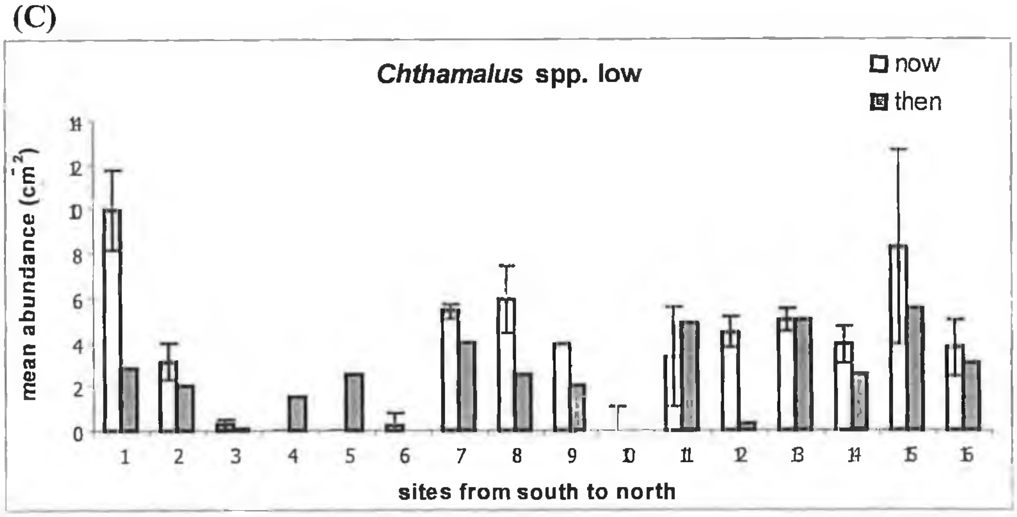
Chthamalus spp. high
now
then
mean abundance (cm⁻²)
0 2 4 6 8 10 12 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
sites from south to north

(B)



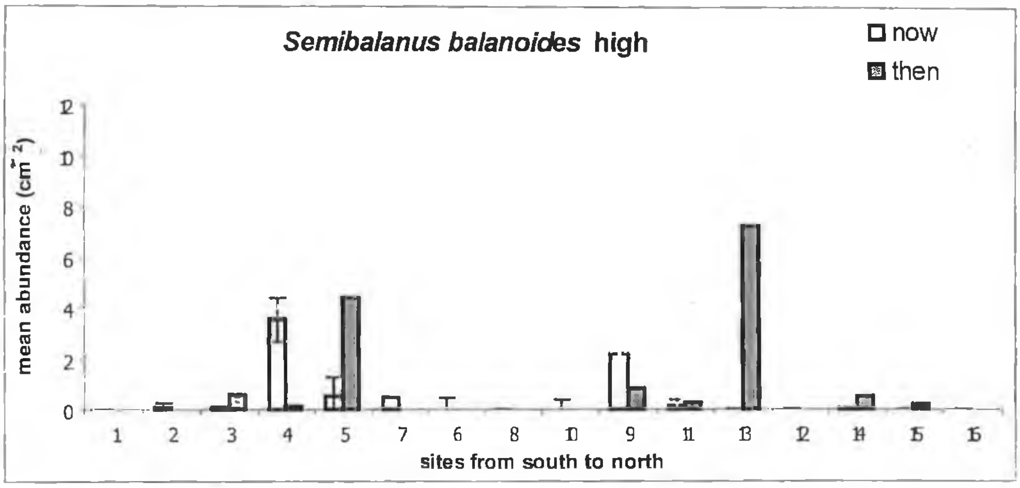
Chthamalus spp. middle
now
then
mean abundance (cm⁻²)
0 2 4 6 8 10 12 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
sites from south to north

(C)

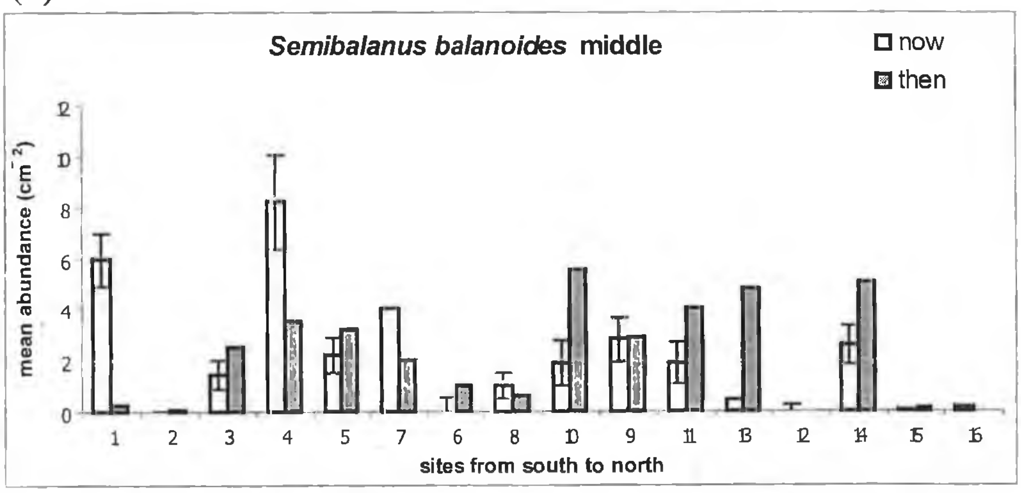


Chthamalus spp. low
now
then
mean abundance (cm⁻²)
0 2 4 6 8 10 12 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
sites from south to north

(D)



(E)



(F)

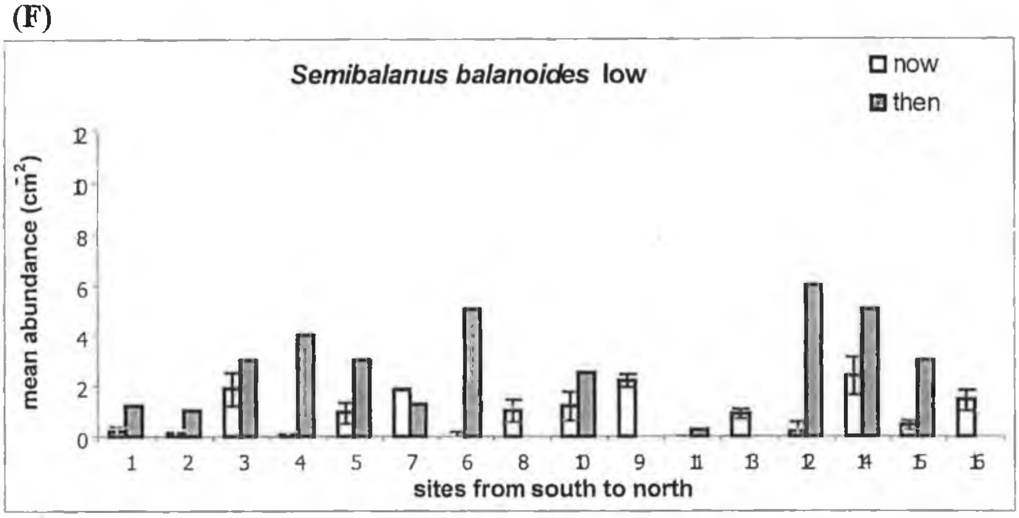


Figure 3.6: Mean abundance (cm^{-2}) of *Chthamalus* spp. and *Semibalanus balanoides* at three barnacle zone heights. Error bars are calculated by standard deviation of three replicate quadrats at each height. There are no error bars for the then (1950's) data because the mean of the replicate quadrats was derived on the shore by Alan Southward and not recorded in notebooks.

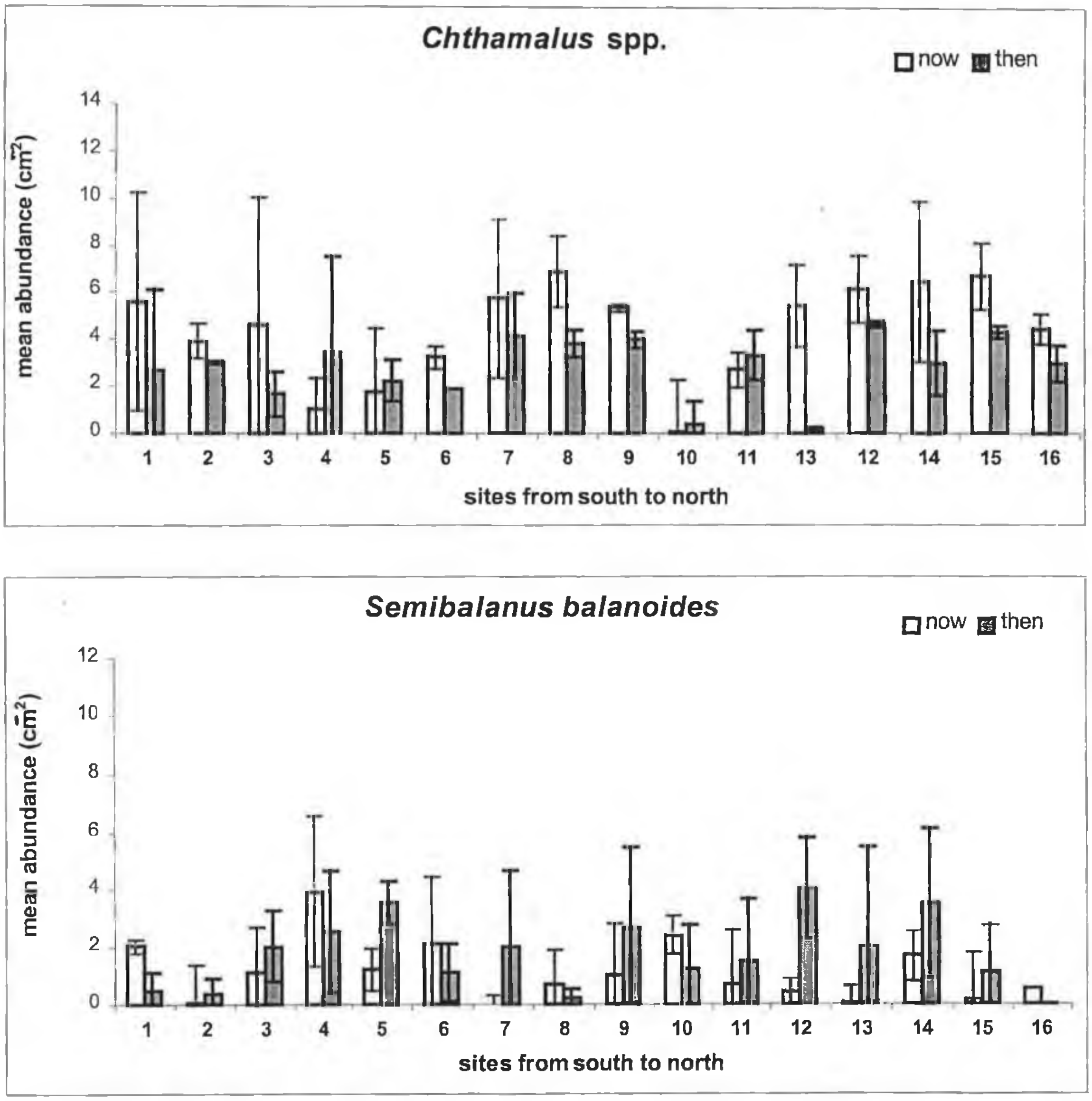


Figure 3.7: Mean abundance (cm^{-2}) of *Chthamalus* spp. and *Semibalanus balanoides* at 16 sites around the Irish coastline. Mean abundance was calculated by taking the average of the mean counts from the high, middle and low barnacle zone at each site (3 quadrats at each shore height). Error bars are based on standard deviations. Sites are arranged from south to north along the x-axis (left to right; Appendix II).

Table 3.6: The frequency of each abundance category recorded during both the 1950's and 2003 for both *Chthamalus* spp. and *Semibalanus balanoides*. Frequencies from 2003 are shown inside parenthesis in bold. The table is based on the 16 shores (Appendix II), which were used for the quantitative barnacle analysis.

