An investigation into the Bryozoa of Ireland including the distributional patterns of the marine Bryozoa of Ireland over the last 150 years

By

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Abstract

Bryozoans are sessile filter feeding marine invertebrates. Research in Ireland on bryozoans has been sparse in recent years but many studies were carried out in the early 1900's by researchers such as Albert Russell Nichols (1859-1933). This study has a number of interlinked aims. It will evaluate the history of bryozoan research in Ireland and discuss the biologist Albert Russell Nichols (1859-1933) and his contribution to bryozoan research. Bryozoan diversity and distributional changes from Nichols' time have been examined very little, this study will examine any changes exhibited over the last 150 years. These changes will be evaluated using both a north south and east west divide by looking at historical records and the results of a recent sampling programme. A taxonomically ordered atlas using SEM images and photographs has been compiled of the bryozoans recorded from Ireland using both recent and historical records. In the last 15 years 4 non-native bryozoan species have been recorded in Ireland. *Watersipora subatra*, *Tricellaria inopinata*, *Bugula neritina* and *Schizoporella japonica* and other potential invasive bryozoans are discussed to evaluate their potential arrival methods and distribution around Ireland. *Bugula neritina* is often found as an epiphyte on algae and foliose bryozoans. The occurrence of bryozoan epiphytes and their substrate use is assessed here using specimens taken from 42 sites around Ireland.

Chapter 1

Introduction

1.1 Introduction

Research involving Irish bryozoans has been very sparse in recent years with much of the recent literature concentrating on the reporting of newly arrived non-native species such as *Watersipora subatra* and *Tricellaria inopinata* (Kelso & Wyse Jackson 2012), *Schizoporella japonica* (Loxton *et al* 2017), *Bugula neritina* (Ryland *et al*. 2011) and the freshwater bryozoan *Plumatella geimermassardi* (Wood & Okamura 2004). Bryozoans are an important constituent of Ireland's benthic community and assist in making it a diverse and productive community. Continued research has evaluated the use of bryozoans as indicators of climate change (O'Dea and Okamura 2000, Fortunato 2015) and also compounds produced by some species that may have medicinal properties (Newman 1996, Hussain *et al*. 2011, Maltseva *et al*. 2017). The varied and valuable uses for bryozoans is evident and a current investigation assessing the distribution and diversity of Ireland's bryozoans will enable future research investigating how we can best use them or the information they provide.

Aims of this research

The thesis has a number of interlinked aims, firstly, in this chapter 1, we will introduce bryozoans including discussing their classification, ecology, structure and methods of feeding. In order to learn how we can use bryozoans to our advantage in the future, it is important to evaluate the history of bryozoan collecting and reporting in Ireland. The turn of the 20th century saw many new sampling programmes for a variety of marine species, as interest increased institutions and organisations such as the Royal Irish Academy, the Fauna and Flora Committee and the Dublin Bay Dredge Committee began to collect and publish bryozoan data as well as placing these early specimens into museum collections for reference. Biologists such as Albert Russell Nichols were large contributors to the early records for Ireland's bryozoans and many of the museum records available today are due to his sampling programmes. During the data collection for the current study, much of the museum specimens and records viewed by the author were due to Nichols' efforts in expanding our bryozoan knowledge. Chapter 2 of the current study will assess the history of Bryozoa research in Ireland and discuss A. R Nichols' contribution to the bryozoan records of Ireland.

Chapter 3 will evaluate the diversity and distributional changes of Ireland's bryozoans which have not been previously assessed. Literature reviews have compiled bryozoan records from the earliest records in 1754 to 1980's (Wyse Jackson 1991) and these records together with records from The Natural History Museum Dublin (NHMI), The Natural History Museum of Belfast (NHMU), The Natural History Museum London (NMHUK), a bryozoan survey by the author and other reliable literature sources have been used to assess the diversity changes from the museum and other early records with the current bryozoan distribution. Chapter 3 aims to update the current bryozoan species list for Ireland while assessing the distribution and diversity of bryozoans in Ireland

The taxonomy of bryozoans is constantly being updated at present with species and genera being revised (Viera *et al*. 2013), resulting in many distribution records being incorrect. An up to date correct taxonomic list for Irelands Bryozoans is needed. Chapter 4 will provide a taxonomically correct list of bryozoans recorded from Irish marine habitats with images and location details for each species. This will include and non-indigenous species recorded during this study. In 1953 the first edition of part G of the Treatise on Invertebrate Paleontology was published. Part G concentrated on the bryozans of the world, both fossil and extant discussed. This publication describes taxonomy, ecology, morphology and geography of all Bryozoa and has now been revised and 3 volumes are available with bryozoan information. Multiple authors have worked together to combine their research into the Treatise to ensure easier access to this information and presently additional volumes are being worked on.

A number of non-indigenous bryozoans have been recorded from Irish water in the last decade. *Watersipora subatra, Tricellaria inopinata* (Kelso & Wyse Jackson 2012), *Schizoporella japonica* (Loxton 2017), *Bugula neritina* (Ryland *et al.* 2011) have been recorded from harbours and marina's around the country. Chapter 5 aims to discuss these records and assess why these species have only recently been recorded in Ireland. Their distribution methods and effects on the local environment will be evaluated. Ireland is now obliged under a number of EU laws to monitor and record non-indigenous species in our waters, these legislations will be discussed also in chapter 5.

Substrate dependency has been observed in bryozoans and many species settle as epiphytes and epizooites on flora and fauna. Chapter 6 aims to discuss the substratum used by bryozoans and which species are more commonly found as epiphytes and epizooites.

1.2 What are Bryozoans?

Bryozoans are little known to many people who don't realise that they have actually encountered them many times along the shore or in the water. Bryozoans are freshwater or marine colonial invertebrates that have a widespread distribution from polar to equatorial waters (Schopt 1969, Gordon 1999) but are often invisible to the untrained eye. They can be found in a wide range of marine environments from shallow to abyssal depths and in some locations are the most dominant organism present (Clark *et al*. 2017). Bryozoans in shallow waters frequently encrust shells, seaweeds, or artificial substrates such as plastic and are sometimes called 'seamats' in this form but are also found in lace-like and bushy erect forms. They are found on a wide variety of substrates both natural and anthropogenic such as boat hulls, harbour infrastructure (Kelso and Wyse-Jackson 2012), plastic structures and on other invertebtates such as hydroids (Puce et al 2007) bivalves and crustations (Kuklinski *et al* 2008). With an estimated 8000 extant species (Ryland 1970) and fossil records to of an estimated 15000 species (Gordon 1999), this fascinating animal has been part of many people's beach walks and snorkel trips as they unknowingly passed them by. This is predominantly due to the small size of the colonies and their tendency to settle on other animals (Winston 1986), animal remains (Wyse Jackson *et al.* 2014,) and plants and seaweed (Seed and Harris 1980). Its only when the graceful cilia are viewed with a microscope that the charm of this beautiful creature is revealed in full.

The phylum Bryozoa consists of both freshwater and marine species but is predominantly made up of marine species. They are represented within the fossil records as far back as the Ordovician, 450 million years ago and still present in every ocean worldwide (Ernst *et al.* 2015, Taylor and Ernst 2004, Gordon 1999). The calcium carbonate skeleton of many bryozoans has contributed to the excellent fossil record present today (Smith & Gordon 2011). Due to these extensive fossil records, bryozoans are increasingly used to determine the effects of environmental change and for testing evolutionary hypotheses (Gordon 1999).

The individual bryozoan animal is housed in a calcareous zooecium and together many hundreds produce a zoarium which can take many forms from delicate branching colonies to robust dome-shaped colonies or thin encrusting sheets. The animal consists of a feeding mechanism, the lophophore which comprises up to 32 tentacles that extend into the water for feeding. Bryozoans reproduce sexually, produce a larva that settles and then begins to add additional zooids by cloning.

Bryozoans play significant roles in marine ecosystems in all of the world's oceans. These roles include contributing significantly to temperate and tropical marine carbonate sediments (Maxwell 1968; Nelson *et al* 1988). The formation of erect colonies provide structures which can be utilized by other marine species as nursery grounds or attachment surfaces (Bradford and Gordon 1983), they can also provide many marine fauna such as the nudibranchs *Adalaria proximo* (Alder & Hancock) and *Onchidoris muricata* (Müller) with a reliable food source (Todd and Havenhand 1989). From a more direct human perspective bryozoans are now being investigated for their potential medical applications (Sharp *et al*. 2007). The anti-cancer and immunostimulating properties of *Bulgula neritina* have been investigated to test the effectiveness of Bryostatin-1 in inhibiting the growth of leukemia cells and used in conjunction with conventional treatments for breast, ovarian and lung cancer (Hussain et al 2011).

Bryozoans are notable inhabitants of Irish coastal waters with over 192 species recorded in previous literature (Wyse Jackson 1991) with further records available from museum databases. The first surveys of bryozoans in Irish waters was carried out in the Dublin district by A.H. Hassall in the 1840s and he reported the occurrence of several new species. Later between the 1880 and early 1900s several further reports were published including those on the bryozoan of the north-east (Swanson 1893, Thornely 1904), the east coast (Duerden 1893), from Clare Island, Co. Mayo (Nichols 1911) and from some dredging expeditions off the southwest. In addition Thornely & Haddon (1897) recorded several taxa from the Rockall Bank as did Maughan & De Grave (2000). The last major report on bryozoans from all Irish waters was published in 1911 (Nichols 1911) with a few more localized surveys reported later for example Dinneen *et al.* (1986) listed tens of species from on Kinsale Harbour, while Ryland and Porter (2006) reported on the distribution of *Alcyonidium* around Ireland. More recently *Bugula neritina*, an alien species has been recorded from Malahide (Ryland *et al.* 2011).

The earliest collections of recent Irish bryozoans were collected by researchers such as Nichols, Deurden, Colgan, and organizations such as The fisheries Department of Ireland, Dublin Bay Dredging Committee and Royal Irish Academy. Much of which is now stored at Natural History Museum London and Natural History Museum Dublin. Only a small number of studies have tried to list the bryozoan species present in Ireland namely Wyse Jackson (1991) which assessed the available literature to build a taxonomic list with location data of marine species and Smyth (1994) which describes the freshwater species of Ireland.

By combining published literature, museum collections and on-going collecting this research has determined that there have been 218 species of marine Bryozoa recorded in Irish waters. As was also found in Rouse *et al.* (2013) making comparisons across time periods and geographic regions is made more difficult by inconsistent records with many records missing important pieces of data such as exact location, environment type and depth. A number of the historical records state the collection location as 'Ireland' or 'Great Britain or Ireland' which have had to be omitted from many parts of this research which need exact location data.

1.3 Bryozoan classification

There are 3 classes of extant bryozoans Gymnolaemata and Stenolaemata are comprised of marine species and Phylactolaemata is comprised of freshwater species (Fig 1.1). There are 3 orders within these classes, all of which are represented in Ireland.

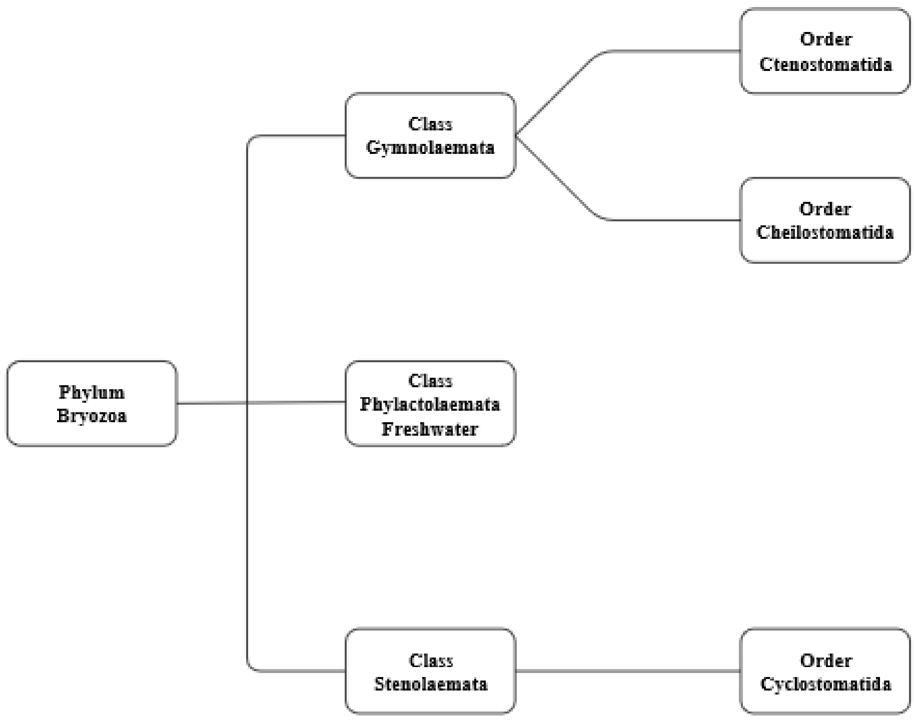

Fig 1.1. Classification Tree of Bryozoa.

Freshwater bryozoans (Phylactolaemata)

Freshwater bryozoans lack in both diversity and numbers when compared to marine species (Ryland 1970) but have a wide geographical distribution. Although they were not included in the survey for the current research they will be addressed briefly to outline the differences between marine and freshwater species.

Freshwater bryozoans are found most often by careful searching of freshwater bodies containing a calm shallow environment and an abundance of plants, with a few exceptions. The asexually produced statoblasts can be found on the surface of the water with the use of a fine small net. When searching for these bryozoans, search shaded tree roots, floating debris and aquatic plants are the most common places they can be found. They are commonly found on the underside of pond lilies where they are sheltered from water level change, this is common in marine species also as a number of species are often found the undersides of floating pontoons in marinas (Kelso and Wyse Jackson 2012). There are only 35 species of freshwater bryozoans recorded worldwide (Bushnell 1966) and only 8 species were recorded in Ireland by (Smyth 1994) and additional species was added to this list by Wood & Okamura (2004). Much like Ctenostomatida, colonies of Phylactolaemata are gelatinous and often encrusting on wood and stones in a low silt environment in still water locations (Smyth 1994). In the study by Smyth (1994) he found that *Fredericella sultana* and *Paludicella articulata* were found in 7 counties spread around the country.

Phylactolaemata are structurally different to other bryozoans in that they do not exhibit polymorphism of the zooids, therefore all zooids are autozooids. The skeletal structures used for morphological identification present in Cheilostomes and Cyclostomes are not present here and can make identification difficult (Ryland and Porter 2006). Structurally Phylactolaemates conform to the accepted bryozoan body plan, exhibiting a lophophore, looped alimentary canal (also circular), retractor muscles and dorsal ganglion (Ryland 1970). The lophophore of *Fredericella sp.* is anexception as they exhibit a circular shaped lophophores (Shunkina *et al.* 2015).

The lophophore of this class of bryozoans is horse shoe shaped and not circular like others with the mouth in a central position. Between the tentacles there is a ciliated groove which leads to the mouth. The mouth leads to the distinctive u shaped alimentary canal. The lophophore is usually larger in size with a higher number of tentacles, sometimes up to

100. Reproduction is achieved by the asexually reproduced buds termed statoblasts. These can be found floating on the surface of the water and collected with a fine mesh net.

1.4 Bryozoan structure

Colonies are made up of genetically identical intercommunicating units called zooids (Ryland 1970). Bryozoan colonies can have extremely diverse morphologies which can cause them to be mistaken for other organisms. Colonies can appear soft and gelatinous such as *Alcyonidium gelatinosum* or as a hard calcareous species such as *Cellaria fistulosa* (Figure 1.2). Colonies can exhibit either an erect form or flat encrusting form, the form appearance is dictated by the species. Each colony will start its life as a single zooid termed the ancestrula which is formed when a larva settles on a substrate and undergoes the process of metamorphosis into the ancestrula which will then produce daughter zooids through asexual reproduction, this continues until the colony reaches the optimum size (Orstrovsky 2013). Colony size is dictated by a number of factors such as species, food availability, space availability, predators and competition from other organisms.

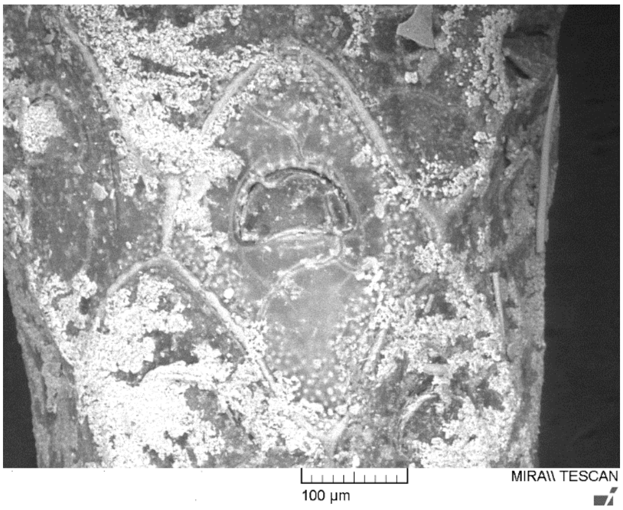

Figure 1.2 SEM image of a calcareous branch section of *Cellaria fistulosa* from Strangford Lough, Down.

Each bryozoan colony is made up of a number of genetically identical zooids which have been asexually produced (Ryland 1970, Porter 2012). The term zooid is used for the asexually budded modules which can be calcified to varying degrees depending on species. A budded zooid will not grow further as the calcified walls prevent any more expansion.

Colony descriptions in this research will refer to colony structure as they are described in Porter (2012), these are;

1) Gelatinous, encrusting
2) Encrusting on algae, lacy
3) Stoloniferous, tufty
4) Nodular
5) Erect, laminar, bushy
6) Twiglike with internodes
7) Encrusting, foliose
8) Disk-shaped
9) Erect,lacy

Class Gymnolaemata

Order Cheilostomatida – Calcified Bryozoa

Cheilostomatida consist of a colony of calcified zooids. A number of species have been confused with plants in the past as they can appear as an erect frondiose laminar colony much like algae. Variation in growth can be related to the pattern of zooid budding for the order of the bryozoan (Ryland 1970). The most common form for bryozoan colonies are encrusting or erect and are normally epilithic or epibiotic (O'Dea and Okamura 2000). Most bryozoans and all species found in Ireland to date are sessile as adults and the colony is attached to the substratum, the attachment type varies depending on the colony form for example *Flustra foliacea (Linnaeus, 1758)* is an erect and bushy form and for the first year of colony growth it will only form the flat disc like anchor used to secure the rest of the colony (Hayward and Ryland 1998).

Order Ctenostomatida – Gelatinous Bryozoa

Ctenostomatida colonies are uncalcified and are soft and gelatinous to touch (Porter 2012). Many Ctenostomes are traditionally adnate. Species such as *Bowerbankia imbricata* (Adams 1798) form creeping stolons of zooids and others such as *Alcyonidium* *gelatinosum* (Linnaeus 1761) form gelatinous unilaminar incrustations (Ryland 1985, Porter 2012). A number of species such as *Vesicularia spinosa* (Linnaeus 1767) often form erect tufts or other three dimensional forms (Porter 2012). These colonies grow through the continuous budding of autozooids and can completely cover the chosen substratum if undisturbed. In stoloniferous species a kenozooidal stolon is responsible for the budding of new autozooids. Attachment of the colony to the substratum is achieved with the use of kenozooidal rootlets which prevent dislodgement of the colony. Gelatinous and encrusting species such as *A. gelatinosum* form colonies on many intertidal algae species. Initial colony formation is species specific with differing budding processes being utilized. Research on these budding processes are still under research (Ryland 1985).

<u>Gymnolaemata</u>

This class of bryozoan is usually cylindrical in shape, bears a circular lophophore and can be calcified or chitinous. Septa or duplex walls separate the coeloms of adjacent zooids. Zooids may be uncalcified and flexible or calcified to different degrees. Each zooid possess's a protective body wall (cystid) and a polypide which contains the lophophore, U- shaped digestive tract and perietal muscles. The lophophore requires the parietal muscles in the body wall for evertion from the cystid by causing deformation of the cystid (Schwaha & Wanninger 2018). Zooid production often follows a branching pattern with the transverse septa used as a growing point. Zooids can be polymorphic with large masses of spermatozoa developing (Ryland 1970). This class of Bryozoa has two orders, Ctenostomatida and Cheilostomatida.