	Abundant	Common	Frequent	Occasional	Rare	Absent
Chthamalus spp.	15 **(14)**	1 **(2)**	0 **(0)**	0 **(0)**	0 **(0)**	0 **(0)**
Semibalanus balanoides	11 **(9)**	4 **(3)**	0 **(3)**	1 **(1)**	0 **(0)**	0 **(0)**

and Steele, 1996) and for this reason, without knowledge of the short-term variation in species abundance, it is difficult to know what caused the significant changes we observed. It may prove useful to conduct a re-survey again in two or three years time, to measure the change undergone by species over a shorter time period.

Of the 12 species in which a significant change in the ACFOR data was recorded only two species increased in abundance (*E. modestus* and *S. balanoides*). The barnacle *E. modestus* is an introduced species whose spread around the Irish coastline has been well documented (O'Riordan, 1996). The significant increase of *E. modestus* from the 1950's to 2003 may be a classic example of a successful invasion and reflecting a rapid colonisation of a new area unrelated to climate change. However, studies have shown that climate change may indirectly affect the interactions between introduced and native species by causing increased stress in native populations (Occhipinti-Ambrogi and Savini, 2003) and earlier recruitment in introduced species (Stachowicz *et al.*, 2002) thus facilitating the expansion of non-native organisms. The barnacle *S. balanoides*, on the other hand, is a northern species and therefore would have been expected to decrease if it was affected by climate change. A direct link between fluctuating temperature regimes and the abundance of *S. balanoides* has been shown by Southward (1991), whereby *S. balanoides* flourishes during cold temperature periods, while during warm temperature periods it decreases in abundance. Globally the 1990's were the warmest decade and 1998 was the warmest year since 1861 (IPCC, 2001), suggesting that *S. balanoides* should have decreased in abundance in response to the warming trends. However, the apparent increase in both *E. modestus* and *S. balanoides* may be an artefact due to operator error (see below).

The other 10 species, which changed significantly in recorded abundance from the 1950's to 2003, showed a decline. Five of these species were northern species, one was a southern species, and four were broadly distributed. The five northern species were the algae *A. esculenta*, *L. saccharina* and *L. hyperborea*, the barnacle *B. crenatus*, and the gastropod *L. littorea*. The growth and survival of both *A. esculenta* and *L. saccharina* have been shown to be negatively affected by ultraviolet radiation, especially in shallow water or low-tide conditions (Makarov, 1999; Michler *et al.*, 2002; Apprill and Lesser, 2003). As the ozone layer continues to decrease, the levels of UV radiation reaching the earth's surface are increasing (Clarke and Harris, 2003). Although not a direct effect of a warming climate, the regeneration of the ozone layer is inhibited by greenhouse gases which drive climate change (Shindell *et al.*, 1998; Clarke and Harris, 2003). Increases in UV radiation are negatively affecting many aquatic species including phytoplankton (Häder *et al.*, 1998), corals (Brown *et al.*, 1994), amphibians (Blaustein *et al.*, 2000), sea urchins (Adams, 2001) and anemones (Westholt *et al.*, 1999). Both *A. esculenta* and *L. saccharina* have shown a decline over the entire coastline (Figures 3.3F and 3.3G), which may be a symptom of increased UV light having an effect on a broad scale. The kelp *L. hyperborea* and the barnacle *B. crenatus* are both northern species and thus their decrease in abundance would follow what is expected to happen under a warming climate scenario. It is important to note that both species showed a decrease over the entire coastline (Figures 3.3H and 3.3I) suggesting that the cause of their decrease might be linked to processes that act over a large scale, such as climate change. The species, *A. esculenta*, *L. saccharina, L. hyperborea* and *B. crenatus* are all shallow sublittoral inhabitants and are generally only easily seen during extreme low tides. It is possible that this factor lead to an under estimation and thus to the decrease in abundance we found for all four species. The northern gastropod *L. littorea* decreased significantly around the whole of the Irish coastline (Figure 3.3K), most likely due to its commercial exploitation. It is collected on virtually all Irish coasts for export to mainland Europe (Fisheries Science Services, 2003). The biomass of *L. littorea* collected has fluctuated since the 1970's but overall, there has been a decrease with 2,400 tonnes being collected in 1970 and only 1,368 tonnes being collected in 2003.

The only southern species to decrease significantly was the sea urchin *P. lividus*. This sea urchin is only found along the western and southern Irish coastline where it has decreased from the 1950's to 2003 (Figure 3.3E). *P. lividus* is a commercially important species and in 1976, 375 tonnes were landed in Ireland (Fisheries Science Services, 2003). Since then a rapid decline in the abundance of *P. lividus* has occurred and during 2000 only 0.7 tonnes were landed (Fisheries Science Services, 2003). This decline is believed to be due to the over-exploitation and slow growth rate of the species (Southward and Southward, 1975). However there is an indication that *P. lividus* populations are being negatively affected by something other than over-exploitation. A recent study at Lough Hyne Marine Nature Reserve, where the removal of any organism within the reserve boundaries is not allowed, showed a decrease in *P. lividus* from the 1970's to present (Barnes *et al.*, 2002). The reasons for this decrease are not clear but may be related to sea surface temperatures and population fragmentation (Barnes *et al.*, 2002).

Calliostoma zizyphinum, *G. cineraria*, *M. neritoides* and *Codium* spp. declined in abundance. The trochids *C. zizyphinum* and *G. cineraria* both showed decreases in abundance over the entire coastline (Figures 3.3K and 3.3L) which suggests that they are being affected by large scale processes. One possibility is that both trochid species are responding to a decrease in the algae (*A. esculenta*, *L. saccharina* and *L. hyperborea*), which may be used as a food or shelter resource. As with some of the species discussed previously, *C. zizyphinum* and *G.cineraria* are lower shore and shallow sublittoral species. Therefore it is possible that the decrease in abundance is due to the difficulties associated with assessing extreme low water species. In addition, both species can be rare in the intertidal making them more difficult to assess. The littorinid *M. neritoides* was shown to have decreased throughout the coastline and was not found along the east coast (Figure 3.3D) at the sites surveyed. The results for *M. neritoides* fell within the percentage of operator error therefore the apparent increase may be an artefact due to operator error. There are 3 taxa of *Codium* in Ireland, two are introduced (*Codium fragile* ssp. *tomentosoides* and *Codium fragile* ssp. *atlanticum*) and one is native, with a southern distribution (*Codium tomentosum*) (Trowbridge, 2001). Distinguishing between the three species in the field is difficult and generally requires a specimen to be brought back to the laboratory for identification (Stefan Kraan personal communication). Due to this difficulty the abundance of all *Codium* species in the field were assessed as *Codium* spp. Both introduced species were present in Ireland before the 1950's survey (Silva, 1955; Trowbridge, 2001), however due, to the same difficulties with identification all findings were recorded as *Codium* spp. The data from the 1950's and 2003 have shown a decrease in *Codium* spp. along the southeast and southwest coastline (Figure 3.3C). The fact that there are three taxa in Ireland makes it difficult to analyse which effects may have contributed to this decrease in abundance.

The original data and the re-survey data could not be analysed using multivariate statistics. The major reason for this was that during the original survey a search for each species was not conducted on every shore. This led to a high number of empty cells where nothing was recorded in the dataset. It was impossible to know whether these blanks represented a genuine absence of a particular taxon or simply a species that wasn't sought or recorded, thus they had to be excluded from the analysis. To create a full data matrix for analysis, an original survey of 205 shores and 27 species was reduced to 24 shores and 11 species. When used in Multi-Dimensional Scaling (Figure 3.4) no distinction between the two groups (*i.e.* original survey and re-survey) could be seen. There are two possible reasons for this, either the size of matrix was not extensive enough to produce a signal through all of the temporal and spatial 'noise' or there may not be any signal. During the 2003 re-survey we looked for and assessed each of 57 species on 63 shores, thus there are no 'blanks' in the dataset and any future monitoring would be able to utilize multivariate analyses.

There is good consistency between operators when they are attributing the categories 'frequent' 'occasional' and 'rare', whereas there is a higher inconsistency when attributing the categories 'abundant' 'common' and 'absent' (Figure 3.5). The high discrepancy between operators when allocating the 'absent' category has implications for identifying species limits of distribution. This exercise has shown that sometimes one operator finds a species and because it may be 'rare' or 'occasional' another operator does not see it. This indicates that 'rare' and 'occasional' species may be missed, especially at their range edges where species tend to be low in abundance and therefore may be represented as absent when they may actually be present. Also, because there is no defined area or sample size within and between shores it is possible that operator's are sampling different sized habitats when on the shore. Having the shore and sample area clearly determined before conducting the survey would greatly decrease the probability of methodological error. Another important problem is the 'zone of most abundance', which depending on which area of the shore is being surveyed, could be considered a different size for each operator.

Two experienced operators, who had been trained together and were sampling on the same shore at the same time, attributed differing abundance categories about 20% of the time (Table 3.4). A previous study using the abundance scale method has suggested that differences of more than one category (*i.e.* more than one order of magnitude) are significant (Baker *et al.*, 1981). Our results showed that two operators attributed different abundance categories of more than one category nearly 4% of the time. The error associated with teams of individuals is even greater, with different categories being attributed 24% of the time and different categories of more than one order of magnitude being attributed 16% of the time. The higher percentage of team operator error as compared with individual operator error could be for two reasons. Firstly, despite efforts to standardize protocols rigorously this may not have been achieved and secondly, shores may have incorrectly located leading to teams sampling different areas. Teams had to locate shores individually using the data from the 1950's while undertaking sampling on consecutive days so that the actions of one team were completely independent of the other. The 'team operator' approach more appropriately reflects the operator error associated with conducting a re-survey because the 1950's survey was conducted by a team of two individuals sampling the same shores but at different times and entirely independent from ourselves in 2003. By applying modern techniques, such as GPS and digital photography, any future survey will be able to relocate sites with more accuracy. Discussions regarding operator error are not often included in ecological studies relying on data collected by more than one operator.

Our results indicated that the apparent significant difference in the abundance of three species (*E. modestus*, *S. balanoides* and *M. neritoides*) might have been caused by operator error (Table 3.5) and not a change due to natural or anthropogenic reasons. The effect of operator error may be decreased if the significance levels for examining change were increased from 95% to 99%. However, this does not affect conclusions reached for *E. modestus*, which showed a very significant change ($P<0.001$, Table 3.2) so increasing the significance level to 99% would not have changed the result for this species. It is curious that the change in *E. modestus* may be due to operator error because other studies have shown that *E. modestus*, an invasive species, which has increased its range significantly around the Irish coastline (O'Riordan, 1996). Perhaps the most useful conclusion is that operator error can have a significant effect on the results gained when looking at changes in species abundances using an ACFOR methodology, even in species that are known to have changed. Although the results for only three species could be directly attributable to operator error the results of all of the other species may have also been affected. However, quantifying the amount (if any) that the use of different operators affected each species was not possible.

With this doubt over ACFOR sensitivity in mind, I used quantitative data on one barnacle genus *Chthamalus* spp. and one barnacle species *S. balanoides* as a comparison with which to test the sensitivity of the semi-quantitative ACFOR data. The overall abundance scale data for the 63 shores re-surveyed showed a significant increase in *S. balanoides* and no change in *Chthamalus* spp. However, as mentioned above, it was found that this increase in *S. balanoides* might have been caused by the error associated with different operators conducting the original survey and the re-survey (Table 3.5). When the quantitative data, for 16 shores, were tested using a parametric paired t-test, results showed no change in the abundance of *S. balanoides* and a significant increase in *Chthamalus* spp. After further investigation the significant increase was caused by an increase in Chthamalid numbers in the high barnacle zone (Figure 3.6A). When the count data was converted to an abundance category and retested using non-parametric methods, results showed no significant change in either barnacle, thus analysis failed to detect the increase in *Chthamalus* spp. These results show that ACFOR is not very sensitive to increases in species abundance, especially if the species was abundant in the previous survey. This is because the abundance categories only go up to 'abundant' meaning that if a species was abundant in the 1950's and increased significantly in abundance it would not be revealed. Another difficulty is that the abundance scales are based on a logarithmic scale so that if there was a category above 'abundant', such as 'super abundant', it would have to be an order of magnitude greater. This is a very large difference and in fact may be well in excess of what constitutes a statistically significant change. The benefit however of having a category or categories above 'abundant' is that increases of species beyond 'abundant' would be detectable.