Ctenostomatida have cylindrical to flat zooids with gelatinous or membranous walls which are not calcified instead they are made of chitin. The zooids are often semi-transparent and some species have chitinous spines present. The basal surface of the zooid is attached to the substratum and the frontal surface bears the orifice in encrusting species. In stoloniferous species, cylindrical autozooids are attached to the stolon with a terminally located orifice. These autozooids can be arranged as small groups or on their own. The orifice is usually terminal and closed with a pleated collar. Specialized zooids such as avicularia and ooecia are absent in this Order and an estimated 40 genera have been described with evidence from the Palaeozoic to the present. Cheilostomatida differ in that the zooids are box shaped and calcified with a frontal orifice bearing a hinged operculum.

The main differences are the gelatinous appearance of Ctenostomatida compared to the calcified appearance of Cheilostomatida and the lack of avicularia in Ctenostomatida. Table 1.1 summarises the distinguishing features and differences of both these orders.

Table 1.1. Distinguishing features between Ctenostomatida and Cheilostomatida. (Data from Ryland 1970).

Morphological characteristics	Ctenostomatida	Cheilostomatida
Zooid shape	Cylindrical to flat	Flat box
Wall type	Membranous or gelatinous	Calcified
Orifice position	Terminal (or nearly)	Frontal or subterminal
Orifice closure	Pleated collar	Hinged operculum
Genera number	About 40	About 600
Time scale present	Palaeozoic - Recent	Mesozoic - Recent
Specialized zooids	No ooecia or avicularia. Kenozooids present	Avicularia and ooecia often present

Class Stenolaemata

Order Cyclostomatida– Calcified tubular Bryozoa

Cyclostome colonies are erect and rigid with colony shape being described in a number of descriptive ways such as ‘straggling tufts’ (Porter 2012) and ‘inside-out umbrella’ (Smith & Gordon 2011). Many species such as *Plagioecia patina* exhibit a disc like appearance with others such as *Crisia eburnea* exhibiting an erect tufted form (Hayward & Ryland 1985, Porter 2012). Colonies can be very small and identification can be difficult in the natural environment if not almost impossible, a microscope is required for accurate identification as many of the morphological features required for identification are only visible with high magnification.

Zooids of cyclostomes have a different appearance to the other calcified bryozoans which can make them easily recognisable to this order (Ryland 1970). Instead of the usual calcified box structure of many cheilostomes, these bryozoans consist of elongated calcified tubes (Porter 2012). This tubular zooid has a terminal orifice which is circular in shape. Heterozooids are present in some species in the form of rhizoids which are used to anchor the colony to its substrate (Ryland 1970).

1.5 Feeding behaviour

The bryozoan lophophore is used for feeding, respiration and excretion (Ryland 1970, Applegate 1966). Feeding is achieved by filter feeding plankton from the water with the circle of tentacles on the lophophore, these tentacles are ciliated with fine hairs. The tentacles beat in a rhythmic manner causing a current which pushes food towards the mouth at the centre of the lophophore (Hayward & Ryland 1998, Porter 2012). The food passes to the u-shaped digestive system and waste is excreted through the anus just below the lophophore (Harris 1990, Hayward and Ryland 1979, Ryland 1970). The lophophore is often kept retracted inside the zooid body and is everted when required using a hydrostatic mechanism. This is carried out in different manners for the 3 orders, cyclostomes displace the water by changing the internal pressure of the zooid using a ‘pseudocoelom’, the non-calcified ctenostomes are capable of flexing the body wall to control lophophore movement and in some cheilostomes an air sac is positioned under the frontal wall (Ryland 1970). The most important food sources are yet to be described but it has been observed that diatom frustules are present in the digestive system but seem to be excreted undigested. It has been suggested that *M. membranacea* can absorb dissolved organic substances from kelp mucus but this is not the case for other species (Hayward & Ryland 1996).

The morphology of the lophophore can vary from species to species, tentacle length can be anything from 124 - 929µm and tentacle number can vary from 8-40 (Riisgård and Manríquez 1997). It has been suggested that the morphology of the lophophore is linked to competition for food (Hayward & Ryland 1998).

1.6 Bryozoan reproduction

Bryozoan reproduction is achieved by both sexual and asexual reproduction. Larva formed during sexual reproduction settle and form an ancestrula which will bud daughter zooids through asexual reproduction. Sperm and eggs are produced inside the zooid and fertilization takes place internally (Ryland 1970). Larva are produced either by brooding strategy which broods eggs until they are developed larva or by broodcasting which releases many fertilised eggs into the water to be developed outside the zooid (Hayward & Ryland 1998). The larva is varying in appearance and mode of locomotion (Ryland 1970).

Ecology

Bryozoans are often found growing on algal beds among the benthic ecosystem. They are commonly found along the intertidal zone as algae, rocks, shells and artificial substrates wash up and become accessible. In benthic communities they can become large and diverse assemblages that provide shelter and food for other species (Smith & Gordon 2011). It is common to find multiple species of bryozoan on rocks and shells along the shoreline. Bryozoans often inhabit small niches in eroded rock which may be too shaded for other fauna in the community (Ryland 1970). Living specimens will only be found before the low tide mark as survival of the colony is dependent on being submerged continually as they are not equipped with the physiological adaptions required for the upper shoreline (Harris 1990). Shallow waters will contain the highest abundance of Bryozoa as the light, food and temperature conditions in this zone are ideal for the growth and survival of most bryozoan species (Ryland 1970, Harris 1990).

When the larva is released into the water column it must find a suitable place to settle. Some species possess a pyriform organ which enables them to determine the texture and odour of a surface through a process called ‘snuffling’, this will ensure they are in their ideal environment (Reed and Cloney 1982). When the larvae settles it will develop into the ancestrula which will be the parent zooid for all other zooids budded through asexual reproduction for that colony. The species *Membranipora membranacea* is found primarily on kelp fronds and can develop very extensive unilaminar colonies. The larvae of this bryozoan are of the cyphonaute type and when settling will use the water flow to determine its orientation to enable growth in the direction of the perennial meristem. This type of settlement and growth pattern is shared by other species such as *Electra pilosa* although this species shows preference to fucoid algae (Hayward and Ryland 1999).

Associations with other species of fauna and flora is very common in a natural habitat. These food and habitat associations are notable as they are often found growing on other species, an example of this is *Alcyonidium parasiticum* which is frequently found on a number of hydroid species as well as crab carapaces (Hayward 1985). They also often prefer algae as substrate and are often found as epiphytes (See chapter 6). Algae such as kelp provide an ideal substrate as they have similar environmental requirements to the bryozoans (Seed and Harris 1980, 1981). Many species of bryozoan can also be found on artificial substrata such as plastic Buoys, ropes, boat hulls and other plastics (Kelso & Wyse Jackson 2012, Loxton *et al.* 2017) often non-native are introduced through maritime activities (See chapter 5).

Bryozoans are very important to the benthic communities which would not have the same diversity and abundance without the presence of bryozoans. As well as being vital substratum and food resource for other species, they play a part in the nutrient cycle during by feeding on organic matter in the water column (Porter 2012).

1.7 Conclusion

Bryozoans are found in a number of marine habitats around Ireland. A large number of bryozoan fossil records exist in Ireland due to the calcium carbonate composition of the majority of the marine species. These records can now be used to assess climate change and evolutionary theories as the basic morphology and form has remained the same since the Ordovician. A diverse array of bryozoans in the benthic community is important for a number of reasons. Bryozoans are an important food source for other fauna such as fish, urchins and nudibranchs which will graze on bryozoans as part of their diet and other fauna such as Pycnogonids are specially adapted to feed on bryozoans and a requirement for their survival (Porter 2012). As filter feeders they are a part the nutrient cycling system of many environments. Some species are being investigated for their medical uses on humans with a possibility that more helpful compounds will be discovered with more research. Ireland's bryozoans have been studied very little recently with many of the research records published in the early 1900's by biologists including Auther Nichols, Nathanial Colgan and Laura Thornley, the former being discussed in the next chapter.

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Chapter 2

Bryozoan research in Ireland during the late 19th and early 20th centuries with biographical information on Albert Russell Nichols

Contents

2.1 Introduction to Irish Bryozoa research 1850-2000

Ireland is home to a varied coastline of over 5500km in length. Within this vast coastline is a large number of marine habitat types which makes it the ideal location for a large number of species to live and survive. Bryozoa have been recorded from Ireland since 1755 when John Ellis reported he had been sent a specimen of the bryozoan *Bugula avicularia* from Dublin Bay and included it in his book *Observations on a remarkable coralline* (Ellis 1755). Previous to this publication it was accepted that bryozoans, which were termed corallines, were more plant like. The location of this specimen has long been lost but another early specimen from 1799 is located in the bryozoan collection in NHMUK.

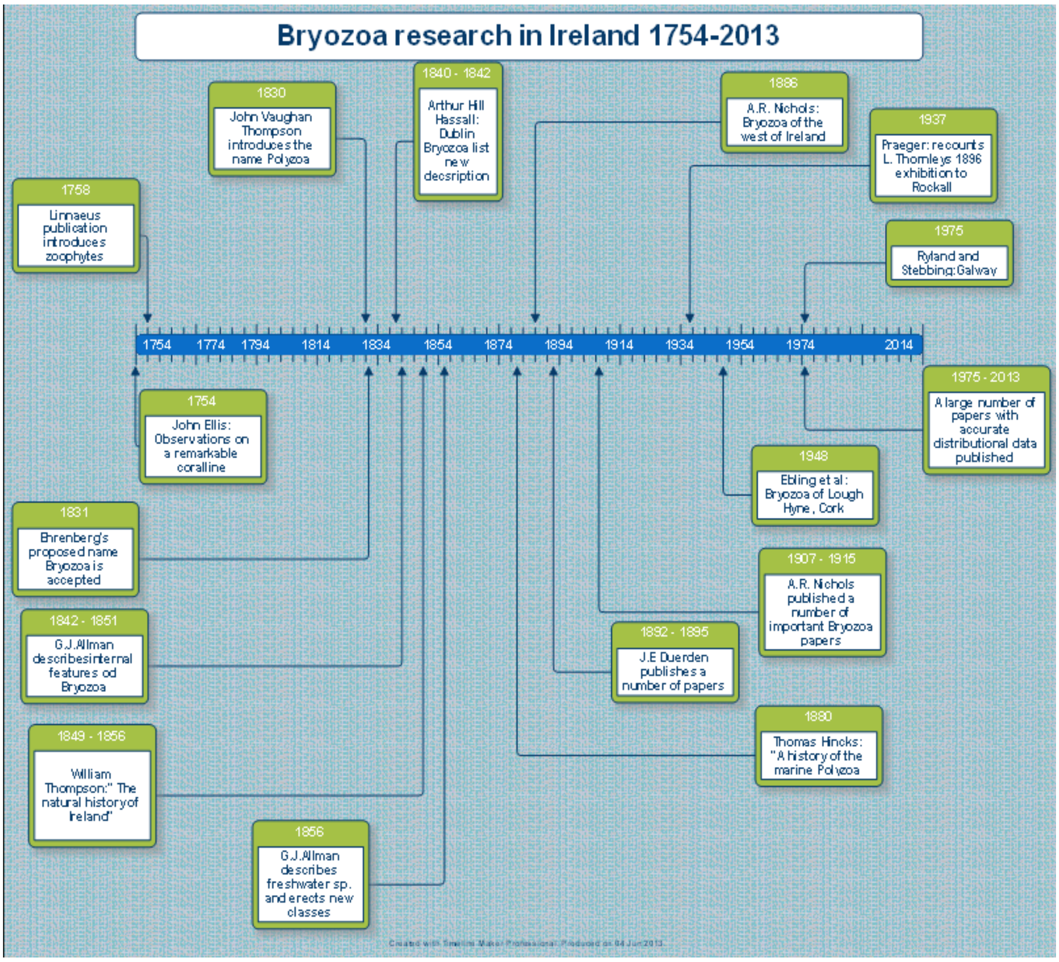

Fig 2.1 Timeline of bryozoan research in Ireland

Aims

This chapter aims to evaluate the past progress to bryozoology in Ireland. Biologists such as A.R Nichols, A.H. Hasall, L. Thornley, and N. Colgan to name a few have contributed greatly to our knowledge of Irish bryozoans (Fig 2.1). Albert Russell Nichols donated many specimens to the Natural History Museum Dublin and this study aims to write a short biography of his life both personal and academic.

2.2 Important researchers of Irish Bryozoa

2.2.1 Albert Russell Nichols (1859-1933)

Albert Russell Nichols (1859-1933) (Fig 2.2) was an English-born naturalist who spent much of his life in Dublin, Ireland. During his career he published just 6 papers on bryozoans, but these are some of the most valuable and comprehensive contributions to Irish Bryozoa records to date. These include his "*Polyzoa* from the coasts of Ireland" published in 1911 (Nichols 1911a) and the Bryozoa part of the "Clare Island Survey" series of papers published by the Royal Irish Academy the following year (Nichols 1912a) which also in

This study will present an account of A. R. Nichols' personal life, professional career and his bryozoological work (Appendix 2.2). Naturalists such as Arthur Hill Hassall, Laura Thornley, J.E. Duerden and Nathanial Colgan also made important contributions to research on Ireland's marine bryozoans. (Wyse Jackson 1991)

One publication by A.R. Nichols included a list of Bryozoa from many locations around the Irish coast (Nichols 1911a) - his was the last national scale comprehensive survey of marine bryozoans from Ireland. Since then other publications have concentrated on specific locations with much work being carried out along the west coast in particular (Wyse Jackson 1991).

Fig 2.2. *Albert Russell Nichols (1859-1933) at opening of the Museum of Science and Art, Kildare Street building in 1890. (Photograph NMINH-PP-777xy © National Museum of Ireland, all rights reserved)*

Personal Biography

Albert Russell Nichols was born in January 1859 in Stowmarket, Suffolk to parents Arthur and Sarah Nichols. His father is listed in the census of England and Wales from 1851-1901 as being an Ironmonger (retired in later years) (Census of England and Wales 1851-1901). Albert was christened on the 9th December 1859 in Stowmarket where his family lived on Market Place until they are recorded in the 1881 census as residing at 22 & 23 Nelson Street, Greenwich. Albert's family was small for the time, he had one brother Ernest Russell Nichols who was 2 years his younger and one sister who was 5 years younger. It was interesting to find that as a child Albert Russell was only called 'Albert' in the 1861 Census, on all subsequent censuses from his English addresses he is listed as 'Arthur Russell'. Once he moved to Ireland he is listed as Albert again. Unlike his brother, Albert did not follow in his father's footsteps as an ironmonger, but rather attended university. In January 1878 (Venn 1922-1958) he entered Clare College, Cambridge to study Mathematics, where he gained a Gold Medal and was a Scholar. He graduated B.A. in 1882 with a first class degree in the subject and was ranked 16th Wrangler. A Wrangler is a student who gained a first-class degree in Mathematics from Cambridge. In any one year the highest ranked student is termed the 'Senior Wrangler' and all other first-class students are ranked consecutively. In 1902 he took his M.A. from Clare College.

It was at the age of 24 that Albert's life as a Naturalist began. One can only imagine that job opportunities for mathematicians at the time were scarce and this may have prompted his career change. As was the norm at the time, Albert took an examination (on 23rd January 1883) used to determine the most suitable candidate for the appointment of Assistant Naturalist in the Natural History section of the Museum of Science and Art (now the National Museum of Ireland), Dublin. He was ranked first and was offered the position and entered museum service in March 1883. Thus was the beginning of his new life in Dublin where he remained for the rest of his life.

Nine years after arriving in Dublin he married Letitia Anne Perry of Cambridge House, 12 Montpelier Hill, in Matthias Church, Adelaide Road on 20th July 1892 (irishgenealogy.ie). At the time of his marriage Albert was living at 20 Charlemont Place, Dublin which was within walking distance to his place of employment. However, by 1901 the married couple were living in a fashionable southside suburb at 284 Grosvenor Square, Rathmines (Fig 2.3) with their daughter Beryl (age five) and their two domestic staff (Irish census records 1901).

Fig 2.3. *30 Grosvenor Square, Rathmines, Dublin*

(Photograph by Prof. Patrick Wyse Jackson)

In May 1905 Albert was promoted to assistant keeper at the museum and remained in this position until August 1921 when at the age of 62 he succeeded Robert Francis Scharff as the Keeper of Natural History (Fig 2.4). Albert did not remain in this position for a long period as in January 1924 he reached the statutory retirement age of 65 and retired from his position at the museum. Aside from his research on various zoological groups, Nichols "did much work in the classifying and arranging of the invertebrates" (Praeger 1949).

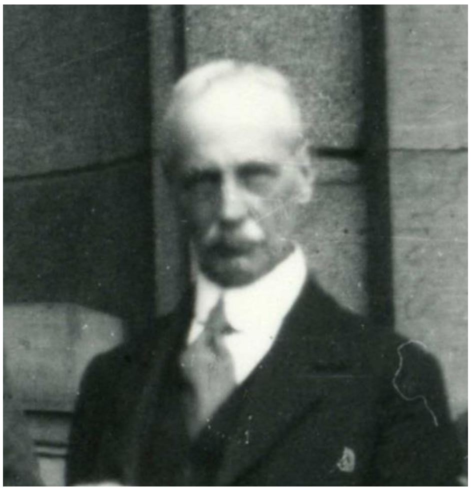

Fig 2.4. *A.R. Nichols towards the end of his working life. (Photograph NMINH-PP-741-Nichols © National Museum of Ireland, all rights reserved)*

Before his second promotion to Keeper of Natural History Albert Nichols, his family and their general servant were recorded as living at the same address at 30 Grosvenor Square, Rathmines, Dublin (Fig 2.3) in the 1911 census of Ireland. This is the address at which Albert would live out his remaining years. On 21st February 1933 Albert Russell Nichols died at the age of 75. He was buried close to his home at Mount Jerome Cemetery, Harold's Cross, Dublin (Fig 2.5), which was the prominent burial ground at the time of the Protestant population. (www.igp-web.co). In his obituary Nichols is described as being very secretive about himself and as always being a perfect gentleman. He was also described as "his harmless and undisguised curiosity about the doings of others" (Stelfox 1933) which sounds like a polite way to say he was unashamedly nosy.

Albert's wife and daughter also lived out there remaining years in the same house in Rathmines. Letitia Anne Nichols died on 7 March 1955, outliving her husband by 22 years. Their daughter, who never married, studied History and Political Science at Trinity College, Dublin (*Dublin University Calendar* 1918). She was later, in 1921, conferred with a doctorate in Canon and Civil Law, (*Irish Times* 1921) and remained closely associated with her alma mater as an active committee member of the TCD Association. She became a noted actress and appeared in a number of radio plays and musical events broadcast by RTE, the Irish national broadcaster between the 1920s and 1940s. From a young age she was interested in animals and in 1909 presented the Royal Zoological Society a rocking horse for the use of the chimpanzees in Dublin Zoo. A contemporary newspaper reported that: "The "Chimps" have not yet become accustomed to the inanimate horse, and look on it with much greater awe than living creatures. The youngest chimpanzee will only *touch* it very gingerly, …" (*Sunday Independent 1909)*. Much later, in the 1960s she served as a committee member of the St Francis Dispensary, a charity in Dublin that cared for animals (*Irish Press* 1963). Beryl died in 1976, a spinster who until shortly before her death lived in her family home.

Of Albert's siblings in England and Ireland neither his sister nor brother left children. His sister Emily Grace Nichols lived out her life in Liverpool with their brother Ernest Nichols and died in 1930 as a spinster. Ernest married quite late in life at the age of 65 years to a Roberta Cowie and died at the age of 93, his wife Roberta Nichols died in 1951. There is a possibility of Albert's father Arthur Nichols having 10 siblings, this is still under investigation and not confirmed as of yet.