Summary and Conclusions

There has been a significant change in the recorded abundance of 12 intertidal species after a 50-year time interval. The reasons for these changes in recorded abundances cannot be determined. There are two sources of error associated with using ACFOR scales as a methodology for detecting change.

Firstly, 'operator' error has been shown to affect the results obtained when analysing for significant changes in the abundance of species. In this case, the factors contributing to a significant change in recorded abundance of 3 (*E. modestus*, *S. balanoides* and *M. neritoides*) out of 12 species could have been attributed to operator error. In addition it has been shown that 'operators' sampling at different times and possibly different 'shores' or areas increase the probability of 'operator error'. Another factor contributing to 'operator error' is that there is no definition for what size the shore or a species 'zone of most abundance' should be and therefore an element of subjectivity is introduced. Secondly, ACFOR scales are sensitive to increases in species that were previously recorded as 'absent', 'rare', 'occasional', 'frequent' or 'common', however they are unable to detect increases in species which were previously recorded as 'abundant'. When looking for increases in species that are naturally abundant and conspicuous on shores (e.g. *Chthamalus* spp.) quantitative data at a subset of sites has been shown to be more sensitive for detecting change than ACFOR at a large number of sites.

No single ecological study can demonstrate that climate change is irrefutably causing the recent biological changes to species and communities (Hughes, 2000; McCarthy, 2001). However there are common threads, including the type and magnitude of changes, amongst most climate studies that allow them to collectively provide evidence for the effects of climate change on biota (McCarthy, 2001). Long-term datasets allow for detailed and in-depth conclusions to be drawn regarding the biological effects of climate change on species, however, they are relatively sparse and therefore new baseline monitoring programs are needed (Hughes, 2000). This study was not only a re-survey of a previous baseline study, but in surveying the Irish rocky coastline in one year we were able to conduct a critical analysis of the existing methodology while creating a full dataset which can be used as a baseline for future monitoring.

CHAPTER 4

An Examination of the Population Structure and Density of Two Trochid Species *Osilinus lineatus* (da Costa) and *Gibbula umbilicalis* (da Costa) around the Irish Coastline.

Abstract

The distributional limits of species can be set by a number of factors, which contribute to the reproductive success, dispersal or survival of individuals. The trochid species, *Osilinus lineatus* and *Gibbula umbilicalis*, reach their northern limits of distribution at or just north of Ireland. A baseline survey documenting the abundance, distribution and population structure of both trochid species around the Irish coastline was carried out during the summer of 2003. Using a historical study, a comparison was made between the abundance of both species, recorded during a 1950's survey and a 2003 re-survey. Neither species changed significantly in abundance after a 50-year time interval, however, both species were found at sites during the 2003 survey were they were not documented during the 1950's. Analysis was also conducted on the population structure and density of *O. lineatus* and *G. umbilicalis* on shores near the 'edge' of their distribution and on shores over 225km away from the 'edge', referred to as 'centre' shores. This comparison showed that densities near the 'edge' were lower than those towards the 'centre'. No distinction could be made between the size structure of shores near the 'edge' and those towards the 'centre'. Results for both species showed that the sizes (and ages for *O. lineatus*) of individuals on shores varied between shores throughout their range in Ireland. This suggests that Irish populations of both species may be affected over small scales by local environmental conditions.

4.1 Introduction

There are three general explanations, which can account for the limitation of a species to its present range (Campbell *et al.*, 1999): (1) the species may never have dispersed beyond its current boundaries; (2) individuals that did spread beyond the observed range failed to survive; and (3) over evolutionary time the species has retracted from a once-larger range to its present boundaries. Essentially, over shorter time scales, there are two ways to characterise limit populations. Those limited by recruitment and dispersal of a species and those limited by survival of individuals caused by intolerance to physical and biological conditions.

Species geographical ranges are believed to follow a general pattern in which the centre of the range is the most optimal location and therefore where the species abundance is greatest (Brown, 1984). As a result, when the distance away from the centre increases, conditions become unfavourable and the population lowers in density until the edge is reached and the species cannot survive (Gaston, 1990). At the limits of species distributions biotic factors (*i.e.* competition, predation, reproduction) and abiotic factors (*i.e.* salinity, temperature; exposure) combine or play a singular role in restricting a species from spreading further. Recent work has shown that the general pattern of species distributions, described by Brown (1984), may not be generally applicable and, in fact, some species are most abundant at the limits of their distribution (Sagarin and Gaines, 2002). If species are being affected by human disturbances on a large-scale such as pollution, over exploitation or climate change they are most likely to react negatively in regions where their population is already at its physical or biological limits (*i.e.* edge populations). Thus it is necessary to understand the dynamics of a species range in order to monitor for effects.

The trochid species *Osilinus lineatus* (da Costa) and *Gibbula umbilicalis* (da Costa) are both species with southern distributions that reach their northern limits at or near Ireland. *Osilinus lineatus* extends from Morocco northward along the Atlantic coast of mainland Europe to its northern most point near Malin Head in County Donegal (Kendall, 1987; Southward and Crisp, 1954b). In Britain its most northerly location is in North Anglesey along the Welsh coast and thus does not reach to Scotland (Desai, 1966; Fretter and Graham, 1977; Crothers, 1994). *Gibbula umbilicalis* extends from Morocco northward along the western coast of Europe to its most northerly location on the north coast of Scotland and Orkney (Lewis *et al.*, 1982; Hayward *et al.*, 1996). It is found all around the Irish coastline except for an unexplained absence, possibly due to physical attributes of the shores, on the east coast (Southward and Crisp, 1954b).

Lewis *et al.*, (1982) suggested that the distributional limits of *O. lineatus* and *G. umbilicalis* might be set by their failure to reproduce with sufficient success to maintain populations or, if they can do this, by failure to survive after settlement (Fretter and Graham, 1994). If recruitment failure were the cause of their limits of distribution we would expect to see an irregular age structure with some year classes missing and a predominance of older, larger animals (Lewis *et al.*, 1982; Crothers, 1994). In contrast, if the population was unable to survive due to some outside factor (such as temperature) we would expect to see a higher proportion of young and small animals at the limits (Lewis *et al.*, 1982; Crothers, 1994).

The population structures of both *O. lineatus* and *G. umbilicalis* have been well studied around the British coastline. It has been shown that *O. lineatus* populations close to their limits of distribution share similar population characteristics. Crothers (1994) found that a population near the eastern range edge, in Somerset along the British Channel, had a large density, high adult mortality and young individuals with small sizes. Similarly, when surveying near the northern limit in Aberaeron, Wales, Kendall *et al.* (1987) found that populations were characterised by a large density and young and small individuals. Studies on *G. umbilicalis* populations have provided evidence to show that populations varied between sites at the limits of distribution and distances away from the limits. For instance, populations in northern Scotland were characterized by poor recruitment, low densities and large individuals (Kendall and Lewis, 1986). In contrast, populations in mid-Wales approximately 700km away from the northern limit, had high recruitment, large densities and individuals were smaller in size (Kendall *et al.*, 1987).

Studies of both *O. lineatus* and *G. umbilicalis* have also been carried out in Ireland. Healy and McGrath (1998) conducted surveys of the population structure (size and age) and density of both *O. lineatus* and *G. umbilicalis* in County

Wexford during 1977 and 1996. Southeast County Wexford represents a limit of distribution for both species along the east coast of Ireland. This limit is thought to be set by physical barriers, such as strong tidal currents and lack of suitable substrate (as shores on the east coast are dominated by sand and pebbles; Southward and Crisp, 1954b). Research found that the *O. lineatus* populations, at Carnsore Point during both 1977 ad 1996, were characterised by a moderate density (~5.9 m^{-2}) and large, old animals (Healy and McGrath, 1998). However, at Kilmore Quay, 15 km from Carnsore Point, populations were more variable through time. In 1977, the population structure was similar to that found at Carnsore, whereas in 1996, the population had a higher density and was characterised by large and younger animals, indicating a faster growth rate. The results for *G. umbilicalis* also varied, with populations during 1977 having high densities and large animals, whereas in 1996, the density was similar but was dominated by smaller animals (Healy and McGrath, 1998).

To date, there has been no study, which examines the population structure and density of *O. lineatus* and *G. umbilicalis* at the limits ('edge') of their distribution and at a distance away from the limits ('centre') of their distribution in Ireland. Therefore the objectives of the present investigation were twofold. The first aim was to describe and document the present day (2003) population structure of both *O. lineatus* and *G. umbilicalis* around the Irish coastline for possible future monitoring. Secondly, since both species are close or at (in the case of *O. lineatus*) their northern range edge in Ireland, I aimed to determine the differences (if any) between 'edge' and 'centre' populations in Ireland in regards to size structure, age structure and density.

4.2 Materials and Methods

Surveys of two trochid species *O. lineatus* and *G. umbilicalis* were conducted on shores throughout Ireland. Quantitative measurements of both species were carried out in conjunction with the ACFOR survey documented in Chapter 3. Counts were conducted on shores where the population was over 1 m^{-2}, at 28 shores for *O. lineatus* and 46 shores for *G. umbilicalis* (Appendix III). On each shore, after the ACFOR protocol was completed, systematic counts were carried out.

- An area with adults and juveniles within the *O. lineatus* zone and *G. umbilicalis* zone (they generally inhabited different zones) was haphazardly selected.
- Within the area selected for each species, five replicate three-minute counts were carried out. Catch per unit time was used, as opposed to counts per unit area, due to the variability in the heterogeneity of the shores used (Kendall and Lewis, 1986; Kendall, 1987).
- For each replicate timed count five different areas within the species zone were haphazardly chosen and used. This ensured that replicates did not overlap. During collections replicate counts were kept separate for further analysis.
- Once all counts were complete the maximum diameter of individuals was measured to the nearest mm using vernier calipers and recorded.
- On selected shores the *O. lineatus* collected during the timed counts were collected and brought back to the laboratory for aging by counting the annual growth checks (Williamson and Kendall, 1981). *Gibbula umbilicalis* were not aged. Kendall and Lewis (1986) found that ageing *G. umbilicalis* was difficult and not suitable due to the shell being frequently worn or covered with encrusting algae. In 1998, Healy and McGrath were able to age 60% of a population of *G. umbilicalis* on the east coast of Ireland. The technique, however, is not validated and therefore was not used during this analysis.
- Photographs and dGPS were used to document each shore.

<u>Analysis</u>

Data collected during the ACFOR survey (Chapter 3) were used to document the current semi-quantitative abundance and distribution of both *O. lineatus* and *G. umbilicalis* in Ireland. A comparison between the distribution and abundance of both species during the 1950's (documented by Southward and Crisp (1954) and Lewis (1964)) and the 2003 survey was made for the eastern and northern coastline. These coastlines represent the areas where both species meet their limits of distribution in Ireland.

Throughout the quantitative analysis, three shores each were chosen to represent 'edge' of range and 'centre' of range shores. Even though Ireland represents the northern limit of *O. lineatus* geographical distribution, the populations of shores nearest to Malin Head were too small for analysis and thus the east coast was used as the 'edge'. *Osilinus lineatus* is missing from Cahore Point, Co. Wexford to Skerries, Co. Dublin, a stretch of approximately 125 km. *Gibbula umbilicalis* reaches its northern limit of distribution in northern Scotland and thus its 'edge' populations in Ireland were considered to be those closest to the area along the east coast (Cahore Point, Co Wexford to Malahide, Co. Dublin) were *G. umbilicalis* is absent (Southward and Crip, 1954b; Figure 4.2). 'Centre' of range refers to the centre of the range in Ireland and not the centre of the species geographical distribution. There were three criteria for picking 'edge' shores. Firstly, only shores with adequate numbers for analysis were used. Many shores near or at the limits of distribution had only rare or occasional *O. lineatus* and *G. umbilicalis* and thus could not be used during analysis. Secondly, 'edge' of range shores were defined as being no more than 100km away from the last known population on the east coast for *O. lineatus* and *G. umbilicalis* (Cahore Point, Co. Wexford). Thirdly, 'edge' populations were defined as those, which were only receiving recruits from one direction, meaning that there were not viable populations on both sides of 'edge' shores. 'Centre' of range shores were also defined by three criteria. They had to be over 225 km from the closest 'edge' shore, with adequate numbers and nearby viable populations on both sides. The three shores chosen to represent the 'edge' and 'centre' of distribution in Ireland were chosen from a selection of shores that filled the criteria above. The 'edge' shores for *O. lineatus* were Greenore Point, Co. Wexford (N52 14.4 W006 18.8), Carnsore Point, Co. Wexford (N52 10.4 W006.21.9) and Forlorn Point, Co. Wexford (N52 10.4 W006 35.6). The 'centre' shores were Abbey Island, Co. Kerry (N51 45.6 W010 08.5), Black Head, Co. Clare (N53 09.2 W009 15.8) and Moneen, Co. Clare (N52 35.1 W009 52.3). The 'edge' shores for *G. umbilicalis* were Carnsore Point, Co. Wexford (see above for dGPS), Forlorn Point, Co. Wexford (see above for dGPS) and Cullenstown, Co. Wexford (N52 12.8 W006 43.8). The 'centre' shores were St. Johns Point, Co. Donegal (N54 34.1 W008

27.7), Kerry Head, Co. Kerry (N52 23.7 W009 54.6) and Whiteball Head, Co. Cork (N51 36.2 W010 02.6).

A parametric independent samples t-test was used to test whether there was any significant difference between the median size of individuals at 'edge' and 'centre' shores. The analysis was used for both *O. lineatus* and *G. umbilicalis*. The assumptions of parametric tests (homogeneous variances and normal distribution; Underwood, 1997) were met so no transformations of the raw data were performed. To analyse the size frequency and age frequency curves of 'edge' and 'centre' shores for *O. lineatus* and *G. umbilicalis* (size frequency only) the non-parametric Kolmogorov-Smirnov (Sokal and Rohlf, 1995) test was used. This test is based on the unsigned differences between the relative cumulative frequency distributions of the two samples being compared (O'Riordan *et al.*, 2001). Growth curves for *O. lineatus* at each of the three 'edge' and 'centre' shores were produced to determine if there were any differences in the growth rates on shores. Conventional quantitative growth models, e.g. von Bertalanffy, Gompertz and logistic functions, have been shown to be inappropriate for quantifying *O. lineatus* growth (Williamson and Kendall, 1981). For this reason, the growth data points found, were fitted with a logarithmic curve and plotted together without any further analysis attempting to find significance.

A two-way mixed model Analysis of Variance (ANOVA) was used to test whether there was a significant difference between the density (catch per minute) at 'edge' and 'centre' shores for both *O. lineatus* and *G. umbilicalis*. The two factors were location, meaning 'edge' and 'centre', which was fixed. The second factor was shore, which was random and nested within location. Two null hypotheses were tested; firstly, there was no significant difference between the density of individuals caught per minute at 'edge' or 'centre' shores; secondly, there was no significant difference in the density of individuals caught per minute between all six shores regardless of whether they were classified as 'edge' or 'centre'. The assumptions of parametric tests were met and therefore no transformations of the raw data were preformed.

4.3 Results

Baseline Data

Maps showing the present (2003) distribution and abundance of *O. lineatus* and *G. umbilicalis* around the Irish Coastline are shown in Figure 4.1. *Osilinus lineatus* was generally abundant and common around the southern and western coastline. It was, however, missing from the north coast (except for Esky, Near Malin Head) and most of the east coast. *Gibbula umbilicalis* was found continuously around the Irish coastline in high abundance (abundant or common), however, along the eastern coastline it was absent for nearly 100km. Maps (Figure 4.2) are presented to show changes to the species abundance and range between the 1950's and present. There have been changes on a local scale to the abundance of *Osilinus lineatus* after a 50-year time interval although the changes are not significant (Chapter 3). It was found at four locations (Ballyquintian Pt., Co. Down, Ardglass, Co. Down, Cahore Pt., Co. Wexford and Baginbun Head, Co. Wexford) during the 2003 survey where it was not recorded during the 1950's. *Gibbula umbilicalis* also showed changes in population abundance after the 50-year interval, which were not significant (Chapter 3). It was found in two locations (Garron Pt., Co. Antrim and Cahore Pt., Co. Wexford) were it was not seen during the 1950's survey.

Size frequency histograms for each of the 28 shores for *O. lineatus* and 46 shores for *G. umbilicalis* are shown in Appendix IV for documentation and possible use in the future. The populations of *O. lineatus* were all bimodal or poly-modal. The highest number of individuals collected during timed counts (15 minutes in total) was at Daniel's Island, Co. Kerry with 392 and the lowest number of individuals was found at Brownstown Head, Co. Waterford with 51. The majority of locations had no missing size classes, and those that did were generally missing more than one size class. There was a predominance at all of the shores for a greater amount of larger individuals in comparison with smaller ones. Nearly all of the *G. umbilicalis* populations were poly-modal with no missing size classes. The highest number of individuals collected during timed counts (15 minutes in total) was at St. Johns Point, Co. Down with 354 and the lowest number of individuals was found at Bendurg Bay, Co. Down with 69.

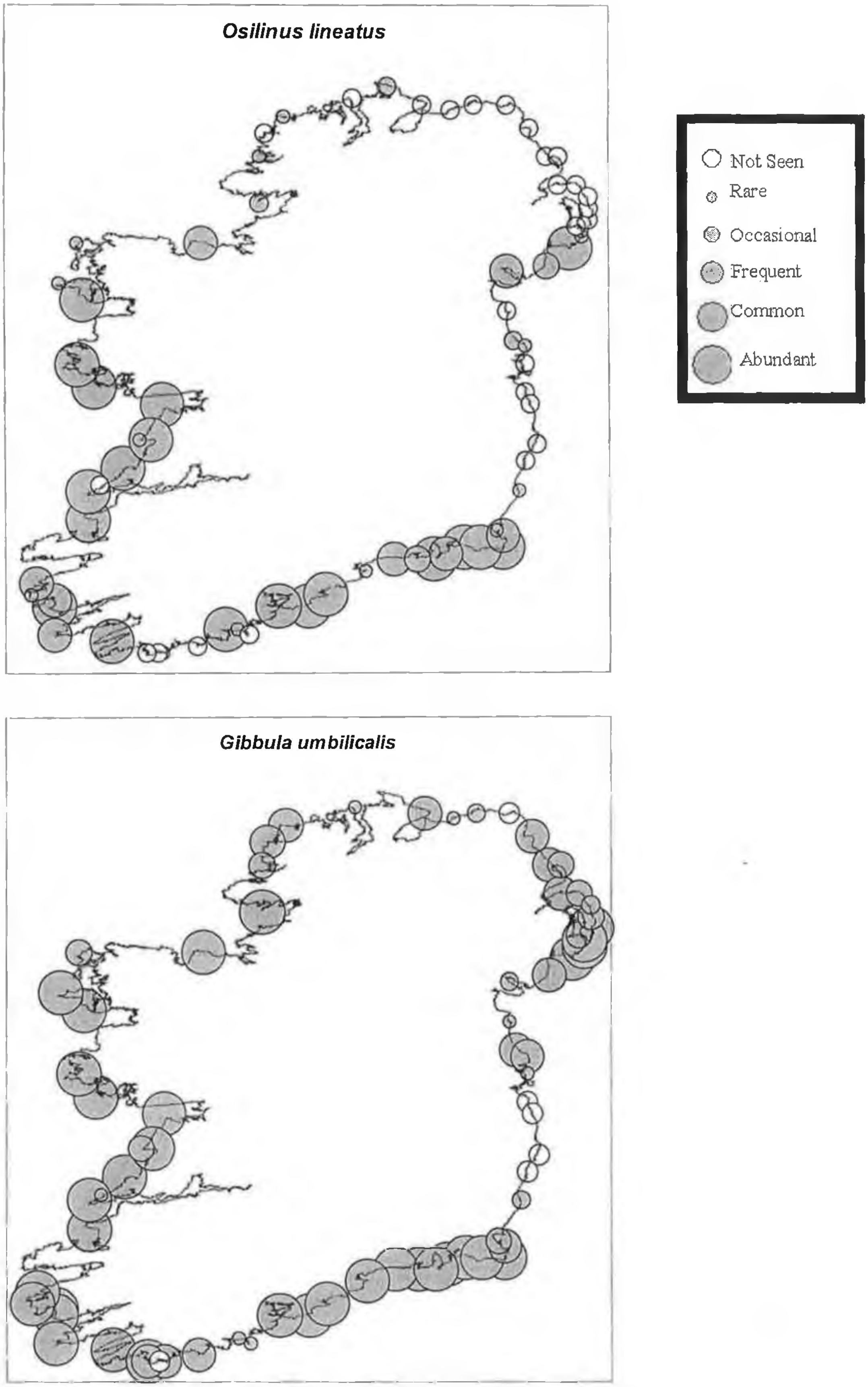


Figure 4.1: Maps of the present (2003) distribution and abundance of two Trochid species around the Irish Coastline (the sites used are those listed in Chapter 3, Figure 3.2 and Table 3.2).

Figure 4.2: The distribution and abundance of *O. lineatus* and *G. umbilicalis* around the eastern and northern Irish coastline (1950's distributions are taken from Southward and Crisp, 1954b and Lewis, 1964).

Similar to *O. lineatus*, *G. umbilicalis* populations showed a predominance of large individuals, however, the size frequencies were not as skewed towards the larger size classes as therefore *O. lineatus*.

Osilinus lineatus

The size structure, age structure and density of *O. lineatus* were analysed at three shores at the 'edge' and 'centre' of the species distribution in Ireland. Table 4.1 lists the six sites used during analysis along with the average density per minute, median size and median age of the *O. lineatus* on each shore. An independent t-test showed that there was no significant difference between the median size on 'edge' and 'centre' shores ($t = 1.387$, 4 d.f., $P = 0.238$). The size frequency distributions for each of the six shores are shown in Figure 4.3. All of the shores showed poly-modal distributions with the exception of Abbey Island, which looks to have a bimodal distribution. The largest sizes of *O. lineatus* were seen at Greenore Point and Carnsore Point, both 'edge' populations with individuals reaching 28mm and 29mm respectively. Individuals at the other four shores did not grow beyond 25mm. The smallest sizes were seen at Black Head with individuals at 6mm in diameter. All six shores have a higher frequency of large individuals than small individuals. Kolmogorov-Smirnov analysis on the six shores has shown that only two shores had similar size frequency's, Greenore Point and Carnsore Point, both 'edge' populations (Table 4.4). All of the other shores were significantly different from each other at the $P<0.001$ or $P<0.005$ level.

The maximum age of *O. lineatus* was 10 years and was found at all three 'edge' shores (Figure 4.4). The other three sites, all 'centre' shores, had populations reaching a maximum age of 9 years. New recruits (aged 1 and 2 years) were found at all of the sites except for Carnsore Point ('edge') and Abbey Island ('centre'). Kolmogorov-Smirnov analyis (Table 4.3) has shown that the age structure of Greenore Point and Carnsore Point (both 'edge' shores) are similar, as well as the age structure on Moneen and Abbey Island (both 'centre' shores). The age frequencies of the other shores are significantly different, ranging from the $P<0.05$ up to $P<0.001$ level. Growth curves show that on all of the shores size and age are correlated but only with certain levels of accuracy ranging

Table 4.1: The six sites used throughout the *O. lineatus* analysis, showing the average density, median size and median age at each shore. Number refers to the overall number of individuals collected during 5 replicate 3-minute counts on each shore.