Fig 2.5. *Burial place of A.R. Nichols, his wife and daughter. Mount Jerome Cemetery, Harold's Cross, Dublin.*

(Photograph by Prof. Patrick Wyse Jackson)

Nichols as a naturalist and bryozoologist

It was not long after his appointment at the museum that Nichols started to produce publications on Ireland's fauna. The earlier years of his career was a time when there was an increased interest in Ireland's flora and fauna due to the recent *Challenger* cruises and Nichols undertook a great deal of his fieldwork during this period. The late 1880s saw the first three marine biology survey cruises conducted by the Royal Irish Academy which were directed by William Spotswood Green (Whyte 1999) with more expeditions to follow by other groups in the 1890s (O'Riordan 1969). A number of these expeditions were undertaken by The Flora and Fauna Committee which was established through the efforts of Edward Perceval Wright. In 1886 Nichols took part in a dredging trip on the *Lord Bandon* off southwest Ireland. This trip led to him writing a publication on Hydrozoa in South-West Ireland (Nichols & Haddon 1886). In 1895 Nichols took part in a trip to Rockall and from this trip described the molluscs collected around this isolated rock (Nichols 1896). Nichols continued to publish papers on Ireland's fauna but it wasn't until a year after his promotion to assistant keeper in 1905 that he published a paper describing the occurrence of the bryozoan *Hypophorella expansa* from Ireland for the first time (Nichols 1906b). These specimens had been dredged by Alexander Goodman More (1830-1895) from off Broadhaven, Mayo in July, 1873. In this publication he mentions that he had recently started to study Ireland's bryozoans.

During 1906 and 1907 Nichols seemed to be very active in writing up his research, in addition to his papers on Lambay Island (Appendix 2.1) he published on the tufted duck, (Nichols 1907c) shrimp, (Nichols 1907d) the Canadian crane, (Nichols 1907e) and Irish gephyrean worms (Nichols 1907f). During the spring of 1907 the Dublin Marine Biological Committee was established with Nichols as a member of the committee. This committee regularly reported their findings in the journal *The Irish Naturalist* (Colgan 1908). The Dublin Marine Biological Committee was one of a number of organisations which Nichols was involved in. He was also elected as a Member of the Royal Irish Academy (RIA). He served as vice-president of the Dublin Naturalists' Field Club in 1908 but did not become President in 1909 as was the normal successional scheme, after this be became the President of Dublin Microscopial Club for a two year term between 1910-1912.

Lambay Island (1907)

During the early 1900s there was also an increased interest in the island biota of Ireland. In an initiative started by Robert Lloyd Praeger, Lambay Island, off the coast of Co. Dublin was targeted and the flora and fauna surveyed, as a result of this survey Nichols published a list of 35 bryozoans which had been collected over 3 days of shore collecting (Nichols 1907a). Each species was accompanied by a short note which may list the location, association with other species or the substrate it was found on. The majority of these specimens are now housed in the Natural History Museum of Ireland, Dublin with 22 of the listed samples represented; the whereabouts of the other specimens are unknown to the author at present. Nichols was also responsible for publishing a list of echinoderms from Lambay resulting from the same survey trip.

Clare Island Survey (1912)

Robert Lloyd Praeger was also responsible for organising a biological and scientific survey on Clare Island, Co. Mayo in which Nichols took part from 1909-1911. Praeger had persuaded a large number of naturalists to survey the flora and fauna of both the island and coastal waters and also, the immediate districts on the mainland, and this remains one of the major scientific contributions in twentieth century biological sciences in Ireland (Guiry 1997). In Nichols' paper on the marine bryozoans (Fig 2.6) he notes that Clew Bay, Westport Bay and Blacksod Bay were also included (Nichols 1915a.). This survey resulted in an enormous amount of papers, with each of the 68 papers dedicated to a different flora or fauna type. Nichols was responsible for the papers on bryozoans (number 53 in the series) and echinoderms (number 57) (Nichols 1912b). Specimens collected by Nichols were from both dredged rocks collected from the fisheries research vessel *S.S. Helga* and from shore collecting. He notes that specimens were mainly found on stones and of the sub-order (now order) Cheilostomatida. In total Nichols recorded 75 marine Bryozoa from Clare Island with 2 of these being first records for Ireland, *Stomatopora fungia*, now known as *Tubulipora penicillata* and *Eucratea chelata* var. *gracilis*, now known as *Scruparia ambigua*.

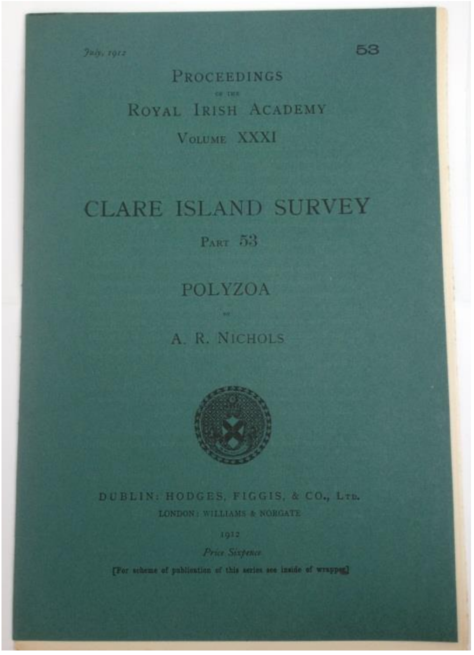

Fig 2.6. *Cover of Nichols' contribution on bryozoans to the Clare Island Survey (1912)*

Handbook to the City of Dublin and the surrounding district (1908)

Nichols contributed a number of sections including that on 'Polyzoa' to a handbook published by the British Association for the Advancement of Science (BAAS) to coincide with the meeting in Dublin in 1908 (Nichols 1908a). In the article he noted the contribution that Dr Arthur Hill Hassall made to bryozoan research collected in and around Dublin, and discussed the progression of Bryozoa collections conducted to date by him and others. He also listed species which have been recorded from the Dublin district only. Nichols also contributed articles to a similar BAAS guidebook for the Belfast area (Nichols 1902)

'Polyzoa from the coasts of Ireland' (1911)

In what is undoubtedly the last most comprehensive survey carried out on Irish bryozoans, Nichols published 'Polyzoa from the coasts of Ireland' in 1911. This publication was based on specimens collected by the Fisheries Branch of the Department of Agriculture and Technical Instruction for Ireland. They were collected off the Irish coasts between 1899 and1907 during both dredging and shore collecting trips. Specimens were collected mainly from encrusted rocks and Nichols notes that more specimens on shells may have increased the species list. The entire species list identified by Nichols totals 101 species with a large percentage of these being found at depths of 50 fathoms (about 90 meters) or more. His paper lists 23 species as first records for Ireland and Nichols provides good location information for each species found and a number of precise species descriptions.

Nichols Collections

The specimens which were collected or identified by Nichols are now housed mainly at the National History Museum, Dublin. One specimen of *Brettia pellucida* var. *gracilis* that was included in his 1911 publication is now housed at the National History Museum, London and is part of the type material for *Bugulella gracilis* (Nichols, 1911). The majority of the specimens are held in the dry collections with a small number held as wet specimens.

2.3 Identification methods of Bryozoa

Before the modern stereo microscope was developed in the early 1890's, examining bryozoans was extremely difficult. After its development, the early 1900's saw a rise in the amount of bryozoan literature available. The advancement of identification techniques brings with it the complicated problem of re-classification of species. Viera *et al* (2014) investigates one of the many genera complex's by using phylogenetic analysis of the morphological characters. Re-classification of species can often be hindered by the lack of type specimens.

Conclusion

A. R. Nichols contributed many records and specimens to the Irish bryozoan records, although he published only 6 papers these records along with other important publications by A.H Hassall and others have provided a sufficient base record for this time period. During the current study the specimens in the Natural History Museum, Dublin, were referenced many times and Nichols is directly listed as either the collector or donor (or both) to 203 specimens out of a list of 1077, many of which were examined during the current study. His collections have ensured a comprehensive baseline list of bryozoan species in Ireland is now present and present day analysis can be compared to evaluate the differences in didtribution and diversity around the Irish coast line.

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2.5 Appendices

Appendix 1. Bibliography of Albert Russell Nichols

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Appendix 2. Timeline of Albert Russell Nichols' life

January 1859: (0 yrs old) Albert Russell Nichols was born in Stowmarket, Suffolk, England to father Arthur Nichols and mother Sarah.

9 December 1859: (11-12 months old) A.R. Nichols was christened in Stowmarket, Suffolk, England.

January 1878: (19 yrs old) A. R Nichols went to Clare College to study maths.

1882: (23 yrs old) Graduated Clare College with 1st class degree.

23 January 1883; (24 yrs old) Sat examination for appointment to Assistant Naturalist in the Natural History section of the Museum of Science and Art (now National Museum of Ireland).

March 1883: (24 yrs old) Began position in museum.

1886: (27 yrs old) Took part in *Lord Bandon* dredging trip off southwest Ireland (Nichols 1886).

20 July 1892: (33 yrs old) Married Letitia Anne Perry.

1895: (36 yrs old) Trip to Rockall. Described the molluscs in Nichols, 1896.

1896: (37 yrs old) Daughter Beryl Nichols born.

1901: (42 yrs old) 1901 Irish census has Nichols living at 284 Grosvenor Square, Rathmines, Dublin with his wife and child Beryl, along with one nurse and a cook. A visitor Mary Perry (probably his wife's aunt) was also present on the night of the census.

May 1905: (46 yrs old) Promoted to Assistant Keeper.

Easter 1906: (47 yrs old) Nichols spent time on Lambay Island and published lists of bryozoans and echinoderms (Nichols 1907a, b).

1906: (47 yrs old) Nichols publishes note on *Hypophorella expansa*.

1907: (48 yrs old) Dublin Marine Biological Committee established. Nichols was a committee member.

1908: (49 yrs old) Served as Vice-President of the Dublin Naturalists' Field Club.

1908: (49 yrs old) Nichols publishes section on Bryozoa in Dublin Handbook.

1910-1912: (51-53 yrs old) President of Dublin Microscopial Club.

1911: (52 yrs old) 1911 Irish census has Albert, his wife and daughter and one general servant living at 30 Grosvenor Square, Rathmines, Dublin.

1911: (52 yrs old) Clare Island Survey work. Nichols publishes on bryozoans (1912a) and echinoderms (1912b).

1911: (52 yrs old) Irish coastline survey published (Nichols 1911)

1915: (56 yrs old) Blacksod Bay survey published (Nichols 1915)

August 1921: (62 yrs old) Succeeded Robert Francis Scraff as Keeper of Natural History.

29 January 1924: (65 yrs old) Reached statutory retirement age.

21 February 1933: (75 yrs old) A. R. Russell dies and is buried at Mount Jerome Cemetery, Harold's Cross, Dublin.

Chapter 3

Distributional patterns of Bryozoa in Ireland past and present

Contents

3.1 Introduction

The Irish coastline is of great interest for the study of marine fauna as it has a wide range of ecosystems along its 7500km length (Kenny and Coveney 2012) which is home to a diverse array of fauna that utilize available resources such as shelter and nutrition (Ferriss *et al.* 2009). Bryozoan species surveys from the late 1800s to the early 1900s have been sparse in Ireland with many of them concentrating on a limited area (Duerden 1894, Thornely 1902, Colgan 1905), comprising of only a handful of species with little information (Colgan 1905) or both. Many of the studies were carried out to assemble data on a number of phylum of marine invertebrates (Duerden 1894, Colgan 1905) which resulted in low species numbers of bryozoans reported. The most productive bryozoan research of this period was carried out by Nichols (1911), "*Polyzoa* from the coasts of Ireland" that recorded 101 species of *Polyzoa*, with 23 of these being first records for Ireland. As recorded in chapter 5 of this thesis, there have been just 4 species of non-indigenous bryozoans recorded recently, this would indicate that the number of bryozoan species has not changed very much from 1911 to now and that Nichols (1911) managed to record around half of the estimated 194 species present at the time (Wyse Jackson 1991) which is the highest number of any single publication from this period. Nichols (1911) provides good location records from each species which was something that other papers sometimes lacked and added immensely to the baseline list of species which had not yet been produced for Ireland. Nichols also conducted other research such as the Clare Island Survey in 1911 which recorded 75 species of Bryozoa, this research was part of a larger research study which produced a series of papers published by the Royal Irish Academy published the following year. On its own Nichols' research does not properly represent the full species list but with other publications from the period it can be used to produce an accurate baseline species list for the period.

Overall species diversity is an extremely important component in assessing the health of an ecosystem (Hilty and Merenlender 2000) and bryozoan diversity around the Irish coastline is just as important as it is utilized by other fauna as food (Pratt and Grason 2007) and shelter (Ryland 1970). Wyse Jackson (1991) compiled a list of bryozoan species from the Irish literature from the late 1800s to 1991, in this publication the number of species found in Ireland during this period was recorded as being 194, a number of these species have since been reclassified as research on this phylum continues to expand and review what we know about the Phylum Bryozoa.

This chapter has two primary aims which are interlinked. It will address these two important areas and several questions in each by means of new collecting and the study of historical collections in museums.

1. The first aim is to document and analyse the spatial distribution of bryozoans around the Irish coast and to investigate possible changes in this distribution over the last century and a half by investigating if a relationship between distribution and substrate type is present. This will be carried out by assembling a baseline survey of Irish bryozoans inhabiting near-shore habitats which will include data from sampling undertaken during this research, data from peer reviewed publications and museum records.This data will be compiled and analyzed to determine the marine bryozoans which have been recorded in Ireland to date. Records will be checked for taxanomic re-classifications and recorded as the current taxanomic nomenclature. An assessment of historical collections contained in museums in Ireland and Britain will be carried out to determine the historical baseline data and the identification of taxa from both recent and museum collections will be required. Records of the geographical distribution of the historical collections will be required, as many of the specimens have not been digitally databased, this database will need to be assembled by collating all sources available.

2. Secondly environmental and ecological factors such as climatic factors and the arrival of alien species will be evaluated to determine if these factors have caused alterations in the bryozoan distributions from the historic and recent data sets.

Bryozoan distribution patterns

Bryozoans can be found from the shoreline to depths of 8300m (Ryland 1970), they are mostly marine but are found in both marine and freshwater environments, this study concentrates on species found in marine environments. There are estimated to be 8000 species present globally, 300 of these are found in British and Irish waters (Porter 2012) with a lesser number recorded in Irish water alone.

Along the intertidal zone of the shoreline, Bryozoa can be found associated with algae, along cliff sides and under boulders and attached to many natural and artificial surfaces as well as interstitial colonies which utilise grains of sand and shells as substrates

(Winston & Hakansson 1986). Species such as *Electra pilosa*, *Cryptosula pallasiana*, *Flustra foliacea* and *Membranipora membranacea* are found commonly on Ireland's shores, this has been shown in many research surveys such as Nichols (1911) and Hassall (1840) as well as during the present study. Specimens found in the intertidal and littoral zones will normally be the dead remains of calcified Cheilostome colonies, as the living zooid needs full water coverage to survive and the gelatinous Ctenostome bryozoans exposed to sun for long periods of time will become quickly desiccated. The bathymetric distribution of bryozoans can be dependent on a number of factors and vary from species to species (Ryland 1970). Bryozoans can be found in a higher abundance in the infralittoral zone then in other uppershore zones but can also be found in high numbers in sheltered rocky areas in the intertidal zone, species such as *Cryptosula pallasiana* and *Umbonula littoralis* for example are found primarily on the inshore and intertidal zones and tufted species such as *Bugulina* and *Scrupocellaria* are often found associated with substrates found in both intertidal and infralittoral zones (Hayward & Ryland 1998). The highest abundance of bryozoans are usually found between the depths of 20-80m with a peak abundance at 40m (Ryland 1970). After this zone the light is reduced dramatically and both the diversity and abundance of bryozoans are reduced although many species are still found, they are usually found associated with shade preferring algal species such as some *Laminaria* species and red algae (Stebbing 1971) species. When depths of 1000m and below are reached the diversity of species decreases greatly (Hughes 2001). Species at these depths usually have an erect form and are found in bushy colonies attached to the few boulders and shells present at this depth. At these depths the lack of suitable substrata could be a contributing factor also to the reduced diversity and abundance at this depth (Ryland 1970).

Bryozoan habitats

In Stach (1936) the relationship between the habitat type, which is linked to the bathymetric distribution, and zooid type are investigated. The zooid types are broken down into 9 types; Membraniporiform, Petraliform, Eschariform, Reteporiform, Vinculariform, Cellariform, Catenicelliform, Flustriform, and Lunulitiform and the typical distribution area for each is discussed. Membraniporiform, for example include the species *Membranipora membranacea*, this species is well studied (Ryland 1998) and often exhibits preference for *Laminaria* thalli (Könnecker & Keegan 1983, Hayward & Ryland 1998). This species' zooid has the basal surface attached to the substrate and the frontal surface is covered by a flexible membranous layer (Hayward & Ryland 1998). This flexible layer prevents the colony from being damaged during the wave action on the intertidal and infralittoral zones. By investigating the physical traits of the zooid, Stach (1936) discusses the most likely bathymetric distribution of each of the 9 zooid types (Table 3.1).

Table 3.1. *Summary of bathymetric distribution based on zooid type from Stach (1936)*

Zooid type	Typical habitat
Membraniporiform	Littoral, sublittoral zones.
Petraliform	Littoral, sublittoral zones. Attached to loose and irregular substrata.
Eschariform	Sublittoral zone to at least 18m.
Reteporiform	Sublittoral zone. Strong wave action and current.
Vinculariform	Deep sheltered waters. Little or no current.
Cellariform	Littoral zone where algae is present.
Catenicelliform	Littoral zone, strong wave action.
Flustriform	Littoral zone.
Lunulitiform	Free living. Sandy bottom, strong wave action

Ecological and environmental factors which affect bryozoan distribution.

Many ecological and environmental factors will affect the distribution patterns of species (Hageman 1997). These factors include substrate type/availability, sedimentation rates, predation and competition of substrate, and water depth (Hageman 1997). Water depth can be correlated with ecological factors such as light, temperature, chemistry and nutrients. When evaluating bryozoan distribution it is important to recognize that these environmental and ecological factors are interrelated and should be investigated together to achieve and accurate conclusion (Hageman 1997)

Substrate availability and habitat settlement

Some species of bryozoan are very particular to the type of substrate they choose and if for any reason that substrata is not present or available it may affect the settlement and/or growth of the potential colony. Generally substrata availability for the attachment of the ancestrula would be the most important factor in the presence of bryozoans (Hayward & Ryland 1999). Areas such as continental shelf seas can have a number of substratum types, areas with a coarse sandy substratum usually have little diversity, with colonies attached to shell valves and isolated pieces of hard substratum. Areas with large amounts of shell valves usually have a high diversity of cheilostomate bryozoans, the bryozoans present will depend on the type of shell present as some species will show preference and/or dominance with certain shells. Rocky locations will have a diverse array of bryozoan species of both encrusting and erect forms. Rocks and boulders create an ideal location for ancestrula attachment (Hayward & Ryland 1999). In more sheltered rocky areas a large number of bryozoans can be found representing all three orders. Some species are predominantly found at certain levels on the tidal zone, such as *Conopeum reticulum* and *Escharella variolosa* which were commonly found while sampling for the current study, along the intertidal zone attached to both shells and stones. Kelp holdfasts are a popular substrata for a number of the most commonly found bryozoan species such as *Escharoides coccinea*, *Callopora lineata* and *Schizoporella unicornis* (Seed & O'Connor 1981, Hayward & Ryland 1999). Many species of bryozoan grow as epiphytes and grow predominantly on algae. *Fucus serratus* is often covered with the bryozoans *Flustrellidra hispida*, *Alcyonidium gelatinosum*, *Alcyonidium hirsutum* and *Electra pilosa* with *E. pilosa* being the less dominant of these species. The lifecycle of these species can seem in sync with its algal substratum with larval release occurring at the same time in a population. The nature of larva requires it to choose a suitable substrata with a few hours and settle while ensuring the population present is kept at the optimum level (Hayward & Ryland 1999). Characteristics of the substratum such as the texture, chemistry and proximity to other colonies can determine where a larva settles but the larval behaviour has a higher importance in ultimately determining the final settlement location of the larva.

Highly turbulent waters can be damaging on fragile bryozoan colonies. At depths where this turbulence is at its highest bryozoan species tend to be encrusting and more resistant to damage then the erect, bushy and foliose species found at deeper depths (Schopf 1969, Ryland 1970). The majority of bryozoan species have a preference for areas of low sediment deposition (Maturo 1959). As already stated no single factor can be considered by itself, sedimentation is linked to factors such as depth, water flow speeds and substrata (Maughan 2001). Areas with high levels of sedimentation will normally have slower water movement (Maughan 2001) and have been shown to have a low diversity of bryozoans (Ryland 1970). High sedimentation rates will affect both the pre-settlement and post settlement processes and can disrupt feeding and survival rates of many species of bryozoan (Maughan 2001). Data examined by Schopf (1969) shows that at depths of more than 1000m where sedimentation is expected to be higher, there can still be high diversity if the water current are strong enough to prevent high sedimentation rates which can prevent feeding by many bryozoan species. Some bryozoan species such as *Kinetoskias smitti* are adapted for life in areas of high sedimentation or mud. They have the ability to attach to the fine particles with rhizoids/ rootlets (Schopt 1969, Ryland 1970). Bryozoa often found in areas of high sedimentation are *Cellaria* sp., *Crisia* sp. and *Scrupocellaria* sp., these bryozoans tend to be jointed with an erect bushy colony form and as previously mentioned, the ability to attach to the sediment particles (Schopt 1969). Lunulitiform bryozoans are free living (Table 3.1) and so are independent of substratum needs (Ryland 1970). *Cupuladria* sp. have discoid shaped free living colonies which live in warmer climates then Ireland (Cadée 1975). They are not dependent on the presence of substrata to live and as such are well adapted to areas of high sedimentation also.

Water depth itself does not seem to be a limiting factor in bryozoan distribution but rather factors associated with depth. Some species are more abundant at deeper depths such as *Bicellarina alderi* (Busk 1859) which has been recorded from depths of 50 – 1000m although it can be found at depths of 6m it is generally found at the deeper depths (Hayward & Ryland 1998). Coastal living bryozoans such as *M. membranacea* with a preferred substratum will be restricted to the depth of the *Laminaria* species it uses as substratum (Hayward & Ryland 1998). One of the environmental factors that can be associated with water depth is temperature (Hageman 1997). Bryozoans have been found to compose up to 80% of the benthic faunal communities in areas with water temperatures less than 20°C (Hageman 1997). The bathymetric distribution of bryozoans can vary with the temperature. Ryland (1963) studied the vertical distribution of bryozoans in the west Norwegian fjords and found that in that location there was a bathymetric boundary of 40-60m in which the majority of the bryozoan species present were found. The temperature of this 40-60m depth fluctuates less than the water above it where the bryozoan diversity is less. In studies investigating bryozoans at deeper depths such as Schopf (1969) which examined data worldwide, it has been found that diversity can be reduced to as little as 10 species at 1000m and 5 species at 2000m. He did find exceptions to this finding such as when suitable substrate like rock was available. He discovered that one station studied by Calvet (1903) at 2018m had 19 bryozoan species associated with it, substrata was available here that was not normally available for Cheilostomatida to settle on at other stations at similar depths.

3.2 Materials and Methods

Bryozoan sampling methods

A number of sampling methods were used and these have been assigned to 4 categories, shore sampling in intertidal areas, settlement panels, scuba diving, dredges and grabs.

Shore collecting was achieved by walking along the shoreline at low tide of the chosen location and collecting samples from both natural and artificial substrates such as rocks, shells, drift plastic and algae. Data was taken about the beach habitat type (sandy, stoney etc), the tide level and time of day. Locations were chosen to achieve as comprehensive a spread of the shoreline as possible. The distance walked varied depending on the site. Where substrata such as shells and rocks were very sparse sand samples were collected also by collecting a small sample of sand in a tube. A number of samples were collected by scraping colonies off large boulders or cliffs, overhanging rocks and plastic buoys as the substrate could not be removed. Specimens collected intertidally were assigned a depth of 0m which is consistent with previous assessments of bryozoan diversity (e.g. Rowden *et al.* 2004).

Settlement panels were placed in Dun Laoghaire Harbour and Belfast Harbour (Fig 3.2). Plastic settlement panels 17cmx17cm in size attached to a metal frame 120cmx44cm. Three plastic tubes 6in long and 2in in diameter attached below the plastic panels and three ceramic tiles (3’’ x 3”) with lightly sanded surface attached below the plastic tubing. Plastic panels, tubes and ceramic tiles were all attached to the frame with cable ties to enable easy replacement (Fig 3.2 B). These were placed with the intention of collecting bryozoan species from a deeper depth and were placed at 5m below MLWS in Dun Laoghaire harbour and 6m below MLWS in Belfast.

Additional sampling methods

A total of 6 samples were collected while scuba diving at Strangford Lough and Dun Laoghaire sites. These samples were collected from depths of 10, 15 and 20 meters.

Dredge samples were collected from Dublin Bay on the S.S. *Celtic Voyager* in October 2011 (Table 3.2). Twenty one specimens were collected from a 20m depth using a beam trawl. Samples of rock, algae, foliose bryozoans, shells and large boulders were collected and the bryozoans were identified as described above. One grab sample was recorded from Strangford Lough during the Blitz the Lough event (Nunn 2013) which was taken from 27.5m depth.

Table 3.2. Locations of dredge samples taken from the S.S *Celtiv Voyager* in 2011

Site name	Co-ordinates	Depth (m)
Dublin bay (site 1)	53.300420, -6.051370	20
Dublin bay (site 2)	53.355470, -6.084850	20
Dublin bay (site 3)	53.322980, -6.104760	20

After collection, samples were treated and stored in a number of ways, some calcareous species were cleaned with water and air dried, others were bleached in 2.5% bleach, rinsed and dried. Any soft bodied specimens were collected and were preserved in 70% ethanol but a number of these specimens were already desiccated and unidentifiable when they were sorted for identification. Sand samples were examined with a stereomicroscope and any bryozoans large enough were identified and recorded for their presence at that site and stored in a cavity slide.

Taxonomic identification was carried out using a stereomicroscope and identification guides Hayward and Ryland (1985, 1999, 1998) and Hayward (1985) for the remaining samples of shells, algae, rock and artificial substrates. Specimens were imaged using Scanning Electron Microscopes located at Trinity College, Dublin and NHMUK (LEO 1455VP.). Measurements of zooid length and width, orifice length and width were recorded where necessary along with other morphological features required for identification.

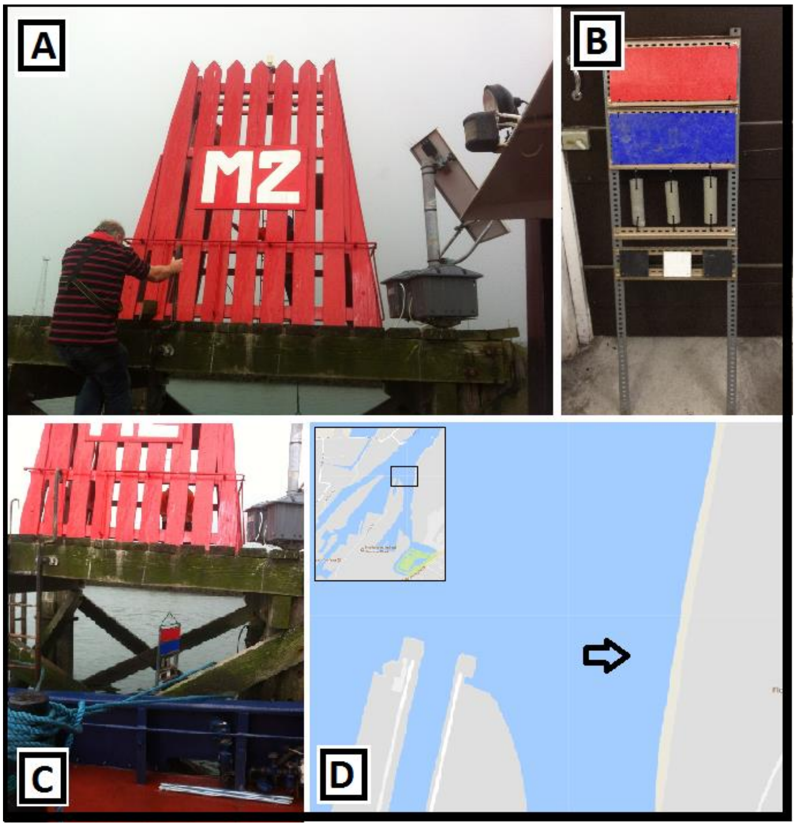

Fig 3.2. Settlement panel in Belfast harbour. **A)** The marker where the panel is attached. **B)** The settlement panel before placement. **C)** The panel frame being lowered from the wooden platform. **D)** Map of Belfast Harbour indicating the location of the panel frame.

Museum collection database sources

The historical records used in this study to assemble a database were obtained from the Natural History Museum, Dublin (NHMI), Natural History Museum, London (NHMUK) and the Natural History Museum, Belfast (NHMU). These records include specimens collected during expeditions carried out by the Dublin Bay Dredging Committee, Fauna & Flora Committee and Council of the Royal Irish Academy. Data extracted from these records were location, date of collection, species name, collection depth, collector, substrate type, collection method and preservation method. All records were either confirmed or adjusted with the use of the Synopses of the British Fauna (Hayward 1985; Hayward & Ryland 1985, 1998, 1999), the World Register of Marine Species (WoRMS) and through personal communication with John Ryland (University College of Swansea), Hans De Blauwe (author) and Mary Spencer Jones (curator of Bryozoa at the NHMUK).

A number of the historical record depth in fathoms, these were converted into meters to achieve consistency on comparison to recent results.

The majority of the contemporary records were accumulated by fieldwork described above collected from 2011-2016 (Fig 3.3). Additional records were also sourced from carefully selected literature and a number of small scale biodiversity surveys, these include Sherkin Island surveys (Bishop 2003), Strangford Lough bioblitz (2013) and Loxton *et al*. (2017). As many of the historical records were incomplete, records with insufficient locality and collection date information have been excluded from any species diversity maps. For the records which have not been identified to species level, identifications have been completed, were possible by examining the material, where this is not possible the record has been excluded from species distribution maps.

Study area: The coast of Ireland

Irish bryozoans are defined as occurring on and adjacent to coast line of Ireland and Northern Ireland and are refered to as Irish records herein. Historical records from Porcupine basin, Rockall bank and Fastnet basin have been assessed also. More than 150 locations were either sampled during the current study or present in the existing records, an example of the sample sites from the current study follow.

Study site: Dun Laoghaire Harbour, Co. Dublin (53° 30’ N, 06° 14’ W) is located to the South-East of Dublin City Centre and one of the largest harbours in the country. The east and west piers are constructed of granite. The marina consists of wooden walkways with concrete supports and plastic buoys. Maximum depth is 20m with the fairways being 5-8m deep. Visual observations during collection trips show that the marina exhibits high levels of sedimentation.

Study area: Belfast Harbour, Co. Antrim (54.628596, -5.883376)

Study Area: Kilbaha Harbour, Co. Clare (52.570770, -9.861668)

Study area: Camp Beach, Dingle Peninsula, Co. Kerry (52.229590, -9.907400)

Study area: Strangford Lough, Co. Down (54.434260, -5.544900) has SAC status. Samples collected in areas including The Dorn, Sketrick Island, Ballyhenry, Holm Bay, Zara Shoal, Horse Island, Abby rock, Islandscorr and Portaferry marina. Strangford Lough is relatively sheltered.

Bryozoan distribution analysis

All bryozan records with usable location data were mapped with ARCGIS to provide distribution layers for both recent and historical records. Habitat type (Fig 3.3) was mapped using data from EMODnet Seabed Habitats, for Ireland and compared with the distribution data.

Biodiversity analysis

The optimal method for the measurement of biodiversity has been subject to much research, both in the past and in current scientific discussions (Narayanaswamy *et al.* 2010). Problems such as species, genotype, habitat and ecosystem have been discussed as varying factors in such a measurement (Gray 2000, Whitaker 2001, Magurran 2004).

In order to determine the bryozoan species present in Ireland currently, 350 samples were collected in total from around the country, 321 with shore collecting, 6 with Scuba diving, 5 using settlement panels, 2 grab samples and 18 from dredging with a beam trawl on the S.S. *Celtic Voyager*. Samples were collected from both natural and artificial substrates such as rocks, shells, drift plastic, lobster pots, algae and other suitable substrata. A large number of the substrates had multiple colonies of multiple species present. Literature with current records were also examined and records extracted to complement the sampling data.

Fig 3.3 Habitat types by biological zone from EMODnet.

3.3 Results

A total of 3027 records were extracted from a number of sources (Table 3.3), both historic and contemporary. Museum records were either kindly supplied by Mary Spencer Jones (curator of Bryozoa at the NHMUK) or access to non digitised records was granted and the Irish records were isolated and digitised. As many of the records were early 1900's there had was a need for taxonomic updates of these records. 218 extant bryozoan species have been recorded from 141 locations on Ireland's coast (Appendix 2). These 218 species represent 156 genera within 36 families across all 3 extant marine orders Cheilostomatida, Ctenostomatida and Cyclostomatida (Table 3.4). Data refered to as historic are records sourced from museums and literature predating 2000, the data after this time will be referred to recent/contemporary (Table 3.3). A large propoartion of the recent records are from the East and South of Ireland and notably fewer records overall are present for North-West Ireland. The distribution of the historical and recent records were illustrated with ARCGIS in figure 3.4.

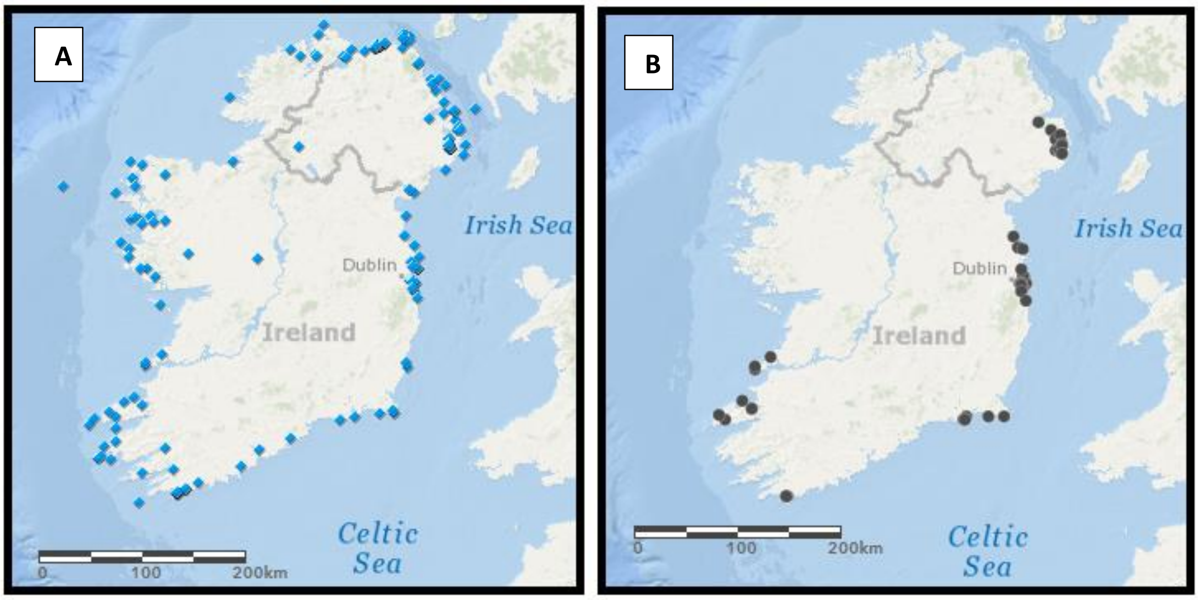

Fig 3.4 Locations from which bryozoans have been recorded in Ireland. A, Historical records were sourced from NHMI, NHMUK and NHMU and selected literature (1799-2010). B, Recent records sourced from selected literature and a field survey carried out by the author (2011-2016).

Biodiversity analysis

An analysis was carried out using Simpson's index of diversity (D) and the Shannon-Weiner index (H) to determine if any changes exist in the biodiversity of bryozoans from the historical data accumulated from museums and the recent data accumulated from a sampling programme and selected literature. It has been determined that D for the historical data was 0.99% for the south and 0.98% for the North. The recent data was analysed in the same way and the D value for the south was 0.94% and the north was 0.97%. The evenness of the distribution was tested by calculating Shannon-Weiner index and determining the equitability. The south and north historic data were determined as 0.73 and 0.71 respectively and the recent data produced values of 0.36 for south and 0.45 for the north (Table 3.5). A total of 218 species have been recorded from the collective datasets (Appendix 1). The historical dataset represents 92% of these species and the recent records represent 37% of these species.

Table 3.3. Bryozoan record sources for all records

Record source	Number of records
NHMI	1077
NHMUK	395
NHMU	69
Present Study	349
Bishop 2003	237
Nunn 2013	37
Wyse Jackson 1991	860
Loxton *et al*. 2017	1
Total	3025

Table 3.4
Summary of Irish marine bryozoans taxonomic database

	Genera	Species
Cheilostomatida	99	156
Ctenostomatida	12	26
Cyclostomatida	20	36
Totals	**156**	**218**

Table 3.5. Simpson's index of diversity (D) and Shannon's Index (E_H) for historical and recent bryozoans records from Ireland where S is number of bryozoan species and R is the number of records.

Data	Simpsons (D)	Shannons (E_H)	S	R
Historic South	0.99	0.73	112	479
Historic North	0.98	0.71	113	423
Recent South	0.94	0.36	46	229
Recent North	0.97	0.45	39	99

Bryozoan distribution and pattern changes in Ireland from 1850-present

When both historical and contemporary distribution data is analysed it is evident that bryozoans have been recorded from a large proportion of the Irish coastline with 17 of the 19 coastal counties (89%) being included in the data, Limerick and Kilkenny were the only counties with no records (Fig 3.5). A large number of the collection sites were from the west coast with Cork and Mayo having a large number of records from the historical dataset. In the contemporary dataset, 3 counties in the north were sampled, Antrim, Down and Meath, the historical records covered a larger number of counties with all 9 of the counties I have assigned as northern (Fig 3.1). In the south, 8 of the 10 counties have bryozoan records in the historical data and 6 from the recent data.

The species recorded in the most counties in the historical data was *S. chelata, A. gelatinosum, M. membranacea, C. hyalina, C. eburnea, E. pilosa* and *E. pilosa* which were recorded in 74%, 68%, 68%, 63%, 63%, 63% and 63% of the coastal counties respectively (Table 3.4). The recent data also showed that although at lower percentages the species found in the most counties remained very similar with *E. pilosa, M. membranipora, C. hyalina* and *C. pallasiana* being found in 42%, 32%, 32% and 32% respectively.

Table 3.6. Species found in the highest percentage of counties from both the historical and recent records.

Species	**Historical (%)**	**Recent (%)**
Scruparia chelata	73.68	5.26
Alcyonidium gelatinosum	68.42	5.26
Membranipora membranacea	68.42	31.58
Celleporella hyalina	63.16	31.58
Crisia eburnea	63.16	15.79
Electra pilosa	63.16	42.11
Microporella ciliata	63.16	15.79
Cryptosula pallasiana	31.58	31.58
Escharoides coccinea	52.63	26.32

As many of the recent records were distributed along the east coast, the species richness was determined for 3 different time periods 1800-1900, 1900-1950 and 1950- 2017.In total 128 different species have been recorded from the east coast of Ireland. The records from these 3 time periods were analysed to determine the change if any that occurred from the south-east, central-east and north-east (Fig 3.6). The central counties have the largest decrease in bryozoan species reported between 1900-1950 with only 9 reported species. This same region then displays the most species reported in the 1950- 2017 at 105 bryozoan species.