	Location	Number	Density per minute	Median Size	Median Age
Greenore Point, Co. Wexford	Edge	76	5.1 +/-3.3	24	6
Carnsore Point, Co. Wexford	Edge	110	7.3 +/- 2.6	24	6
Forlom Point, Co. Wexford	Edge	219	14.6 +/- 2.6	18	5
Abbey Island, Co. Kerry	Centre	175	11.7 +/- 5.2	20	6
Black Head, Co. Clare	Centre	277	18.5 +/- 3.2	16	4
Moneen, Co. Clare	Centre	277	18.5 +/- 4.2	20	5

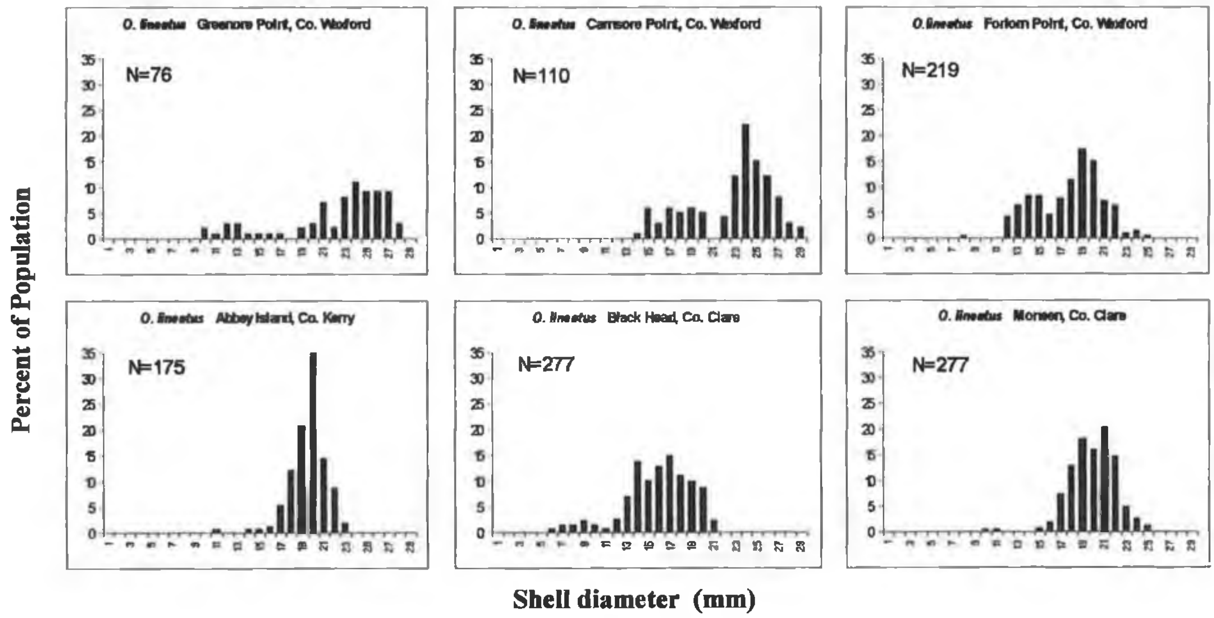


Figure 4.3: Size frequency histograms showing the variation in population structure for *O. lineatus*. The three shores near the edge of their range in Ireland are shown on the top row and the three shores over 100 km from the edge shores are shown on the bottom row.

	Greenore Point	Carnsore Point	Forlom Point	Abbey Island	Black Head	Moneen
Greenore Point		**0.1225**	0.6173****	0.6276****	0.7415****	0.5617****
Carnsore Point			0.6453****	0.6556****	0.7091****	0.5897****
Forlom Point				0.3173****	0.2887****	0.2925****
Abbey Island					0.6059****	0.1839***
Black Head						0.5812****
Moneen						

Table 4.2: Results of Kolmogorov-Smirnov two sample tests for *O. lineatus* size frequencies at three sites from the 'edge' (shown in bold) and three sites from the 'centre'. Numbers represent the unsigned calculated D, if no * is shown it indicates that shores are not significantly different. The significance levels are represented by **** P<0.001 and *** P<0.005.

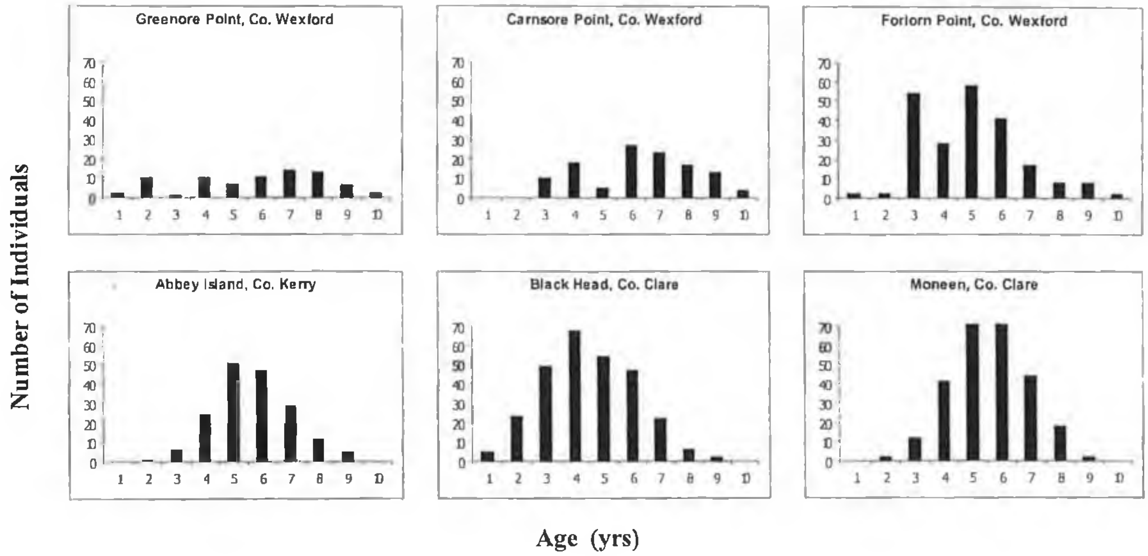


Figure 4.4: Age frequency graphs for *O. lineatus* at the three 'edge' shores (top row) and three 'centre' shores (bottom row). The x-axis represents the year class that the individual was in at the moment of collection, so 1 represents 0+ individuals, 2 represents 1+ individuals and so on. 0+ individuals would have settled in Autumn 2002 since these specimens were collected during the spring and summer of 2003.

	Greenore Point	Carnsore Point	Forlorn Point	Abbey Island	Black Head	Moneen
Greenore Point		**0.1579**	0.3014****	0.1977*	0.3518****	0.2286**
Carnsore Point			0.3725****	0.2243***	0.4389****	0.2552****
Forlorn Point				0.2236****	0.1344*	0.2129****
Abbey Island					0.3482****	**0.0386**
Black Head						0.3261****
Moneen						

Table 4.3: Results of the Komogorov-Smirnov tests on the age frequency curves shown in Figure 4.5. Numbers represent the unsigned calculated D. **** equals a significant difference of P<0.001, *** equals P<0.005, ** equals P<0.01 and * equals a significant difference to P<0.05. Numbers in bold indicate that the age frequencies of the two shores were not significantly different.

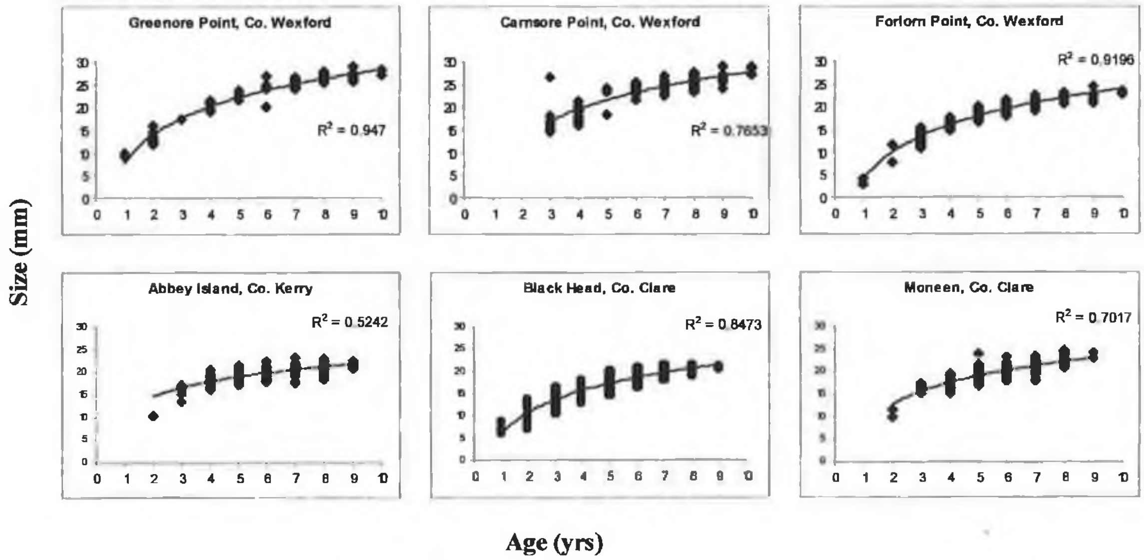


Figure 4.7: Growth curves for *O. lineatus* at the three 'edge' (top row) and three 'centre' (bottom row) shores. The trend line is logarithmic and all R^2 values are shown on graphs.

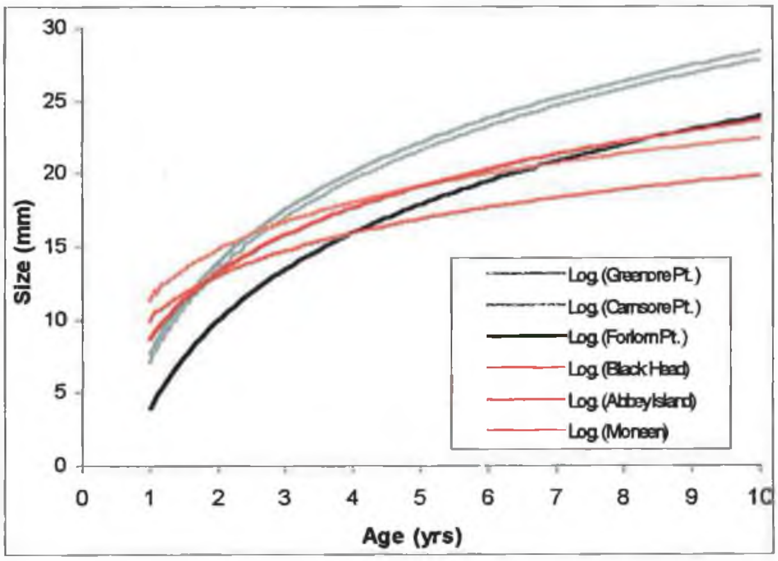


Figure 4.8: Logarithmic growth curves for *O. lineatus* on each of the six shores.

Table 4.2: Results of a mixed model two-way ANOVA looking at the density of *O. lineatus* at 'edge' and 'centre' shores. Location was fixed and shore(location) was random. ***denotes significance of P<0.005 and **** denotes P<0.001

Source of Variation	d.f.	SS	MS	*F*	*P*
Location	1	327.76	327.76	15.56	0.001****
Shore(Location)	2	317.53	158.77	7.54	0.003***
Error	26	547.72	21.07		
Total	29	1193			

from 52% (Abbey Island) to 94% (Greenore Point) (Figure 4.5). When the logarithmic growth curves for each shore were plotted together (Figure 4.6) individuals at Greenore Point were shown to have grown the fastest, followed by Carnsore Point (both 'edge' shores). Forlorn Point and Moneen had older individuals of the same size, however, the small individuals at Moneen grew quicker than those at Forlorn Point. The slowest growing *O. lineatus* were seen at Abbey Island and Black Head (two 'centre' shores).

A two-way analysis of variance (ANOVA) was used to test the null hypothesis that there was no difference between the densities (per minute) of the 5 replicate timed counts for 'edge' and 'centre' shores. Results indicated that the densities between locations ('edge' and 'centre') (d.f.=1; $P<0.001$) and between shores nested within locations (d.f.=2; $P<0.005$) were significantly different (Table 4.4). Therefore there was a significant difference between the densities of *O. lineatus* on 'edge' and 'centre' shores. However, there was also a significant difference between the densities of *O. lineatus* on shores within the locations of 'edge' and 'centre'. The densities of *O. lineatus* on 'edge' shores was 5.1, 7.3 and 14.6, whereas the densities on 'centre' shores was 11.7, 18.5 and 18.5 (Table 4.1).

Gibbula umbilicalis

The six shores used throughout the analysis for *G. umbilicalis* are shown in Table 4.5 along with the average density per minute and median size of individuals. An independent t-test showed that there was no difference between the median size at 'edge' and 'centre' shores ($t = 1.206$, 4 d.f., $P = 0.294$). Size frequency graphs indicate that each of the six shores had a poly-modal size distribution with fewer smaller individuals than larger individuals (Figure 4.7). The largest individuals were seen at Carnsore Point and Cullenstown, both 'edge' populations with individuals reaching 18 mm and 19 mm respectively. Individuals at the other four shores did not grow above 16mm. The smallest individual, at 3mm was found at St. John's Point, a 'centre' shore. A Kolmogorov-Smirnov test showed that none of the six shores have similar size frequencies, meaning that all shores were significantly different from each other, ranging from $P<0.05$ to $P<0.001$ (Table 4.6).

Table 4.5: The three 'edge' shores and the three 'centre' shores randomly chosen for analysis for *G. umbilicalis* population structure. Number refers to the overall number of individuals collected during 5 replicate 3-minute counts on each shore.

	Location	Number	Density per minute	Median Size
Carnsore Point, Co. Wexford	Edge	214	14.3 +/- 3.6	13
Cullenstown, Co. Wexford	Edge	211	14.1 +/- 6.1	15
Forlorn Point, Co. Wexford	Edge	188	12.5 +/- 2.0	13
St. Johns Point, Co. Donegal	Centre	289	19.25 +/- 4.9	11
Kerry Head, Co. Kerry	Centre	207	13.8 +/- 3.6	14
Whiteball Head, Co. Cork	Centre	275	18.3 +/- 3.7	12

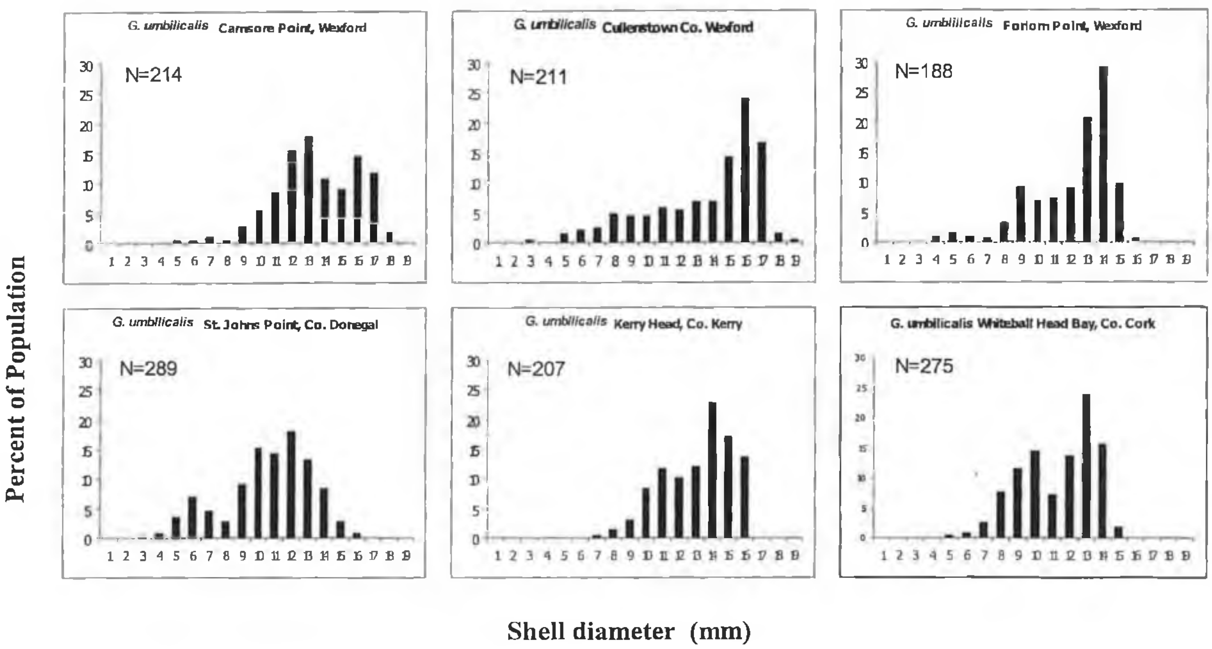


Figure 4.7: Size frequency histograms showing the variation in population structure for *G. umbilicalis*. The three 'edge' shores are shown on the top row and the three 'edge' shores are shown on the bottom row.

	Carnsore Point	**Forlorn Point**	**Cullenstown**	St. Johns Point	Kerry Head	Whiteball Head
Carnsore Point		0.2751****	0.1948****	0.40501****	0.1451*	0.3509****
Forlorn Point			0.4629****	0.3519****	0.2033****	0.2191****
Cullenstown				0.5294****	0.1460*	0.5458****
St. Johns Point					0.4138****	0.1654****
Kerry Head						0.3569****
Whiteball Head						

Table 4.6: Results of Kolmogorov-Smirnov two sample tests for *G. umbilicalis* size frequencies at three sites from the 'edge' (shown in bold) and three sites from the 'centre'. Numbers represent the unsigned calculated D, all of the above shores are significantly different. The significance levels are represented by **** $P<0.001$, *** $P<0.005$, ** $P<0.01$, * $P<0.05$.

Table 4.7: Results of a mixed model two-way ANOVA looking at the density of *G. umbilicalis* at 'edge' and 'centre' shores. Location was fixed and shore(location) was random. * denotes significance of $P<0.05$.

Source of Variation	d.f.	SS	MS	*F*	*P*
Location	1	92.54	92.54	5.08	0.033*
Shore(Location)	2	40.26	20.13	1.1	0.347
Error	26	474.05	18.23		
Total	29	606.85			

A two-way ANOVA was used to test the null hypothesis that there was no difference between the densities (per minute) of *G. umbilicalis* at the 'edge' and 'centre' shores. Results indicate that location (meaning 'edge' or 'centre') was significant (Table 4.7), meaning that there was a significant difference (d.f.=1; $P<0.05$) between the density of individuals on 'edge' and 'centre' shores. The 'edge' shores had densities of 14.3, 14.1 and 12.5 whereas the 'centre' shores had densities of 19.25, 13.8 and 18.3 (Table 4.5). Therefore, the density of 'edge' shores was significantly lower than the densities of 'centre' shores for *G. umbilicalis*.

4.4 Discussion

The broad-scale survey carried out to look for changes in species abundances after a 50-year time interval has shown that the *O. lineatus* and *G. umbilicalis* populations have changed at some localities but the change is not significant when looking at the larger scale of the whole coastline. Although we found both species at sites where they were recorded as absent during the 1950's it would be difficult to classify these as 'range extensions'. It is possible that both species are increasing their range, and if so, the results would conform to what is expected to happen if a warming trend in global temperatures was having an effect (Fields *et al.*, 1993). However, work conducted by McGrath and Nunn (2002) has shown that *O. lineatus* has repeatedly gone extinct and then recolonized localities around the Irish coast. If it is possible for these extinctions and recolonizations to happen within the geographical range of *O. lineatus*, there is no reason why these same fluctuations cannot happen at the range limits. These findings have important implications for reports on range extensions in *O. lineatus* and suggest that 'range extensions' on a small scale are not reliable extensions of the species range.

Our results for *O. lineatus* have confirmed the conclusions from the broad-scale survey by showing that the populations are locally variable. The size frequencies and the maximum size of large individuals were similar for two 'edge' shores, Greenore Point and Carnsore Point. However, the size frequencies were significantly different between the other four shores and when looking at the maximum size of individuals it was seen that the other four shores reached a smaller maximum size. One of these four shores, Forlorn Point, is an 'edge' population. Thus, suggesting that there may be variation between the size structures of populations within 100 km of the limits of *O. lineatus* geographical distribution. Similarly, there is no consistent pattern when looking at size structure amongst the 'centre' shores. The technique for quantifying the size of large individuals used by Kendall (1987), the diameter of animals at the 90th percentile of a cumulative frequency plot, was not used throughout this study because using percentages as a measure allows an effect at one end of the scale to change the other end of the scale, regardless of whether any absolute change in the number of large individuals has occurred. Thus if the diameter of animals at the 90th percentile is the same for two populations and a large influx of recruitment appears at one population, although the size of the adults did not change between the shores, the D90 for the population with recruits will be smaller than the D90 of the other population.

Williamson and Kendall (1981) suggested that *O. lineatus* might exhibit density-dependant growth. Indicating that as the population density increases growth rates would begin to slow as individuals competed for resources. The two shores with the fastest growing *O.lineatus* populations, Greenore Point and Carnsore Point (Figure 4.6), were also the two shores with the lowest densities of individuals (Table 4.1). Similarly, a shore with the highest density, Black Head, showed *O. lineatus* with the slowest growth. However, this pattern does not hold true for the three other shores.

Lewis *et al.* (1982) stated that if recruitment failure were the cause of a species limit of distribution we would expect to see irregular age structures with missing age classes at limit populations. The three 'edge' (near limit) populations where *O. lineatus* was aged showed no missing age classes (except for years 1 and 2 at Carnsore Point, which is explained below), although the numbers of individuals at each class were often low (reflecting the low densities of these populations). The results of the analyses of the density (per minute) of *O. lineatus* populations showed a significant difference in the density of individuals at 'edge' and 'centre' populations ($P<0.001$). The three 'edge' shores had lower densities than the three 'centre' shores, suggesting that recruitment success or survival of animals after settlement is more restricted at the 'edge' shores. As 'edge' shores were very close to the limits of distribution they were probably only receiving recruits from one side of their distribution. In contrast, 'centre' shores were generally surrounded by viable populations and therefore were most likely receiving recruitment input from shores on two sides. The density of individuals between shores, regardless of whether they were 'edge' or 'centre' populations were also significantly different ($P<0.005$).

The densities of the Irish *G. umbilicalis* 'edge' and 'centre' populations were significantly different ($P<0.05$) and were found to be similar to those found in Britain (Kendall *et al.*, 1987). Low densities characterize populations near the limits of distribution. In contrast, populations within the 'centre' of the species distribution were characterised by high densities. The size structures of the six shores used throughout the *G. umbilicalis* analysis were all significantly different. There looked to be a pattern where the 'edge' shores had individuals of a larger size when compared with 'centre' shores. However, a t-test of the median size showed no significant difference between the 'edge' and 'centre' shores.

It is believed that in stable populations, where recruitment, growth and mortality are constant, the youngest year class is the most abundant because while an animal may die at any age, it can only be born at age 0 (Crothers, 1994). For the Irish populations, of *O. lineatus* and *G. umbilicalis*, the youngest year class was never the most abundant. It was a feature of these two species that young recruits were continually under sampled, due to their size (sometimes less than 2mm) and the cryptic habitats in which they're found (Lewis, 1986; Kendall and Lewis, 1986; Healy and McGrath, 1998). The 28 shores surveyed for *O. lineatus* and the 47 shores for *G. umbilicalis* throughout the baseline survey also follow this trend where the frequency of very small individuals was always less than that for larger individuals.

Overall, the results for both species show that the only significant difference between 'edge' and 'centre' shores was density. In Ireland, no differences were found between the size and age structure, of *O. lineatus* and *G. umbilicalis* (size only), at 'edge' and 'centre' shores. The conclusions, therefore, were that populations of both species were variable in size and age, regardless of whether they were near the limits of distribution. Previous studies have shown that *O. lineatus* can be variable over short time scales (Healy and McGrath, 1998;

McGrath and Nunn, 2002), and may react negatively to cold temperature events (Southward and Crisp, 1954b; Crisp, 1964; Crothers, 1998). Similarly *G. umbilicalis* populations have been shown to vary over short time scales (Kendall and Lewis, 1986; Healy and McGrath, 1998). This variability over short time scales indicates that both *O. lineatus* and *G. umbilicalis* populations may be affected by local environmental conditions.

This study provides a good baseline description of the size structure and density of *O. lineatus* and *G. umbilicalis* populations around the Irish coastline. Future work needs to determine what environmental conditions most affect populations of both species around the coastline. Understanding what effects different physical and biological factors have on both species is essential if we are to use them as potential indicators for the future monitoring of climate change.

CHAPTER 5

General Overview and Discussion

This thesis has used past work and a present day survey to create a baseline for the future. In Ireland, ecological studies on rocky shore organisms and communities have been carried out for a number of years. During the past 50 years, many of the assessments of rocky shore communities have been semi-quantitative and descriptive with limited statistical analyses. These historical studies have added much to our knowledge of the general pattern of species' abundances and distributions along shores. However, more present day work is needed to continue this trend and add a temporal component to the analysis. Jackson (2001) suggested that changes to species caused by humans are the signal and natural variability constitutes the noise that obscures the human footprint. This is the challenge to ecologists *i.e.* to attribute changes in species to human induced effects, such as pollution, over-exploitation and climate change.