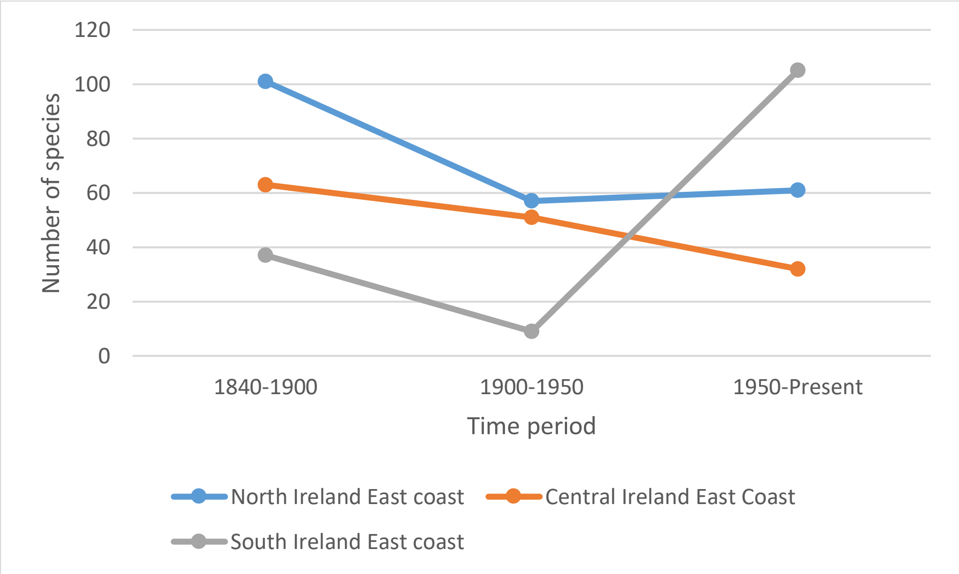

Fig 3.5. Comparison of Bryozoa species richness in Ireland between 1850-2017

Total species richness exhibits a decrease from 128 to 75 during the period 1900-1950 and then increases again to almost the maximum at 122 species (Table 3.5). This may well be as a result of less collecting in the intermediate period.

Table 3.7. Species richness for North Ireland East coast (NEI)*, Central Ireland East coast (CEI)*, South Ireland East coast (SEI)* over the time periods 1800-1900

Location	1800-1900	% overall species	1900-1950	% overall species	1950-Present	% overall species
NEI	101	46	57	26	61	28
CEI	63	29	51	23	33	15
SEI	37	17	9	4	105	48
Species recorded	**128**	**59**	**75**	**34**	**122**	**56**

*NEI – includes Antrim, Down, Louth * CEI – includes Meath, Dublin, Wicklow *SEI – includes Wexford, Waterford

Early historical collections: museum and literature records

Museum record database evaluation

Museum records are one of the most important sources of baseline data for many biologists. During this study the specimens and data provided by Natural History Museum Dublin (NHMI), Natural History Museum London (NHMUK) and the Natural History Museum Belfast (NHMU) were invaluable in creating the baseline records for the areas required.

<u>Natural History Museum Dublin</u>

This collection contains 1077 catalogued specimens, a small number of these have been collected outside of Irish waters. A digital database was available to be examined but as with many older records, a number of the records are incomplete with information such as nomenclature, collection locality or date and collector missing. There is an estimated 100 species recorded in this collection from Irish waters but with many missing species names it is difficult to determine an exact number without further identifications. The catalogue does not have any specimens recorded as type specimens and further investigation is required to determine if there are any present here and not recorded as such in the catalogue. The collection includes some of the specimens collected during studies carried out by The Dublin Bay Dredging Committee, A. R Nichols, J. E. Duerden, N. Colgan, Fauna and Flora Committee, The Dublin Naturalists' Field Club and the Royal Irish Academy. Specimens from this collection range in date from 1877 to 1978 with varying degrees of date accuracy from an exact date of 3rd September 1891 for a specimen of *Turbicellepora avicularia* collected by the Dublin Naturalists' Field Club to many with no collection date at all.

<u>Natural History Museum London</u>

The Bryozoa catalogue books and specimens were examined at NHM London and the records pertaining to Ireland were extracted and digitally recorded. This bryozoan collection contains 395 specimens collected from Irish waters. This includes specimens of 127 different bryozoan species. There are 11 type specimens, 4 syntypes, 2 lectotypes, 2 neotypes and 3 figured specimens (Table 3.6). The collection year of a number of specimens is not recorded but from those that are, it is evident that some specimens date back to the year 1799 as described previously. Many of the specimens were once part of smaller collections such as the Busk, Norman, Hincks and Johnston collections but are now stored as one collection. There are a small number, about 38 specimens that have been preserved wet in the spirit collection, these specimens were not examined but the records have been evaluated. Only 59 specimens have a collector recorded, these include but are not limited to Rev. W.S Green, Robert Brown, Dr. Greufell, Dr. J. A. Kitching, W. Thompson and Miss Elliot.

Table 3.8
Type and figured specimens from Ireland held at NHMUK

Species	Type	Syntype	Lectotype	Neotype	Figured
Alderina imbellis	X				
Amphiblestrum flemingi	X				
Bugulina flabellata	X				
Cribrilina punctata			X	X	X
Puellina radiata					X
Bugulella gracilis	X				
Haplopoma graniferum	X				
Herentia hyndmanni	X				
Hincksina flustroides	X				
Celleporella hyalina		X			
Amphiblestrum auritum		X			
Micropora normani				X	
Neolagenipora eximia	X				X
Phylactella labrosa	X				
Smittina landsborovii				X	
Stomatoporina incurvata	X				
Triticella flava	X				
Tubulipora plumosa					X

Natural History Museum Belfast

The collection held at NHM Belfast is a more recent collection and has been digitally databased, all data required is present with very detailed records. During the current research no specimens from this collection were examined. The database consists of 69 records collected from more than 30 sites in Counties Down and Antrim. There are 34 species in this collection with no type specimens. All of the specimens have been collected from the counties Antrim and Down between 1979 and 1985.

Sampling programme from current study

The collection phase of this study took place from July 2011 to July 2015. In this time 55 bryozoan species were recorded from 349 identified specimens from the coasts of Ireland by the author and a small number of donors. These include 3 Ctenostomes, 8 Cyclostomes and 44 were Cheilostomes (Table 3.7) and were added to the overall records.

3.4 Discussion

The aim of this study was to assess and document the diversity and spatial distribution of bryozoan in Ireland using biodiversity indices and to account for any demonstrated changes from the historical records to the recent records. An assessment of the historical collections contained in the museums in Britain and Ireland was also carried out. The results of this study will provide baseline information on Irish bryozoans and will indicate areas of the country which require further study as well as indicating from the museum records, how they can be improved upon.

Biodiversity analysis

The historic records for Ireland show that there was a very high rate of diversity overall with a high evenness of species in the available records (Table 3.5). The historical records exhibited 92% of the 218 known species for the country. A large proportion of the museum records were part of large surveys carried out by key institutions and yielded many species from each survey. This will have contributed to the high bryozoan diversity and evenness of the records collected from the country during this period of time. The recent records also exhibit a similarly high diversity but the evenness of the recorded species is much lower. Of the 218 total bryozoan species recorded from Ireland, 37% of the species were represented in the recent records. This low percentage could be due to the fact that a number of counties were not sampled during the sampling programme. The majority of samples were taken at depths of less than 5 meters, many were sampled along the lower shore. This would greatly reduce the opportunities to encounter species which exhibit a preference for deeper depth such as *Omalesecosa ramulosa* and *Reteporella* sp.

(Hayward & Ryland 1999, Porter 2012). The north to south analysis has shown that there is no variation in the diversity from north to south of Ireland within the same time scale. Only the evenness of the records from the historic to the recent showed a variation but this is more likely to be a symptom of the lower number of records in this dataset.

Ecological comparisons of the distribution were not possible due to variations in the availability and quality of data from the historical records. Parameters such as water temperature and water turbidity were unable to be taken during the sampling programme. Average temperatures between the north and south of the country vary very little with the average sea temperature in the north at 14°C and the south 15°C. As water depth and sea temperature are related, depth may have more of an effect on species but this was not investigated here.

Bryozoan distribution and pattern changes

Bryozoans were recorded from 89% of coastal counties from the records. The 2 counties excluded, Limerick and Kilkenny have no records but as many of the locations have been omitted from museum records there may be some present but not labelled as such. Wyse Jackson (1991) examined a large number of papers and this publication also has no mention of these counties. It can be assumed that due to the geographical location of Kilkenny in relation to its neighbouring counties Wexford and Waterford that it would have a very similar if not identical bryozoan assemblage; however it has a tiny coastal zone which is largely brackish. The Limerick coast line shares a bay with Clare and Kerry and it can be assumed that they will have a similar bryozoan assemblage also

The analysis of the eastern coast revealed that the south east counties had 17% of Irish bryozoans recorded from the years 1800-1900 but during the 1900-1950 period only 4% of Irish bryozoan species were recorded. The recent surveys and sampling programme increased this number to 48%. This large increase is due mainly to the records added during the sampling programme of the current study as many samples were collected from Wexford. During the 1900-1950 studies along the east coast occurred (Nichols 1907, Massey 1912) but few of these samples were added to the museum collections.

Assessment of museum records and sampling programme

The museum collections used in the current study were vital in assembling the baseline data and species lists. The NHMUK, NHMU and NHMI collections and records exhibited differing amounts of data for each sample. A number of the specimens can be investigated to try to determine the missing information and the taxonomy can be updated in the database. Taxonomic analysis of many bryozoan genera has been taking place in the last decade. The specimens held in these museums is vital for this work as type specimens are vital when a taxonomic investigation takes place, the NHMUK collection houses 11 type specimens of Irish origin some of which were imaged for the current study.

3.5 Conclusion

In this study any differences in the diversity and distribution of Irish bryozoans are described. Sampling effort in the recent dataset was uneven as there was a gap in the dataset along the northwest coast. An increased sampling effort is required to assess the pattern changes in a more robust way. Using indices such as the average taxonomic distinctness of species (AvTD) and the variation in taxonomic distinctness (VarTD) will provide more comparable results

3.6 References

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https://www.seatemperature.org/

3.7 Appendices

Appendix 3.1. Full list of all species recorded from Ireland from 1800- present *

Genus	species	Author
Aetea	*sica*	(Couch,1844)
Aetea	*anguina*	(Linnaeus, 1758)
Aetea	*truncata*	(Landsborough, 1852)
Alderina	*imbellis*	(Hincks,1860)
Ammatophora	*nodulosa*	(Hincks, 1877)
Amphiblestrum	*auritum*	(Hincks,1877)
Amphiblestrum	*flemingii*	(Busk,1854)
Amphiblestrum	*solidum*	(Packard, 1863)
Anarthropora	*monodon*	(Busk, 1860)
Arthropoma	*cecilii*	(Audouin,1826)
Aspidostoma	*giganteum*	(Busk, 1854)
Beania	*mirabilis*	Johnston, 1840
Bicellariella	*ciliata*	(Linnaeus, 1758)
Bicellarina	*alderi*	(Busk, 1859)
Bugula	*neritina*	(Linnaeus, 1758)
Bugulella	*gracilis*	(Nichols,1911)
Bugulina	*flabellata*	(Thompson in Gray, 1848)
Bugulina	*avicularia*	(Linnaeus, 1758)
Bugulina	*turbinata*	(Alder, 1857)
Bugulina	*stolonifera*	(Ryland, 1960)
? Bugulina	*simplex*	(Hincks, 1886)
Buskea	*dichotoma*	(Hincks, 1862)
Caberea	*boryi*	(Audouin, 1826)
Caberea	*ellisii*	(Fleming, 1814)
Callopora	*lineata*	(Linnaeus, 1767)
Callopora	*rylandi*	Bobin & Prenant, 1965
Callopora	*dumerilii*	(Audouin, 1826)
Callopora	*discreta*	(Hincks, 1862)
Carbasea	*carbasea*	(Ellis and Solander, 1786)
Cauloramphus	*spiniferum*	(Johnston,1832)
Cellaria	*fistulosa*	(Linnaeus, 1758)
Cellaria	*sinuosa*	(Hassall,1840)
Cellaria	*salicornioides*	Lamouroux, 1816
Cellepora	*pumicosa*	(Pallas, 1766)
Celleporella	*hyalina*	(Linnaeus,1767)
Celleporina	*costazii*	(Audouin,1826)
Celleporina	*caliciformis*	(Lamouroux, 1816)
Celleporina	*decipiens*	Hayward, 1976
Celleporina	*tubulosa*	(Hincks, 1880)
Chartella	*papyracea*	(Ellis and Solander,1786)
Cheiloporina	*circumcincta*	(Neviani,1896)
Chorizopora	*brongniartii*	(Audouin,1826)
Collarina	*balzaci*	(Audouin,1826)
Conopeum	*reticulum*	(Linnaeus,1767)
Cradoscrupocellaria	*ellisii*	(Vieira & Spencer Jones, 2012)
Crassimarginatella	*solidula*	(Hincks,1860)
Cribrilaria	*radiata*	(Moll, 1803)
Cribrilaria	*innominata*	(Couch, 1844)

Cribrilina	*cryptooecium*	Norman, 1903
Cribrilina	*annulata*	(Fabricius, 1780)
Cribrilina	*punctata*	(Hassall, 1841)
Cryptosula	*pallasiana*	(Moll,1803)
Dendrobeania	*murrayana*	(Bean in Johnston, 1847)
Diporula	*verrucosa*	(Peach, 1868)
Einhornia	*crustulenta*	(Pallas,1766)
Electra	*pilosa*	(Linnaeus, 1767)
Electra	*monastachys*	(Busk, 1854)
Escharella	*immersa*	(Fleming, 1828)
Escharella	*variolosa*	(Johnston, 1838)
Escharella	*labiosa*	(Busk, 1856)
Escharella	*laquenata*	(Norman,1864)
Escharella	*ventricosa*	(Hassall,1842)
Escharella	*abyssicola*	(Norman, 1869)
Escharella	*octodentata*	(Hincks, 1880)
	dutertrei	Zabala, Maluquer and Harmelin
Escharina	*haywardi*	1993
Escharina	*johnstoni*	(Quelch,1884)
Escharina	*vulgaris*	(Moll,1803)
Escharoides	*coccinea*	(Abildgaard, 1806)
Escharoides	*mamillata*	(Wood,1844)
Eucratea	*loricata*	(Linnaeus,1758)
Fenestrulina	*malusii*	(Audouin,1826)
Figularia	*figularis*	(Johnston,1847)
Flustra	*foliacea*	(Linnaeus, 1758)
Hagiosynodos	*latus*	(Busk, 1856)
Haplopoma	*graniferum*	(Johnston,1847)
Haplopoma	*impressum*	(Audouin,1826)
Haplopoma	*bimucronatum*	(Moll, 1803)
Hemicyclopora	*multispinata*	(Busk,1861)
Hemicyclopora	*polita*	(Norman, 1864)
Herentia	*hyndmanni*	(Johnston,1847)
Hincksina	*flustroides*	(Hincks,1877)
Hippoporidra	*lusitania*	Taylor and Cook, 1891
Hippothoa	*distans*	MacGillivray, 1869
Hippothoa	*divaricata*	Lamouroux, 1821
Hippothoa	*flagellum*	Manzoni, 1870
Jellyella	*tuberulata*	(Bosc, 1802)
Kinetoskias	*smitti*	Danielssen, 1868
Lagenipora	*lepralioides*	(Norman,1868)
Larnacicus	*corniger*	(Busk, 1859)
Megapora	*ringens*	(Busk, 1856)
Membranipora	*membranacea*	(Linnaeus,1767)
Membraniporella	*nitida*	(Johnston,1838)
Micropora	*coriacea*	(Johnston,1847)
Micropora	*normani*	Levinsen,1909
Microporella	*ciliata*	(Pallas, 1766)
Neolagenipora	*collaris*	(Norman,1867)
Neolagenipora	*eximia*	(Hincks,1860)
Notoplites	*jeffreysii*	(Norman, 1868)
Omalosecosa	*ramulosa*	(Linnaeus,1767)
Oshurkovia	*littoralis*	(Hastings, 1944)
Osthimosia	*eatonensis*	(Busk, 1881)

Palmicellaria	*aviculifera*	Canu and Bassler,1928
Palmiskenea	*skenei*	(Ellis and Solander,1786)
Parasmittina	*trispinosa*	(Johnston,1838)
Pentapora	*fascialis*	(Pallas,1766)
Pentapora	*foliacea*	(Ellis & Solander, 1786)
Phaeostachys	*spinifera*	(Johnston,1847)
Phylactella	*labrosa*	(Busk,1854)
Pomocellaria	*inarmata*	(O'Donoghue & O'Donoghue, 1926)
Porella	*compressa*	(Sowerby,1805)
Porella	*concinna*	(Busk,1854)
Porella	*minuta*	(Norman,1868)
Porella	*struma*	(Norman, 1868)
Prenantia	*cheilostoma*	(Manzoni, 1869)
Puellina	*radiata*	(Moll, 1803)
Puellina	*gattyae*	(Landsborough,1852)
Puellina	*setosa*	(Waters, 1899)
Pyripora	*catenularia*	(Fleming,1828)
Ramphonotus	*minax*	(Busk, 1860)
Reptadeonella	*violacea*	(Johnston,1847)
Reteporella	*couchii*	(Hincks,1878)
Reteporella	*grimaldii*	(Jullien, 1903)
Reteporella	*beaniana*	(King, 1846)
Rhynchozoon	*bispinosum*	(Johnston, 1847)
Rosseliana	*rosselii*	(Audouin, 1826)
Schizobrachiella	*sanguinlea*	(Norman,1868)
Schizomavella (Calvetomavella)	*discoidea*	(Busk,1859)
Schizomavella (Schizomavella)	*linearis*	(Hassall,1841)
Schizomavella (Schizomavella)	*auriculata*	(Hassall, 1842)
Schizomavella (Schizomavella)	*hastata*	(Hincks,1862)
Schizoporella	*errata*	(Waters, 1878)
Schizoporella	*unicornis*	(Johnston in Wood 1844)
Schizoporella	*dunkerii*	(Reuss, 1848)
Schizoporella	*japonica*	Ortmann, 1890
Schizotheca	*fissa*	(Busk,1856)
Schizotheca	*divisa*	(Norman, 1864)
Scruparia	*ambiqua*	(d'Orbigny, 1841)
Scruparia	*chelata*	(Linnaeus,1758)
Scrupocellaria	*reptans*	(Linnaeus, 1767)
Scrupocellaria	*scruposa*	(Linnaeus, 1785)
Scrupocellaria	*scrupea*	Busk, 1852
Securiflustra	*securifrons*	(Pallas,1766)
Smittina	*landsborovii*	(Johnston,1847)
Smittina	*cervicornis*	(Pallas, 1766)
Smittina	*bella*	(Busk, 1860)
Smittoidea	*reticulata*	(MacGillivray,1842)
Temachia	*microstoma*	(Norman, 1864)
Terminoflustra	*barleei*	(Busk, 1860)
Tessaradoma	*boreale*	(Busk, 1860)

Tricellaria	*inopinata*	d'Hondt & Occhipinti Ambrogi, 1985
Turbicellepora	*avicularis*	(Hincks,1860)
Turbicellepora	*armata*	(Hincks, 1860)
Turbicellepora	*boreale*	Hayward and Hansen 1999
Turbicellepora	*avicularis*	(Hincks, 1860)
Umbonula	*ovicellata*	Hastings, 1944
Watersipora	*subatra*	(Ortmann, 1890)
Alcyonidioides	*mytili*	Dalyell,1848
Alcyonidium	*albidum*	Alder, 1857
Alcyonidium	*diaphanum*	(Hudson, 1778)
Alcyonidium	*mammillatum*	Alder, 1857
Alcyonidium	*gelatinosum*	(Linnaeus,1761)
Alcyonidium	*hirsutum*	(Fleming, 1828)
Alcyonidium	*parasiticum*	(Fleming, 1828)
Amathia	*lendigera*	(Linnaeus, 1758)
Amathia	*imbricata*	(Adams,1798)
Amathia	*pustulosa*	(Ellis and Solander,1786)
Amathia	*citrina*	(Hincks, 1877)
Amathia	*pustulosa*	(Ellis and Solander, 1786)
Amathia	*gracilis*	(Leidy, 1855)
Amathia	*imbricata*	(Adams, 1798)
Arachnidium	*simplex*	Hincks,1880
Arachnidium	*fabrosum*	Hincks, 1880
Farrella	*repens*	(Farre,1837)
Flustrellidra	*hispida*	(Fabricius,1780)
Hypophorella	*expansa*	Ehlers, 1874
Nolella	*dilatata*	(Hincks, 1860)
Penetrantia	*densa*	Silén, 1946
Triticella	*flava*	Dalyell, 1848
Triticella	*pedicellata*	(Alder, 1857)
Vesicularia	*spinosa*	(Linnaeus, 1758)
Walkeria	*tremula*	(Hincks, 1862)
Walkeria	*uva*	(Linnaeus,1758)
Annectocyma	*major*	(Johnston,1847)
Coronopora	*truncata*	(Fleming, 1828)
Crisia	*eburnea*	(Linnaeus, 1758)
Crisia	*ramosa*	Harmer,1891
Crisia	*aculeata*	Hassall, 1841
Crisia	*denticulata*	(Lamarck, 1816)
Crisidia	*cornuta*	(Linnaeus, 1758)
Crisularia	*plumosa*	(Pallas,1766)
Crisularia	*purpurotincta*	(Norman,1868)
Crisularia	*plumosa*	(Pallas, 1766)
Diplosolen	*obelium*	(Johnston,1838)
Disporella	*hispida*	(Fleming, 1828)
Entalophoroecia	*deflexa*	(Couch,1842)
Exidmonea	*atlantica*	(Forbes in Johnston, 1847)
Filicrisia	*genticulata*	(Milne Edwards,1838)
Filifascigera	*fasciculta*	(Hincks, 1880)
Frondipora	*verrucosa*	(Lamouroux,1821)
Hornera	*lichenoides*	(Linnaeus, 1758)
Hornera	*foliacea*	(MacGillivray, 1869)
Hornera	*frondiculata*	(Lamarck, 1816)

Oncousoecia	*dilatans*	(Johnston, 1847)
Oncousoecia	*Diastoporides*	(Norman, 1896)
Patinella	*verrucaria*	(Linnaeus, 1758)
Patinella	*radiata*	(Audouin, 1826)
Patinella	*verrucaria*	(Linnaeus, 1785)
Penciletta	*penicillata*	(fabricius, 1780)
Plagioecia	*patina*	(Lamarck,1816)
Plagioecia	*sarniensis*	(Norman,1864)
Stigmatoechos	*violacea*	(M. Sars, 1863)
Stomatoporina	*incurvata*	(Hincks,1859)
Tubulipora	*liliacea*	(Pallas, 1766)
Tubulipora	*flabellaris*	(Fabricius,1780)
Tubulipora	*plumosa*	Thompson in Harmer,1898
Tubulipora	*expansa*	(Packard,1863)
Tubulipora	*lobifera*	Hastings, 1963
Tubulipora	*phalangea*	Couch, 1844

* List compiled using records from NHMI, NHMUK, NHMU, Nunn (2013), Bishop 2003, Wyse Jackson 1991, Loxton *et al.* 2017.