If climate change begins to have an effect on species, signs of this effect may appear at a range of levels of organisation (Walther *et al.*, 2002), from the highest level of ecosystems, through to communities, populations and individuals. The history of useful baseline intertidal surveys, in Ireland, was outlined in Chapter 2 and one of these surveys was used as a basis for the re-survey of rocky shore community changes (Chapter3). As the work was a re-survey of a previous survey and thus, only involved two time points, the temporal fluctuations of rocky shore species could not be analysed. However, results showed that after a 50-year time interval, 12 intertidal species out of the 27 re-surveyed changed significantly in abundance. To determine what factors caused these changes more in-depth work on the tolerances and ecologies of each species would need to be conducted. During the original survey, the abundance of species was assessed using the semi-quantitative ACFOR scale, whereas, fully quantitative data was collected for barnacle species only. This quantitative data created an opportunity with which to analyse the differences between using semi-quantitative and fully quantitative methods to detect change. This comparison indicated that because semi-quantitative scales are essentially a category with a top and bottom value, a species may decrease or increase within the category and no change will be detected. In some cases, such as that for *Chthamalus* spp., a species might not only change within a category but the change may be significant.

When conducting re-surveys or collecting long-term data sets it is often impossible for the same person to do all of the data collection. For this reason, it is important that the issue of 'operator error' is examined. Operator effects are rarely examined in ecological studies, and future work should consider these in more detail as they may confound biological conclusions (Chapter 3). The present investigation has shown that some intertidal species have experienced changes in their abundance and distributions around the Irish coastline. These may be correlated to climate change data but future investigations are required to confirm the link between alterations in climate and changes to species abundance and distribution. In order to gain a fuller picture of the effects of climate change (and other human induced changes) on biota, measurements below the community level are also required (e.g. population or physiological). Chapter 4 has provided an in-depth analysis of the population structure (size and age) and density of two species, *O. lineatus* and *G. umbilicalis*, which may be a useful baseline for future work. This work could be conducted in conjunction with community level surveys for a broader understanding of the effects of climate change.

5.1 Future Work

Although the use of semi-quantitative methodologies allows a larger geographical area to be sampled over a shorter time period, it is important to know whether the data that is being recorded is appropriate for the question being asked. This is a classic dilemma for ecologists (broader spatial scale and less detail vs. smaller scale and greater detail). It has yet to be investigated which type of data is more appropriate for monitoring climate change. Perhaps this is due to the complexity of climate change itself and the long-time scales over which it is expected to act. A good starting point, however, would be to conduct a comparative survey between semi-quantitative and fully quantitative data. This would involve carrying out a large-scale semi-quantitative survey, similar to that carried out in Chapter 3, and within the same time period carrying out a fully quantitative, detailed survey on a range of shores. The range of shores would cover the same geographical area as the semi-quantitative study, however, it would not cover nearly as many locations. It would be critical that the survey was conducted at a three-year interval so that both methodologies could be tested for their ability to detect change. The main hypothesis of the study would be to determine which survey method, a semi-quantitative survey with a high number of locations or a fully quantitative survey with a much smaller amount of locations, may be more useful for detecting change in the intertidal of Ireland.

If species ranges are expected to change due to climate change, it is important that the abundance and distribution of a species is understood throughout its entire geographical distribution. In future studies of *O. lineatus* and *G. umbilicalis*, it would be useful to measure their abundance and population structure from North Africa to Scotland. If the climate warms, as is predicted, their population characteristics, such as density and size in Ireland may become more like they are in the warmer climate of Portugal. As well as this, the seasonal and annual variation of species needs to be quantified, such that the fingerprint of humans can be detected.

APPENDIX I

List of species:

Alaria esculenta	*Actina fragacea*	*Littorina saxatilis*
Ascophyllum nodosum	*Actinia equina*	***Melarhaphe neritoides***
Bifurcaria bifurcata	***Anemonia viridis***	***Mytilus spp.***
Chondrus crispus	*Asterias rubens*	***Nucella lapillus***
Codium spp.	*Aulactinia verrucosa*	*Onchidella celtica*
Cystoseira spp.	***Balanus crenatus***	***Osilinus lineatus***
Fucus distichus	*Balanus perforatus*	***Paracentrotus lividus***
Fucus serratus	***Calliostoma zizyphinum***	*Patella depressa*
Fucus spiralis	*Campecopea hirsuta*	***Patella ulyssiponensis***
Fucus vesiculosus	***Chthamalus montaqui***	*Patella vulgata*
Halidrys siliquosa	***Chthamalus stellatus***	*Psammechinus miliaris*
Himanthalia elongata	*Clibanarius erythropus*	***Sabellaria alveolata***
Laminaria digitata	***Elminius modestus***	*Sabellaria spinulosa*
Laminaria hyperborea	***Gibbula cineraria***	***Semibalanus balanoides***
Laminaria ochroleuca	*Gibbula pennanti*	*Tectura testudinalis*
Laminaria saccharina	***Gibbula umbilicalis***	
Mastocarpus stellatus	*Halichondria panicea*	
Pelvetia canaliculata	*Haliotis tuberculata*	
Sargassum muticum	*Leptasterias mulleri*	
Lichina pygmaea	***Littorina littorea***	

*Species in bold were sampled during the 1950's.

APPENDIX II

Shores used for quantitative and semi-quantitative barnacle analysis (shown in Chapter 3), listed from south to north.

Site Name	Latitude	Longitude
Toe Head Bay, Co. Cork	N51 29.055	W009 14.479
Galley Head, Co. Kerry	N51 31.774	W008 57.266
Gyleen, Co. Cork	N51 47.613	W008 11.726
Ballycotton, Co. Cork	N51 49.605	W008 00.049
Helvick Head, Co. Cork	N52 03.284	W007 32.439
Cullenstown Reef to W, Co. Wexford	N52 12.875	W006 43.843
Kerry Head, Southside, Co. Kerry	N52 23.795	W009 54.668
Furreera, Co. Clare	N52 56.074	W009 25.753
Bunowen Point, Co. Galway	N53 24.228	W010 06.999
Malahide Coast, Co. Dublin	N53 27.100	W006 08.472
Dooagh Achill Island, Co. Mayo	N53 58.371	W010 07.944
St. Johns Point, Co. Down	N54 13.719	W005 39.145
Easky, east of quay, Co. Sligo	N54 17.494	W008 57.136
Maghery-Termon, Co. Donegal	N54 55.942	W008 26.823
Bloody Foreland, N+S, Co. Donegal	N55 09.065	W008 17.901
Culdaff, nr Dunmore Hd, Co. Donegal	N55 17.655	W007 07.708

APPENDIX III

Shores where counts were carried out on *G. umbilicalis* and *O. lineatus*. Latitude and longitude were taken with dGPS.

Gibbula umbilicalis

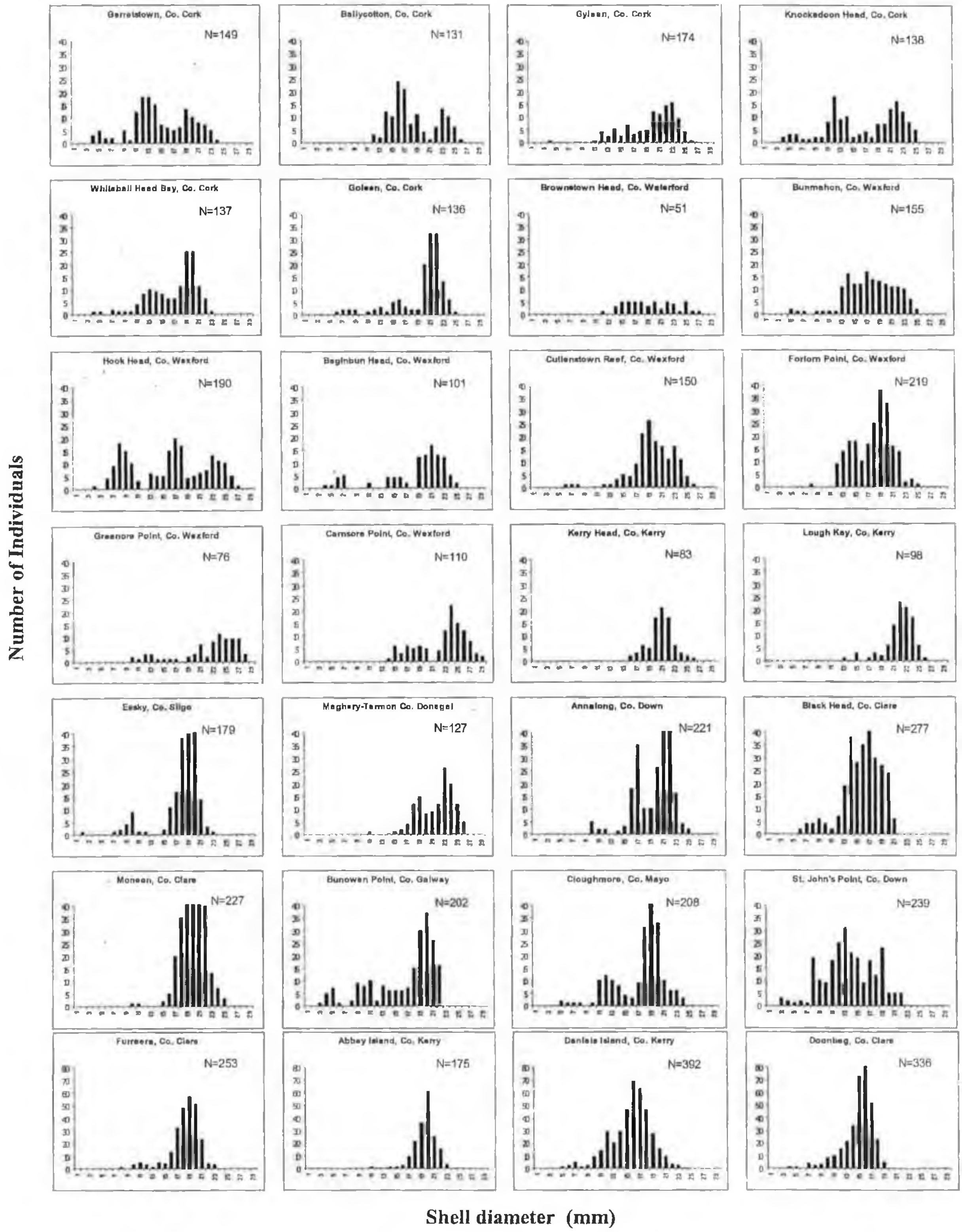
Site Name	Latitude	Longitude
Garretstown, Co. Cork	N51 38.664	W008 35.061
Ballycotton, Co. Cork	N51 49.605	W008 00.049
Gyleen, Co. Cork	N51 47.613	W008 11.726
Knockadoon Head, Co. Cork	N51 53.105	W007 51.976
Helvick Head, Co. Cork	N52 03.284	W007 32.439
Tranabo Pier, Co. Cork	N51 29.883	W009 17.157
Toe Head, Co. Cork	N51 29.007	W009 14.100
Whiteball Head Bay, Co. Cork	N51 36.209	W010 02.679
Goleen, Co. Cork	N51 29.585	W009 42.262
Galley Head, Co. Cork	N51 31.774	W008 57.266
Brownstown Head, Co. Waterford	N52 07.749	W007 06.210
Bunmahon, Co. Waterford	N52 08.315	W007 22.245
Hook Head, Co. Wexford	N52 07.439	W006 55.871
Baginbun Head, Co. Wexford	N52 10.491	W006 50.233
Cullenstown Reef to W, Co. Wexford	N52 12.875	W006 43.843
Rosslare Harbour, Waddingsland Point, Co. Wexford	N52 14.722	W006 19.487
Forlorn Point/Crossfarnoge, Co. Wexford	N52 10.379	W006 35.630
Greenore Point, Co. Wexford	N52 14.439	W006 18.821
Carnsore Point, Co. Wexford	N52 10.427	W006 21.938
Balbriggan, Co. Dublin	N53 36.974	W006 10.991
Skerries, Co. Dublin	N53 35.141	W006 06.202
Kerry Head, Southside, Co. Kerry	N52 23.795	W009 54.668
Portmagee Channel, Opposite Bray HeadCo. Kerry	N51 53.027	W010 23. 618
Lough Kay, Doulus Bay, Co. Kerry	N51 56.680	W010 16.610
Abbey Island, Derrynane, Co. Kerry	N51 45.626	W010 08.528
Daniels Island, Near Whitestrand, Co. Kerry	N51 46.259	W010 01.253
Black Head, Co. Clare	N53 09.264	W009 15.847
Furreera, Co. Clare	N52 56.074	W009 25.753
Doonbeg, Co. Clare	N52 44.698	W009 31.892
Moneen, Loop Head, Co. Clare	N52 35.110	W009 52.365
Mannin Bay, Clifden, Co. Galway	N53 27.523	W010 02.594
Dooagh Achill Island, Co. Mayo	N53 58.371	W010 07.944
Easky, east of quay, Co. Sligo	N54 17.494	W008 57.136
Culdaff, nr Dunmore Hd, Co. Donegal	N55 17.65	W007 07.708
Fanad Head, Co. Donegal	N55 16.678	W007 38.197
Bloody Foreland, N+S, Co. Donegal	N55 09.065	W008 17.901
St. Johns Point, Co. Donegal	N54 34.063	W008 27.745
Portmuck, Co. Antrim	N54 50.904	W005 43.678
Larne, on the Glenarm A2 coastal Rd., Co. Antrim	N54 52.134	W005 48.801
Red Bay, Garron Point, Co. Antrim	No GPS reading	
Ballywalter, Co. Down	No GPS reading	
Ardglass, Co. Down	No GPS reading	
Ballyquintin Point, Co. Down	No GPS reading	
Annalong, Co. Down	N54 06.264	W005 53.784
St. Johns Point, Co. Down	N54 13.719	W005 39.145
Bendurg Bay, Co. Down	No GPS reading	

Osilinus lineatus

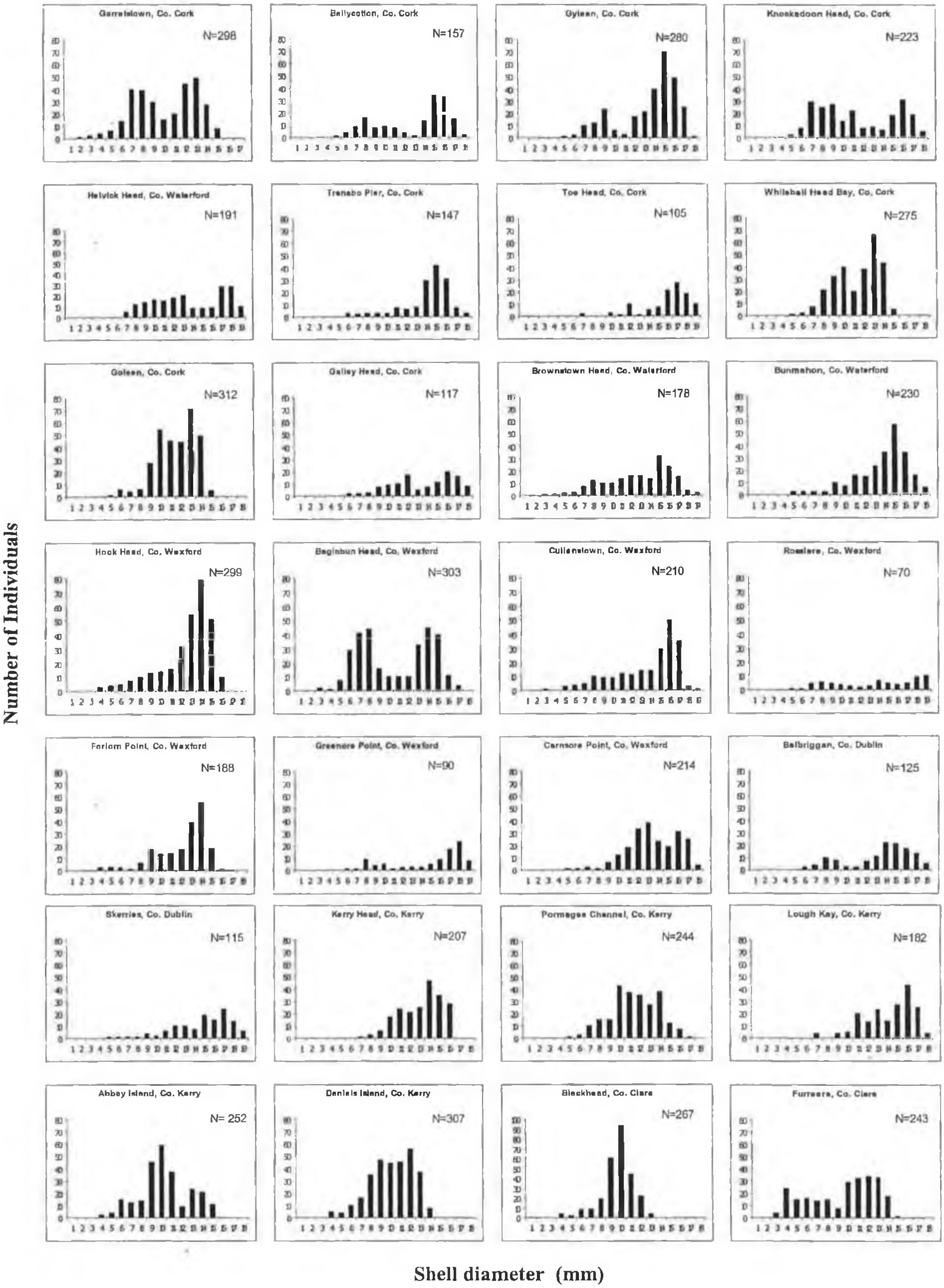
Site Name	Latitude	Longitude
Garretstown, Co. Cork	N51 38.664	W008 35.061
Ballycotton, Co. Cork	N51 49.605	W008 00.049
Gyleen, Co. Cork	N51 47.613	W008 11.726
Knockadoon Head, Co. Cork	N51 53.105	W007 51.976
Whiteball Head Bay, Co. Cork	N51 36.209	W010 02.679
Goleen, Co. Cork	N51 29.585	W009 42.262
Brownstown Head, Co. Waterford	N52 07.749	W007 06.210
Bunmahon, Co. Waterford	N52 08.315	W007 22.245
Hook Head, Co. Wexford	N52 07.439	W006 55.871
Baginbun Head, Co. Wexford	N52 10.491	W006 50.233
Cullenstown Reef to W, Co. Wexford	N52 12.875	W006 43.843
Forlorn Point/Crossfarnoge, Co. Wexford	N52 10.379	W006 35.630
Greenore Point, Co. Wexford	N52 14.439	W006 18.821
Carnsore Point, Co. Wexford	N52 10.427	W006 21.938
Kerry Head, Southside, Co. Kerry	N52 23.795	W009 54.668
Lough Kay, Doulus Bay, Co. Kerry	N51 56.680	W010 16.610
Abbey Island, Derrynane, Co. Kerry	N51 45.626	W010 08.528
Daniels Island, Near Whitestrand, Co. Kerry	N51 46.259	W010 01.253
Black Head, Co. Clare	N53 09.264	W009 15.847
Furreera, Co. Clare	N52 56.074	W009 25.753
Doonbeg, Co. Clare	N52 44.698	W009 31.892
Moneen, Loop Head, Co. Clare	N52 35.110	W009 52.365
Bunowen Point, Co. Galway	N53 24.228	W010 06.999
Cloghmore Achill Sound, Co. Mayo	N53 52.556	W009 57.991
Easky, east of quay, Co. Sligo	N54 17.494	W008 57.136
Maghery-Termon, Co. Donegal	N54 55.942	W008 26.823
Annalong, Co. Down	N54 06.264	W005 53.784
St. Johns Point, Co. Down	N54 13.719	W005 39.145

APPENDIX IV

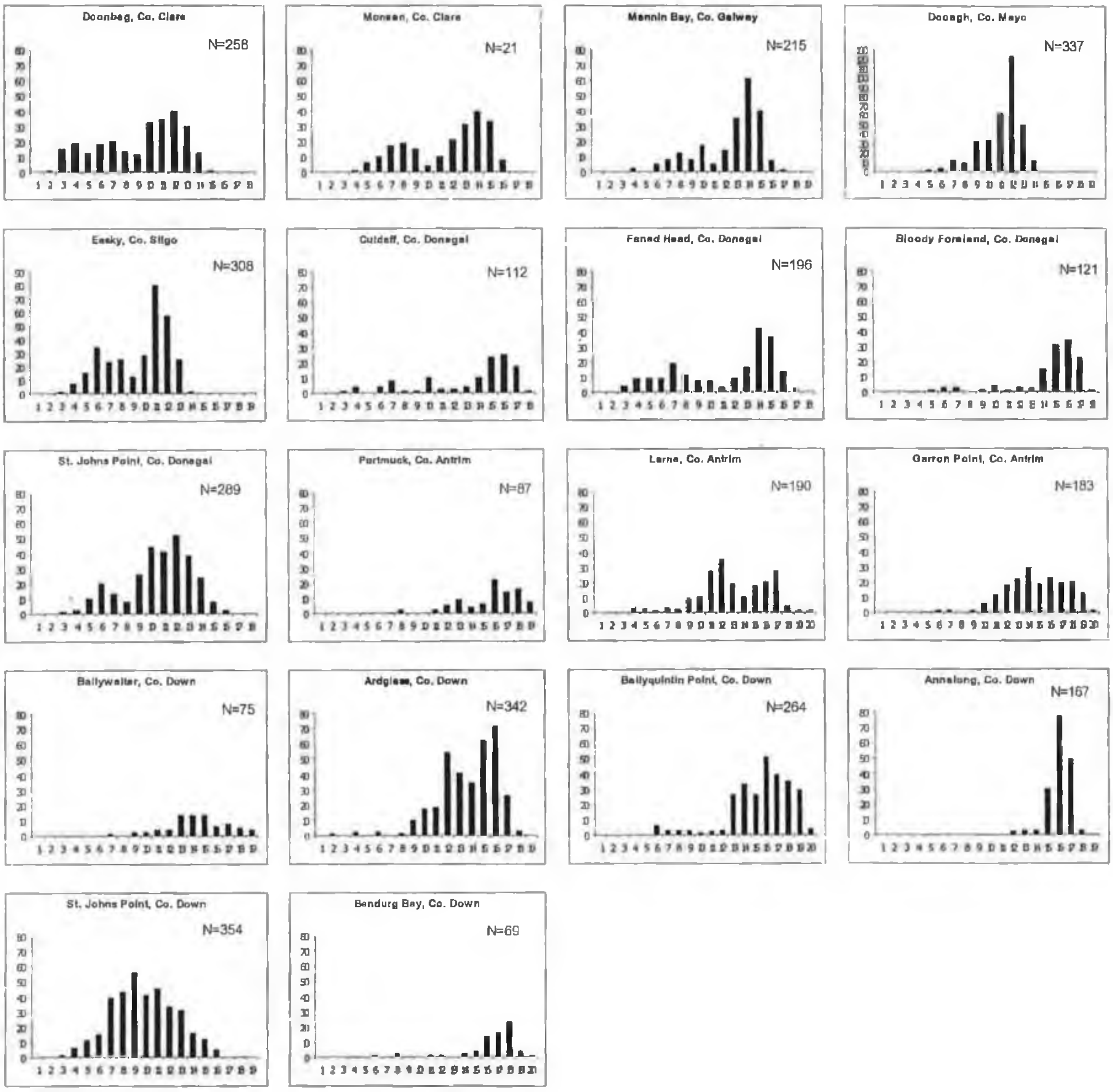
Osilinus lineatus size frequency graphs from the 28 sites where quantitative counts were conducted. Note that the bottom row has a different y-axis then all of the other graphs.



Gibbula umbilicalis size frequency graphs from the 46 sites where quantitative counts were conducted. Note that Black Head Co. Clare, Easky Co. Sligo and Dooagh, Co. Mayo have different y-axis then all of the other graphs.



Gibbula umbilicalis size frequency graphs continued.



Number of Individuals

Shell diameter (mm)

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