? *B. simplex* was recorded by Boaden *et al.* 1975 but may be misidentified.

Appendix 3.2. Locations of all bryozoans reported from the historical data and recent data

Location	Co-ordinates	Recent	Historical
Achill island, Mayo	53.937124, -10.084526		X
Antrim	54.954815, -5.868972		X
Ardelly, Mayo	54.144514, -10.056486		X
Arran, Galway	53.087237, -9.65990		X
Baginbun bay, Wexford	52.173620, -6.833490	X	
Bailey Dublin Bay, Dublin	53.387069, -6.051721		X
Hampton cove, Balbriggan beach, Dublin	53.603830, -6.164352	X	
Balintrae, Antrim	55.142418, -7.484199		X
Ballycastle, Antrim	55.213413, -6.249788		X
Ballygalley Head, Antrim	54.901298, -5.660117		X
Balscaddan Bay Howth, Dublin	53.386901, -6.061263		X
Bangor, Down	54.667990, -5.673462		X
Bantry Bay, Cork	51.681046, -9.461381		X
Bartragh, Westport Bay, Mayo	53.797719, -9.592722		X
Belfast bay, Antrim	54.628596, -5.883376		X
Berehaven, Cork	51.650595, -9.906971		X
Bettystown Beach, Meath	53.692490, -6.241420	X	
Beufort Dyke, Antrim	54.716667, -5.233333		X
Birterbuy Bay,Galway	53.389590, -9.837967		X

Black Head off, Antrim	54.766622, -5.686933		X
Blackrock, Dublin	53.302956, -6.176598		X
Blacksod Bay, Mayo	54.083330, -10.01667		X
Boffin Harbour, Galway	53.611708, -10.214009		X
Bolus Head, Kerry	51.766667, -10.333333		X
Booley Bay, Wexford	52.137070, -6.928560	X	
Brandon Creek, Kerry	52.266188, -10.157743		X
Bray, Wicklow	53.202749, -6.09533		X
Bray Head, Valencia, Kerry	51.882293, -10.424419		X
Broadhaven Bay, Mayo	54.252859, -9.892250		X
Buncrana, Donegal	55.134721, -7.465780		X
Bundoran, Donegal	53.484699, -8.293744		X
Cahore,Wexford	52.559825, -6.194885	X	
Camp Beach, Dingle Peninsula, Kerry	52.229590, -9.907400	X	
Carlingford Lough, Down	54.055962, -6.173822	X	
Carnsore point, Wexford	52.172460, -6.365070	X	
Carrowmon Pier, Mayo	54.077530, -9.991077		X
Castlerock, Derry	55.169420, -6.791408		X
Church Bay, Rathlin Island, Antrim	55.292722, -6.198806	X	
Clare Island, Mayo	53.802146, -9.946599		X
Cleggan, Galway	53.557480, -10.108850		X
Clew Bay, Mayo	53.833333, -9.800000		X
Clonmassy Strand, Donegal	54.801476, -8.660742		X
Connemara, Gaway	53.491416, -10.102025		X
Cork harbour, Cork	51.850000, -8.266667		X
Ballywalter, Down	54,558551, -5.468297		X
Cross, Mayo	53.524901, -9.258138		X
Dalkey Sound, Dublin	53.275248, -6.091085		X
Dingle Marina, Kerry	52.138160, -10.276330		X
Donaghmore, Wexford	52.593220, -6.210733		X
Drolain Point, Sherkin island,	51.460545, -9.415681	X	
Dublin bay (site 1), Dublin	53.300420, -6.051370	X	
Dublin bay (site 2), Dublin	53.355470, -6.084850	X	
Dublin Bay (site 3), Dublin	53.322980, -6.104760	X	
Dublin Bay, (3BR), Dublin	53.302570, -6.065070	X	
Dublin Bay, near Rosberg Bank (1NB), Dublin	53.364070, -6.100780	X	
Dun Laoghaire Marina, Dublin	53.296850, -6.134770	X	
Dun Laoghaire, Dublin	53.292000, -6.128690	X	
Dursey head, Cork	51.391708, -9.946939		X
Eagle Island, Mayo	54.282947, -10.086786		X
Black Head, Rathlin Island, Antrim	55.301707, -6.167934		X
Little Skellig, Kerry	51.782577, -10.502181		X
Eddy Creek, Lough Hyne, Cork	51.500211, -9.295788		X
Erris Head, Mayo	54.180500, -9.595000		X
Fahamore Pier, Kerry	52.302180, -10.040630	X	

Farganlack Point, Rathlin Island, Antrim	55.309976, -6.263604		X
Garrahies, Camp beach, Kerry	52.229590, -9.907400	X	
Gavney Shoals, Copeland Sound, Down	54.411938, -5.36770		X
Giant's Causeway, Antrim	55.240807, -6.511555		X
Glandore Harbour, Cork	51.565953, -9.122134		X
Globe Rock , Sherkin island, Cork	51.465371, -9.404063		X
Great Skellig, Kerry	51.770562, -10.546973		X
Greencastle, Malin Head, North Donegal	55.198565, -6.978475		X
Greystones, Wicklow	53.149235, -6.062034		X
Howth, Dublin	53.389958, -6.059413		X
Inishowen, Donegal	55.310195, -7.435190		X
Ireland's Eye, Dublin	53.404709, -6.066568		X
Kearney Point, Ards Peninsula, Down	54.613834, -5.503162		X
Kenmare River (mouth of), Kerry	51.872305, -9.595747		X
Kilbaha harbour, Clare	52.570770, -9.861668	X	
Kilkee, Clare	52.682706, -9.647571	X	X
Kilkieran Bay, Galway	53.320700, -9.730982		X
Killiney, Dublin	53.263147, -6.107423		X
Killsallagh, Mayo	53.775323, -9.739232		X
Kilmore Harbour, Wexford	52.173790, -6.587350		X
Kinish Narrows East, Sherkin Islands, Cork	51.477915, -9.416212	X	
Kinsale, Cork	51.705312, -8520697		X
Lady's Island Lake, Wexford	52.196271, -6.395698		X
Lambay Island, Dublin	53.488298, -6.004785		X
Laytown, Meath	53.680110, -6.235133		X
Lough Earn, Donegal	54.397875, -7.693429		X
Lough Foyle, Donegal	55.130574, -7.087945		X
Lough Hyne, Cork	51.502413, -9.303057		X
Malahide, Dublin	53.449701, -6134258		X
Malin Head, Donegal	55.386202, -7.371681		X
Mayo	54.031747, -10.284906		X
Meath	53.828915, 06.210873		X
Muglins, Dublin bay, Dublin	53.275156, -6.076268		X
Mulroy Bay, Northwater, Donegal	55.135816, -7.68607		X
Off Clare Island, Mayo	53.807719, -10.078109		X
Portmarnock beach, Dublin	53.420480, -6.119280		X
Portnakilly Clare Island, Mayo	53.817419, -10.006367		X
Portrush, Antrim	55.204889, -6.657743		X
Poulacurra , Sherkin Islands, Cork	51.468967, -9.427011		X
Rathlin Island, Antrim	55.309096, -6.215968		X
Red Bay, Antrim	55.067501, -6.052851		X
Renoufs bay, Lough Ine, Cork	51.503691, -9.298578		X
Roonagh, Mayo	53.763804, -9.905746		X
Rospenna, Donegal	55.182564, -7.834824		X
Ross Bay, Clare	52.594710, -9.854670		X

Roundstone, Galway	53.396648, -9.916548		X
Russell's Rock, Maidens, Antrim	54.857957, -5.791195		X
Sand eel bay, Wexford	52.161190, -6.881530	X	
Sandycove beach, Dublin	53.288500, -6.114470	X	
Shanganagh, Co Dublin	53.238720, -6.111380	X	
Skelligs, Kerry	51.775852, -10525299		X
Skerries beach, Dublin	53.582257, -6.103130	X	
Skullmartin Rock, Ballywalter, Down	54.544361, -5476211		X
Slade Beach, Wexford	52.134760, -6.910240	X	
Slade Harbour, Wexford	52.134520, -6.909530	X	
Sligo	54.285042, -8637527		X
Strangford Lough (South of Abby Rock), Down	54.522970, -5.579580	X	
Strangford Lough (Ballyhenry Bay), Down	54.560520, -5.697600	X	
Strangford Lough (Chapel Island), Down	54.446432, -5.610320	X	
Strangford Lough (Holm Bay), Down	54.406090, -5.642230	X	
Strangford Lough (Horse Island), Down	54.465070, -5.543580	X	
Strangford Lough (Islandacorr), Down	54.392630, -5.576630	X	
Strangford Lough (Portaferry Marina), Down	54.380310, -5.549300	X	
Strangford Lough (Sketrick Island), Down	53.582160, -6.107950	X	
Strangford Lough (The Dam), Down	54.447290, -5.540820	X	
Strangford Lough (The Dorn), Down	54.434260, -5.544900	X	
Strangford Lough, Down	54.418530, -5.597400	X	X
Strangford Lough (Zara Shoal), Down	54.370940, -5.552860	X	
Strangford Lough (Ballyhenry, Inner Lee's Wreck), Down	54.388450, -5.571580	X	
Tearaght, Kerry	52.075682, -10656277		X
Valencia Harbour, Kerry	51.927970, -10279955		X
Inish tooskert, Kerry	52.131565, -10.590244		X
Waterford	52.114231, -7.142912		X
Dingle Bay, Kerry	52.038267, -10.276762		X
Whitecastle, Donegal	55.120922, -7.044035		X
Wine Strand, Smerwick Harbour, Kerry	52.177620, -10.368480	X	X
Youghal, Cork	51.954596, -7.844781		X

Appendix 3.3. List of bryozoan species collected during the sampling programme of the current study from the coasts of Ireland with notes on location and substrate.

Order	Species	County recorded	Substrate
Ctenostomatida	*Alcyonidium diaphanum* (Hudson,1762)	Dublin	Algae
	Flustrellidra hispida (Fabricius, 1780)	Dublin	*Fucus serratus*
	Amathia imbricata (Adams, 1798)	Down	*S. scruposa*
	Total species = 3		
Cyclostomatida	*Crisidia cornuta* (Linnaeus, 1758)	Down, Wexford	Lobster pot, Algae
	Crisia eburnea (Linnaeus, 1767)	Down, Dublin, Meath, Wexford	*F.foliacea*,Lobster pot, Rock, Algae
	Plagioecia patina (Lamarck, 1816)	Kerry	Shell
	Crisia aculeata Hassall, 1841	Down	Algae
	Crisia denticulata (Lamarck, 1816)	Dublin, Down, Meath	Rock, *F.foliacea*
	Filicrisia geniculata Milne Edwards, 1838	Down, Kerry	Algae, *C. papyracea*
	Tubulipora liliacea (Pallas, 1766)	Kerry, Wexford	Rock, Lobster pot
	Total species = 7		
Cheilostomatida	*Membranipora membranacea* (Linnaeus, 1767)	Cork, Down, Dublin,Kerry, Meath, Wexford	Algae
	Conopeum reticulum (Linnaeus, 1767)	Clare, Dublin, Kerry, Wexford	Plastic bottle, Rock, Shell,
	Electra pilosa (Linnaeus,1767)	Antrim, Cork, Clare, Down, Dublin, Kerry, Meath, Wexford,	Settlement panel, Algae, Shell, Coal, *F. foliacea*, Plastic, Crab carapace, Lobster pot, Rock, Sediment

Flustra foliacea (Linnaeus, 1758)	Cork, Down, Dublin, Meath, Wexford	Rock. Algae, Shell
Callopora dumerilli (Audouin, 1826)	Antrim, Clare, Dublin, Kerry,	Settlement panel, Algae, Oyster shell, Rock
Callopora lineata (Linnaeus, 1767)	Dublin, Kerry, Wexford,	Rock, Algae, Lobster pot
Callopora rylandi Bobin and Prenant, 1965	Clare, Kerry	Plastic bottle, Rock
Bugulina flabellata (Thompson in Gray, 1848)	Down, Dublin	*F. foliacea*
Bugula neritina (Linnaeus, 1758)	Down, Dublin	Concrete marina piling
Bicellariella ciliata (Linnaeus, 1767)	Down, Dublin, Wexford	Lobster pot, Rock
Caberea boryi (Audouin, 1826)	Wexford	Lobster pot
Scrupocellaria reptans (Linnaeus, 1767)	Cork, Dublin, Kerry	*F.foliacea*, Algae, Lobster pot
Scrupocellaria scruposa (Linnaeus, 1758)	Down, Dublin, Wexford	Rock, Lobster pot
Cradoscrupocellaria ellisi (Vieira & Spencer Jones, 2012)	Down, Dublin, Kerry, Wexford,	*F.foliacea*, Algae, Lobster pot
Tricellaria inopinata d'Hondt & Occhipinti Ambrogi, 1985	Dublin	Algae
Chartella papyracea (Ellis & Solander, 1786)	Dublin	Rock
Scruparia chelata (Linnaeus, 1758)	Down	Algae
Cellaria fistulosa (Linnaeus, 1758)	Down, Wexford	Grab sample, Lobster pot, Sand sample
Eucratea loricata (Linnaeus, 1758)	Down	Algae
Cauloramphus spiniferum (Johnston, 1832)	Down, Wexford	Shell, lobster pot, Rock

Cribrilina cryptooecium Norman 1903	Down	Rock
Cribrilina annulata (Fabricius, 1780)	Kerry	Shell
Celleporella hyalina (Linnaeus, 1767)	Clare, Cork, Down, Dublin, Kerry, Wexford	Algae, Plastic Bottle, *C. papyracea*, Lobster pot, Rock
Escharoides coccinea (Abildgaard, 1806)	Cork, Down, Dublin, Kerry, Wexford	Algae, Rock, Lobsterpot, Sand sample
Escharella immersa (Fleming, 1828)	Down, Dublin, Kerry	Plastic Bouy, Lobster pot, shell, Rock
Escharella variolosa (Johnston, 1838)	Clare, Kerry	Lobster pot, Rock
Escharella labiosa (Busk, 1856b)	Down	Rock
Watersipora subatra (Ortmann, 1890)	Dublin	Plastic buoy
Cryptosula pallasiana (Moll, 1803)	Cork, Down, Dublin, Kerry, Meath, Wexford,	Settlement panel, Rock, Shell, Algae, Plastic, Boat hull
Schizoporella unicornis (Johnston in Wood, 1844)	Cork, Down, Dublin, Kerry	Shell
Celleporina calciformis (Lamouroux, 1816)	Cork, Down, Dublin, Kerry	Shell, Rock, Algae, Lobster pot, sand sample
Celleporina decipiens Hayward, 1976	Dublin	Hydroid Stem
Turbicellepora boreale Hayward and Hansen 1999	Wexford	Lobster pot
Phaeostachys spinifera (Johnston, 1847)	Down, Dublin	Algae, Rock, Shell
Omalosecosa ramulosa (Linnaeus, 1767)	Wexford	Lobster pot
Fenestrulina malusii (Fleming, 1828)	Down, Dublin	Shell, Rock

Oshurkovia littoralis (Hastings, 1944)	Down	Rock
Cellepora pumicosa (Pallas, 1766)	Down, Cork	Rock
Microporella ciliata (Pallas, 1766)	Down, Dublin, Wexford	Rock, shell, Lobster pot
Chorizopora brongniartii (Audouin, 1826)	Clare	Plastic Bouy
Schizomavella (Schizomavella) linearis (Hassall, 1841)	Dublin	Rock
Pyripora catenularia (Fleming, 1828)	Dublin, Kerry	Plastic
Schizoporella errata (Waters, 1878)	Clare	Plastic bottle
Total species = 43		

Chapter 4

A taxonomic atlas of the bryozoans of Ireland

An atlas of the bryozoans of Ireland

Bryozoa are a phylum within the animal kingdom. The phylum was originally called Polyzoa and many scientific articles from the early 1900's can be found using this term. The term Bryozoa may not be common knowledge to all but many will have encountered these animals unknowingly while on the coast. Bryozoans are often found as white encrustations on algae, rocks and shells but can also have body forms much like the flora and fauna it often encrusts.

Ireland has had 218 bryozoan species recorded from its shores since the late 1800's. Many of the specimens collected during the initial surveys are still available to investigate from a number of museum collection in Britain and Ireland. In recent years a number of new non-native and sometimes invasive Bryozoan species have been recorded from harbours and marinas around the country (Kelso & Wyse Jackson 2012, Nunn 2013, Loxton *et al.* 2017). This atlas of Irish bryozoans will list, in taxonomic order the bryozoan species' recorded from Irish shores. Images will be included where available and the distributional data for the species. Species description for this collection of bryozoans are available in detail in the identification guides by Hayward and Ryland (1985, 1999, 1998) and Hayward (1985). A small number of newly introduced species are not described in these identification guides but can be found in (Porter 2012).

Class Gymnolaemata

Order Cheilostomatida Busk, 1852

Suborder Inovicellina Jullien, 1888

Superfamily Aeteoidea Smitt, 1867

Family Aeteidae Smitt, 1867

Aetea anguina (Linnaeus, 1758)

Aetea sica (couch, 1844)

Aetea truncata (Landsborough, 1852)

Family Scrupariidae

Scruparia ambigua (d'Orbigny, 1841)

Scruparia chelata (Linnaeus, 1758)

Location: Antrim, Cork, Derry, Down, Dublin, Galway, Kerry, Mayo, Sligo, Meath, Wexford, Wicklow.

Specimen: NHMUK 1940.11.6.1(pt)

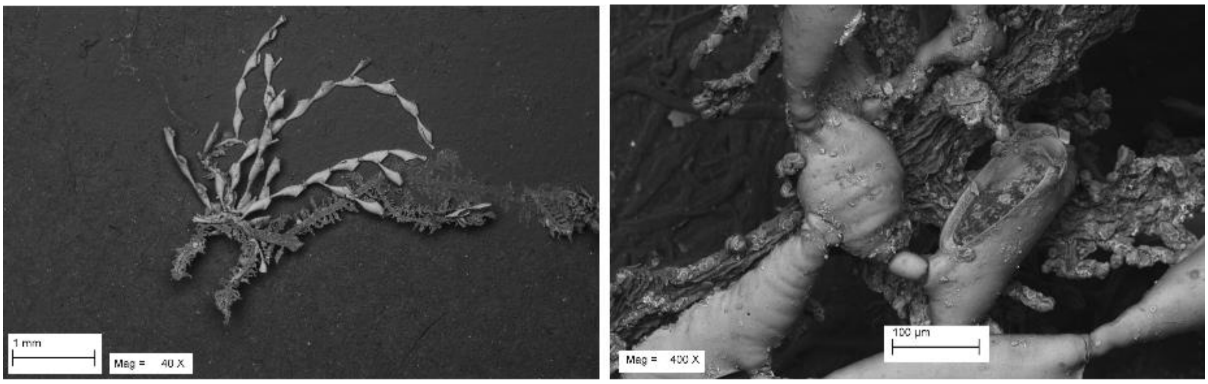


Fig 4.1. *Scruparia chelata* (Linnaeus, 1758) showing horn shaped autozooids and oval frontal membrane.

Family Eucrateidae Hincks, 1880

Eucratea loricata (Linnaeus, 1758)

Suborder Malacostegina Levinsen, 1909

Family Membraniporidae Busk, 1852

Membranipora membranacea (Linnaeus, 1767)

Jellyella tuberculata (Bosc, 1802)

Family Electridae d'Orbigny, 1851

Conopeum reticulum (Linnaeus, 1767)

Einhornia crustulenta (Pallas, 1766)

Electra monastachys (Busk, 1854)

Pyripora catenularia (Fleming, 1828)

Location: Antrim, Cork, Down, Dublin, Mayo, Wexford.

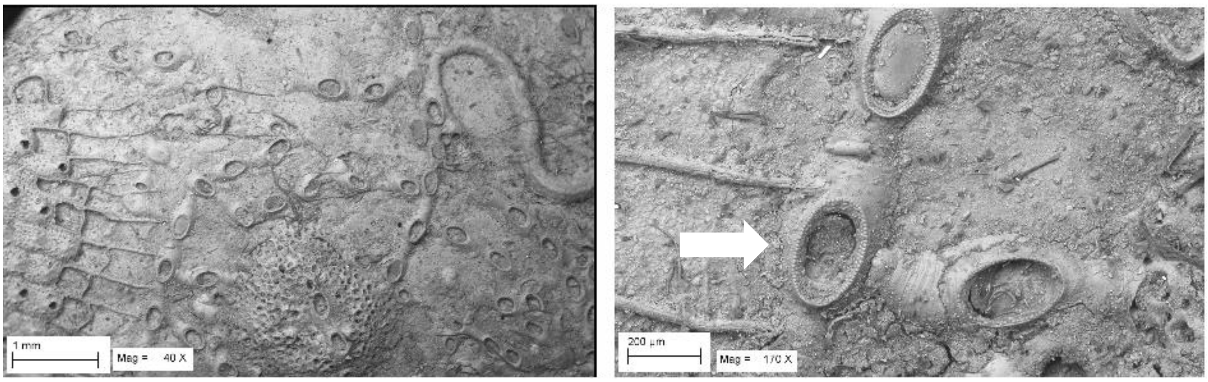


Fig 4.2. *Pyripora catenularia* (Fleming, 1828) Left: Long branching chains of autozooids. Right: Cryptocyst with narrow granular rim.

Electra pilosa (Linnaeus, 1767)

Location: Amtrim, Cork, Down, Dublin, Galway, Kerry, Mayo, Meath, Wexford.

Specimen: NHMUK 1940.11.6.1(pt)

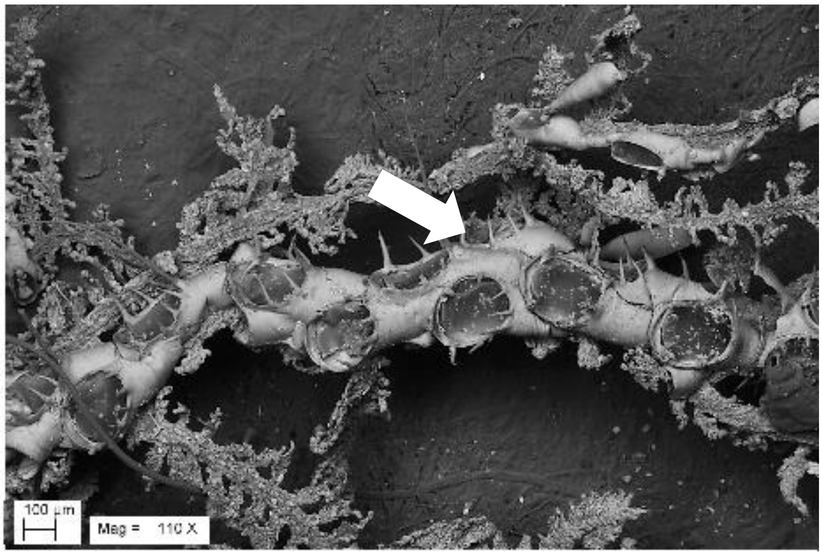


Fig 4.3 *Electra pilosa* (Linnaeus, 1767) with prominent proximal spine.

Suborder Flustrina

Superfamily Flustroidea Fleming, 1828

Family Flustridae Fleming, 1828

Carbasea carbasea (Ellis & Solander, 1786)

Chartella papyracea (Ellis & Solander, 1786)

Securiflustra securifrons (Pallas, 1766)

Hincksina flustroides (Hincks, 1877)

Terminoflustra barleei (Busk, 1860)

Flustra foliacea (Linneaus, 1758)

Location: Antrim, Cork, Derry, Down, Dublin, Galway, Meath, Wexford

Specimen: NHMUK 1899.5.1.14

Fig 4.4. *Flustra foliacea* (Linneaus, 1758) Broad palmate fronds with epizooites.

Superfamily Calloporoidea Norman, 1903

Family Calloporidae Norman, 1903

Callopora lineata (Linneaus, 1767)

Callopora rylandi Bobin & Prenant, 1965

Callopora discreta (Hincks, 1862)

Callopora dumerilii (Audouin, 1826)

Location: Antrim, Clare, Dublin, Kerry

Specimen: NHMUK Unregistered

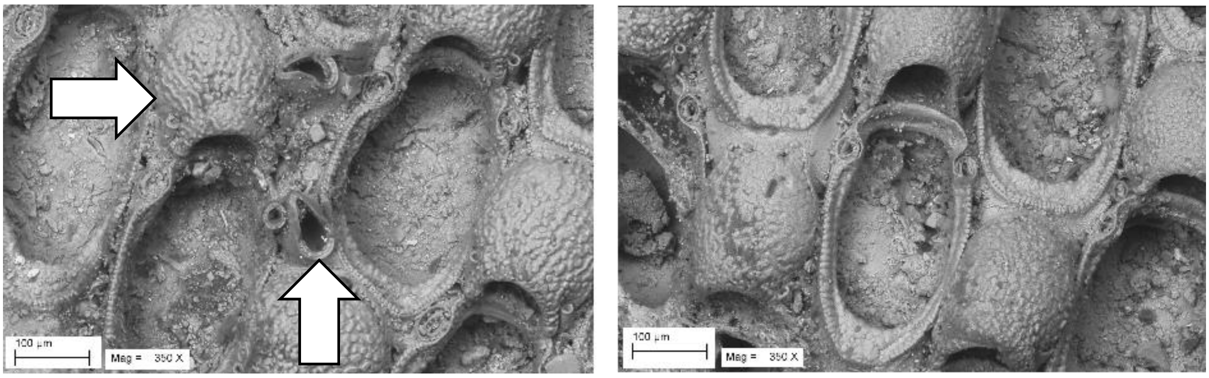


Fig 4.5. *Callopora dumerilii* (Audouin, 1826) Left: Ovicellate autozooids and avicularia.

Alderina imbellis (Hincks, 1860)

Location: Antrim, Down, Galway, Kerry, Mayo

Specimen: NMHUK 99.5.1.593

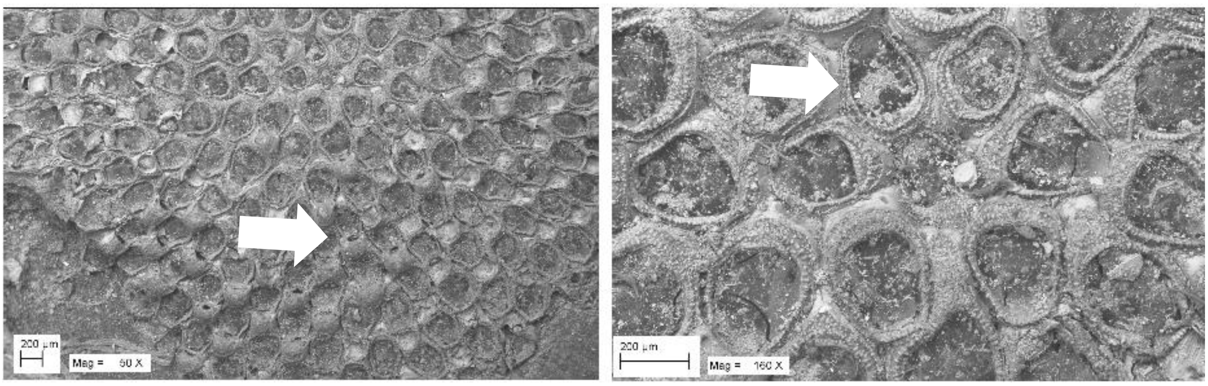


Fig 4.6. *Alderina imbellis* (Hincks, 1860) Left: Prominent globular ovicell. Right: Triplet buds of ancestrula visible in right picture.

Crassimarginatella solidula (Hincks, 1860)

Location: Antrim, Cork, Galway

Specimen: NHMUK 1899.5.1.593

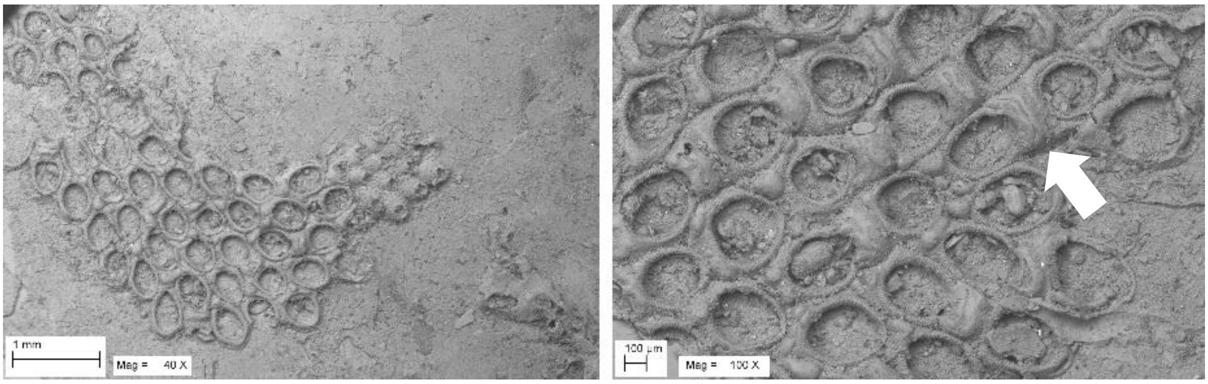


Fig 4.7. *Crassimarginatella solidula* (Hincks, 1860) Left: Irregular colony sheet separated by shallow grooves. Right: Ovicellate autozooids.

Cauloramphus spiniferum (Johnston, 1832)

Amphiblestrum auritum (Hincks, 1877)

Amphiblestrum flemingii (Busk, 1854)

Amphiblestrum solidum (Packard, 1860)

Megapora ringens (Busk, 1856)

Ammatopora nodulosa (Hincks, 1877)

Membraniporella nitida (Johnston, 1838)

Ramphonotus minax (Busk, 1860)

Family Chaperiidae Jullien, 1888

Larnacicus corniger (Busk, 1859)

Superfamily Buguloidea Gray, 1848

Family Bugulidae Gray, 1848

Bugula neritina (Linnaeus, 1758)

Bugulina flabellata (Thompson in Gray, 1848)

Bugulina avicularia (Linnaeus, 1758)

Bugulina turbinata (Alder, 1857)

Bugulina stolonifera (Ryland, 1960)

Bugulina simplex (Hincks, 1886)

Bugulella gracilis (Nichol, 1911)

Crisularia plumosa (Pallas, 1766)

Crisularia purpurotincta (Norman, 1868)

Dendrobeania murrayana (Bean in Johnston, 1847)

Bicellariella ciliata (Linnaeus, 1758)

Bicellarina alderi (Busk, 1859)

Kinetoskias smitti Danielssen, 1868

Family Beaniidae Canu & Bassler, 1927

Beania mirabilis Johnston, 1840

Family Candidae d'Orbigny, 1851

Caberea boryi (Audouin, 1826)

Caberea ellisii (Fleming, 1814)

Notoplites jeffreysii (Norman, 1868)

Scrupocellaria reptans (Linnaeus, 1767)

Scrupocellaria scrupea Busk, 1852

Scrupocellaria scruposa (Linnaeus, 1758)

Cradoscrupocellaria ellisii (Vieira & Spencer, 2012)

Pomocellaria inarmata (O'Donoghue & O'Donoghue, 1926)

Tricellaria inopinata d'Hondt & Occhipinti Ambrogi, 1985

Location: Dublin

Specimen: M15 Authors collection

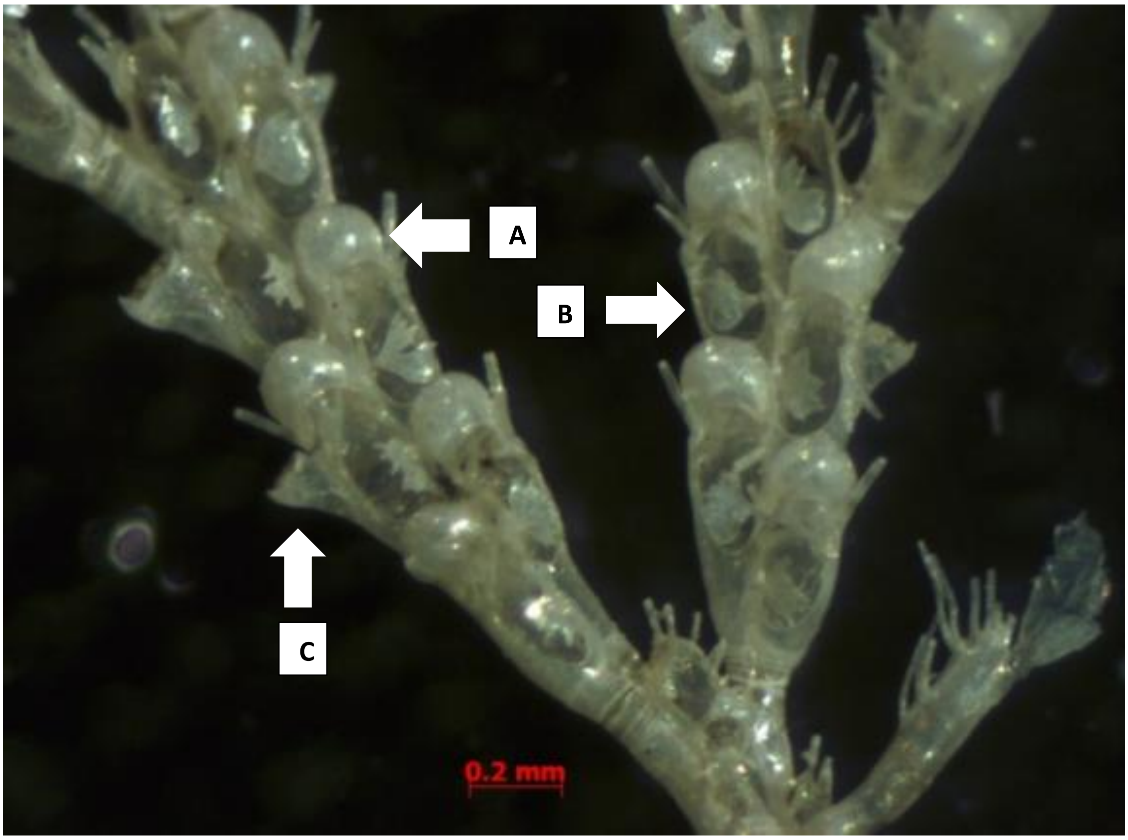


Fig 4.7. *Tricellaria inopinata* d'Hondt & Occhipinti Ambrogi, 1985. A, Ooecia. B, Irregular shaped scutum. C, Small proximally directed avicularia.

Superfamily Microporoidea Gray, 1848

Family Microporidae Gray, 1848

Micropora coriacea (Johnston, 1847)

Micropora normani Levinsen, 1909

Roseliana rosselii (Audouin, 1826)

Family Aspidostomatidae Jullien, 1888

Aspidostoma giganteum (Busk, 1854)

Superfamily Cellarioidea Lamouroux, 1821

Family Cellariidae

Cellaria fistulosa (Linnaeus, 1758)

Cellaria salicirniodes Lamouroux, 1816

Cellaria sinuosa (Hassall, 1840)

Superfamily Cribrilinoidea Hincks, 1879

Family Cribrilinidae Hincks, 1879

Cribrilina annulata (Fabricius, 1780)

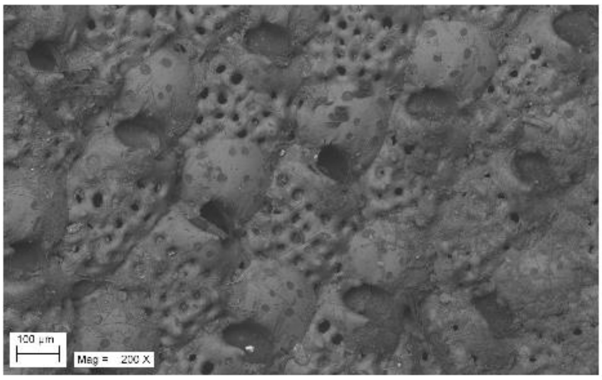
Cribrilina cryptooecium Norman, 1903

Cribrilaria radiata (Moll, 1803)

Cribrilina punctata (Hassall, 1841)

Location: Antrim, Cork, Down, Dublin, Galway, Mayo, Wexford.

Specimen: NHMUK 1899.7.1.1343



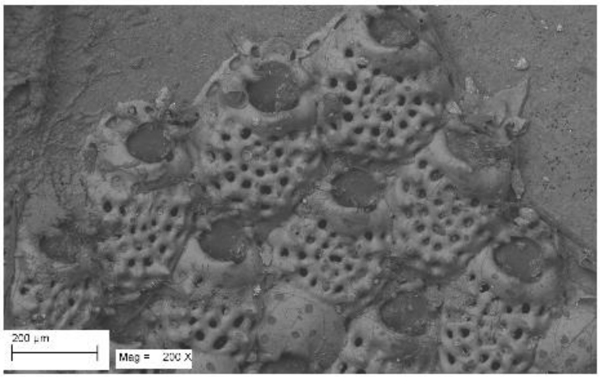


Fig 4.8. *Cribrilina punctata* (Hassall, 1841)

Collarina balzaci (Audouin, 1826)

Location: Down, Galway

Specimen: NHMUK 1911.10.1.690

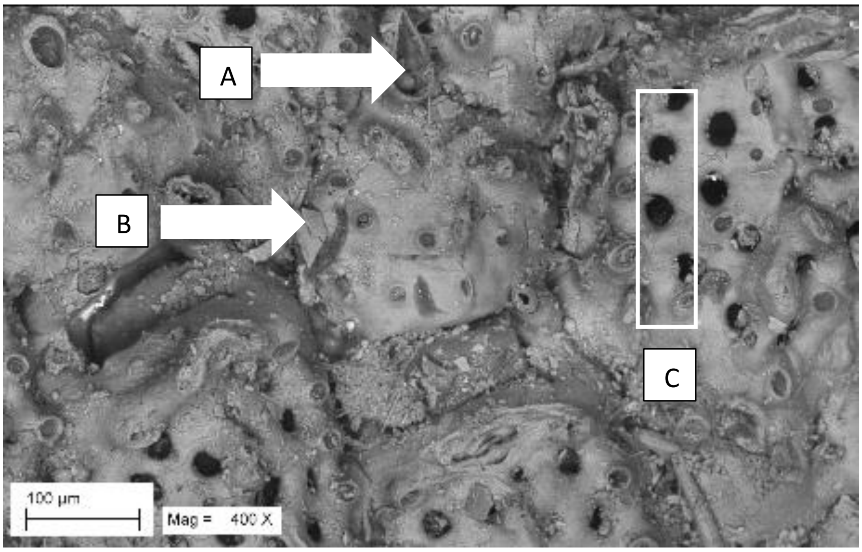


Fig 4.9. *Collarina balzaci* (Audouin, 1826). A, Distal avicularia on ovicell. B, Punctulated ovicell. C, Tuberculate pseudopore at the base of each costa.

Cribrilaria innominata (Couch, 1844)

Location: Antrim

Specimen: NHMUK 1899.5.1.723

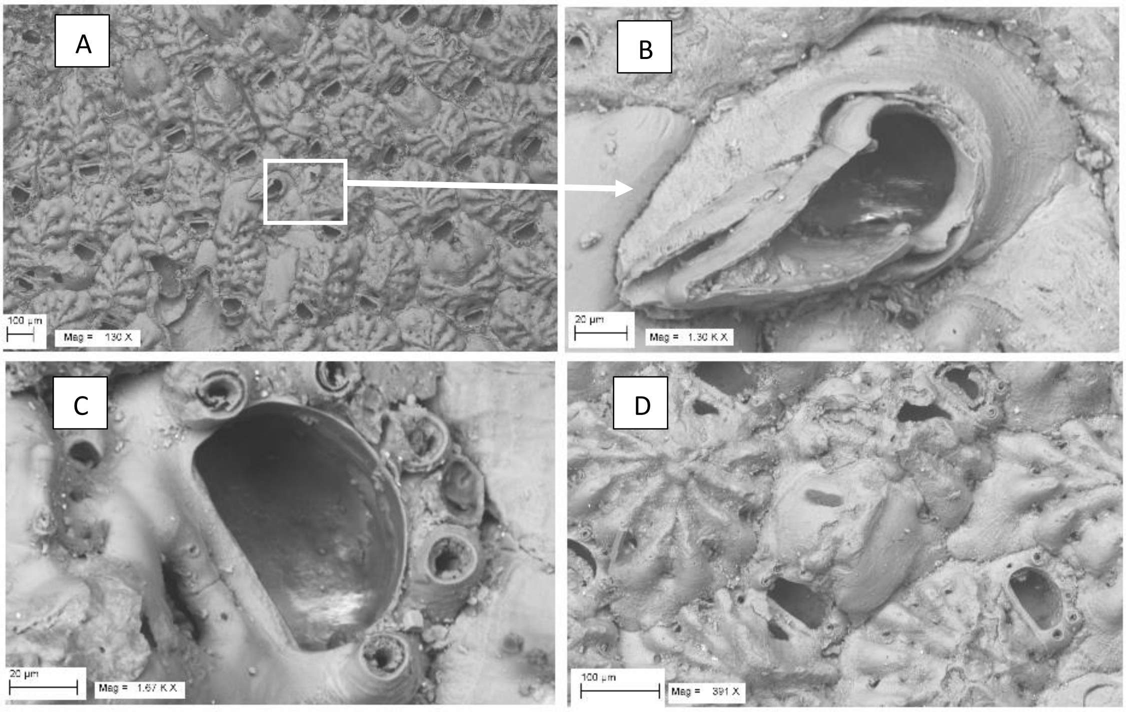


Fig. 4.10. *Cribrilaria innominata* (Couch, 1844). A, Part of colony with ovicells and avicularia. B, Avicularia with elongate triangular mandible. C, Orifice D-shaped with 5 oral spines. D, Ovicell with median umbo.

Puellina radiata (Moll, 1893)

Puellina gattyae (Landsborough, 1852)

Puellina setosa (Waters, 1899)

Figularia figularis (Johnston, 1847)

Location: Antrim, Galway

Specimen: NMHUK 1911.10.1.690t

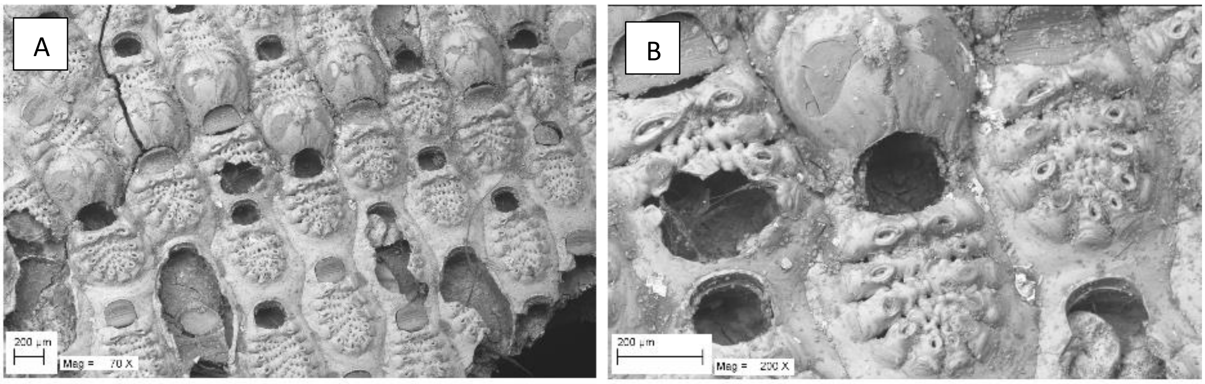


Fig. 4.11. *Figularia figularis* (Johnston, 1847). A, Part of colony with autozooids sepatated by shallow grooves. B, Ovicellate autozooids with globular ovicell and median umbo.

Superfamily Hippothooidea Busk, 1859

Family Hippothoidae Busk, 1859

Hippothoa divaricata Lamouroux, 1821

Hippothoa flagellum Manzoni, 1870

Hippothoa distans MacGillivray, 1869

Celleporella hyalina (Linnaeus, 1767)

Family Haplopomidae Gordon in De Blauwe, 2009

Haplopoma graniferum (Johnston, 1847)

Haplopoma impressum (Audouin, 1826)

Haplopoma bimucronatum (Moll, 1803)

Family Chorizoporidae Vigneaux, 1949

Chorizopora brongniartii (Audouin, 1826)

Location: Antrim, Cork, Clare, Mayo, Wexford.

Specimen: NHMUK 1988.5.1.851

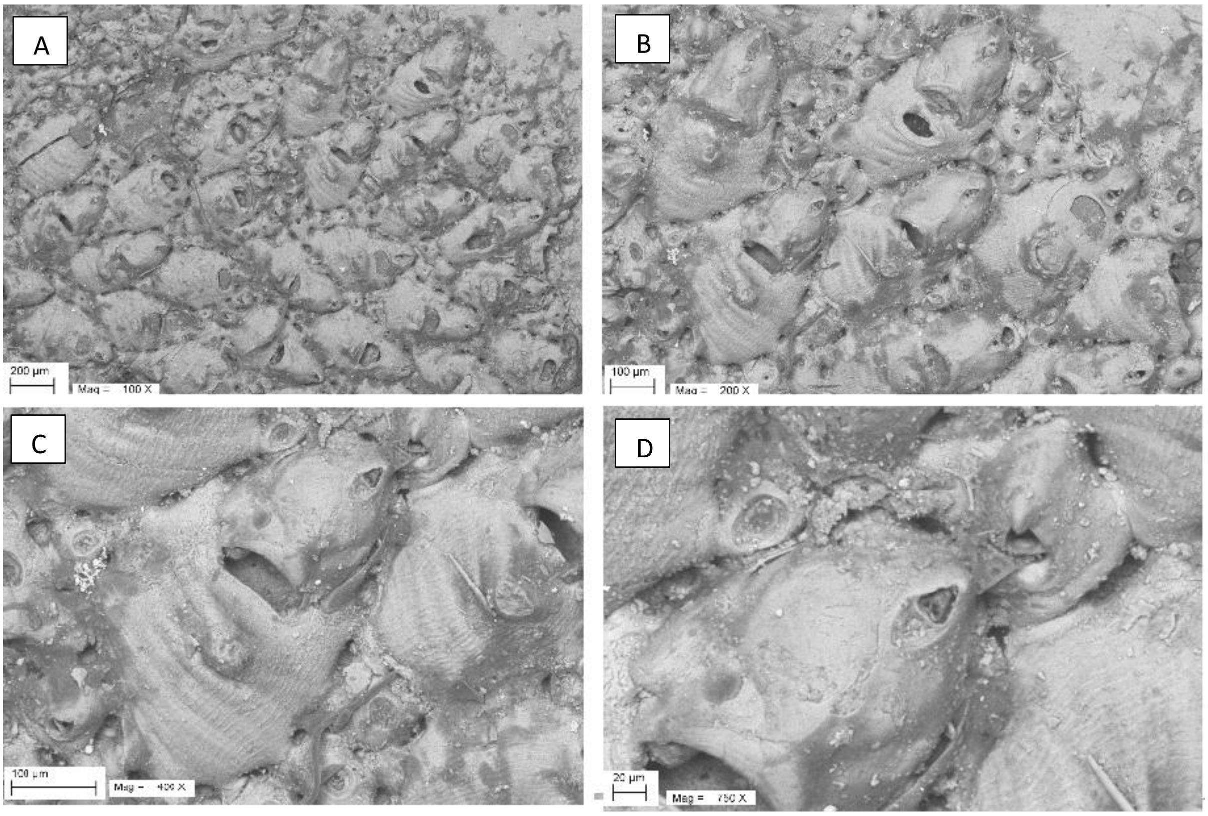


Fig 4.12. *Chorizopora brongniartii* (Audouin, 1826). A, Part of colony. B, Ovicellate autozooids. C, Conical frontal umbo. D, Prominent ovicell with longitudinal frontal ridge and distal avicularium.

Superfamily Lepralielloidea Vigneaux, 1949

Family Lepraliellidae Vigneaux, 1949

Celleporaria vagans (Busk, 1881)

Family Umbonulidae Canu, 1904

Oshurkovia littoralis (Hastings, 1944)

Umbonula ovicellata Hastings, 1944

Family Exochellidae Bassler, 1935

Escharoides coccinea (Abildbaard, 1806)

Escharoides mamillata (Wood, 1844)

Family Romancheinidae Jullien, 1888

Escharella immersa (Fleming, 1828)

Location: Antrim, Cork, Dublin, Down, Kerry, Mayo Wexford.

Specimen: NHMUK 1899.5.1.593

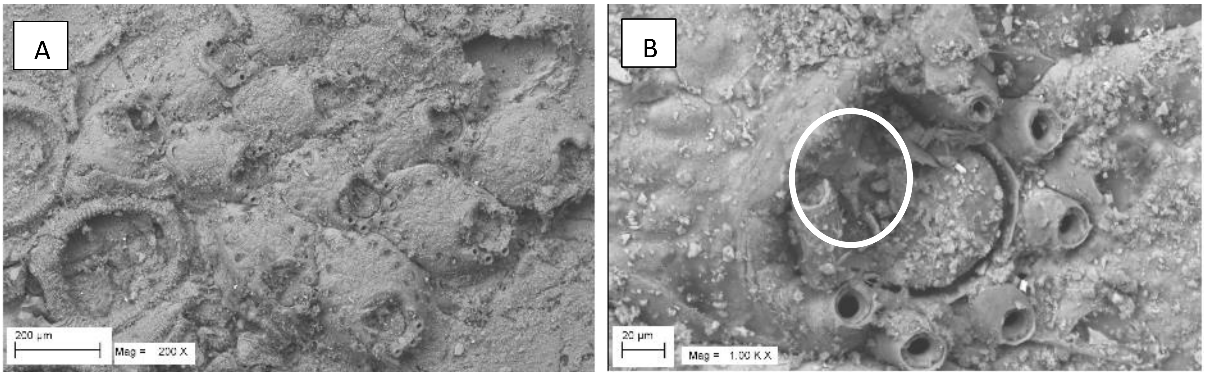


Fig. 4.13. *Escharella immersa* (Fleming, 1828). A. Part of colony. B, Orivice with six oral spines and anvil-shaped lyrula (circled).

Escharella labiosa (Busk, 1856)

Escharella laquenata (Norman, 1864)

Escharella ventricosa (Hassall, 1842)

Escharella abyssicola (Norman, 1869)

Escharella octodentata (Hincks, 1880)

Hemicyclopora multispinata (Busk, 1861)

Hemicyclopora polita (Norman, 1864)

Temachia microstoma (Norman, 1864)

Escharella variolosa (Johnston, 1838)

Location: Clare, Cork, Galway, Down, Dublin, Mayo Wexford.

Specimen: NHMUK 1899.7.1.1820

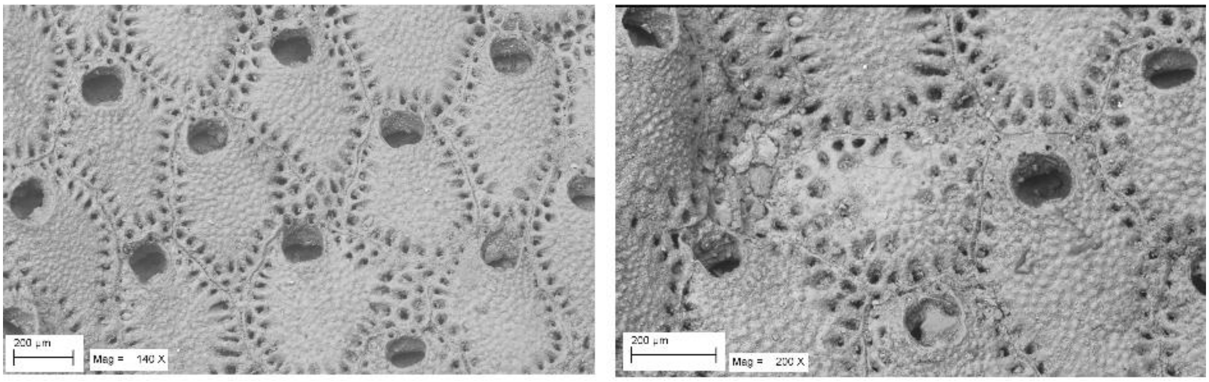


Fig. 4.14. *Escharella variolosa* (Johnston, 1838)

Neolagenipora collaris (Norman, 1867)

Location: Down, Antrim

Specimen: NMHUK 1911.10.1.1547A

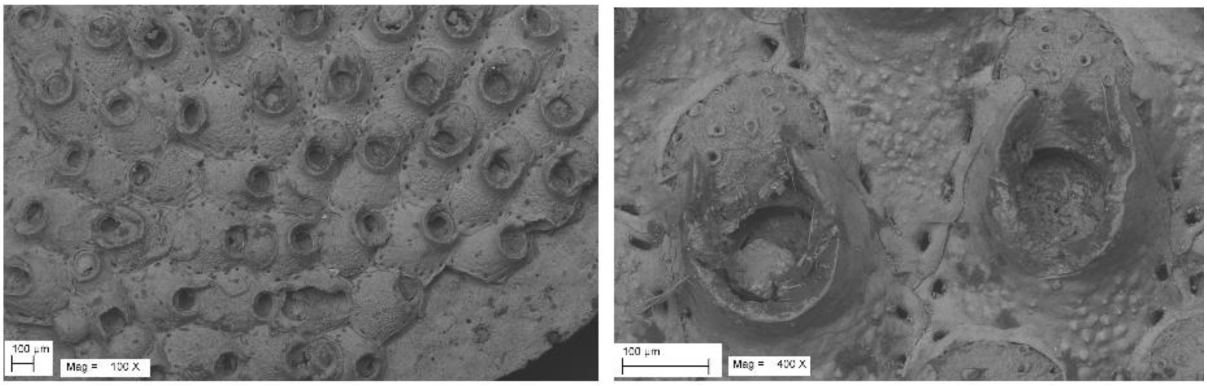


Fig. 4.15. *Neolagenipora collaris* (Norman, 1867)

Neolagenipora eximia (Hincks, 1860)

Location: Down, Galway

Specimen: NHMUK 1899.5.1.851

Remarks: Type specimen

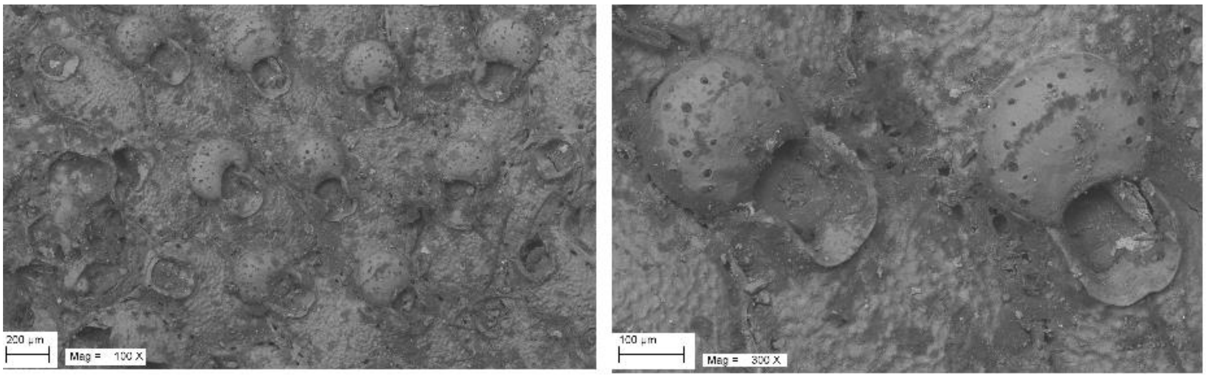


Fig. 4.16. *Neolagenipora eximia* (Hincks, 1860)

Family Bryocryptellidae Vigneaux, 1949

Porella concinna (Busk, 1854)

Location: Antrim, Cork, Derry, Down, Galway, Mayo.

Specimen: NMHUK 1899.7.1.2049

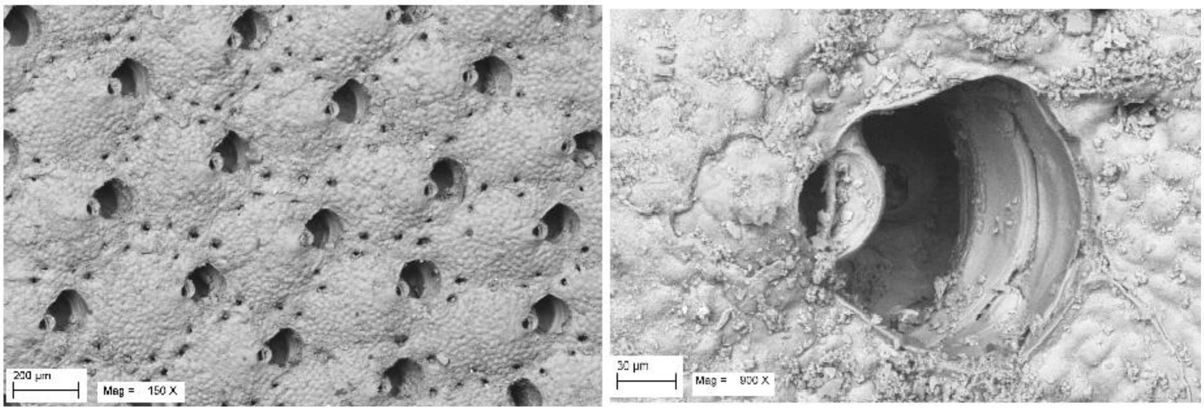


Fig. 4.17. *Porella concinna* (Busk, 1854)

Porella compressa (Sowerby, 1805)

Porella minuta (Norman, 1868)

Porella struma (Norman, 1868)

Palmiskenea skenei (Ellis & Solander, 1786)

Family Tessaradomidae Jullien, 1903

Tessaradoma boreale (Busk, 1860)

Superfamily Arachnopusioidea Jullien, 1888

Family Exechonellidae Harmer, 1957

Anarthropora monodon (Busk, 1860)

Superfamily Adeonoidea Busk, 1884

Family Adeonidae

Reptadeonella violacea (Johnston, 1847)

Superfamily Schizoporelloidea Jullien, 1883

Family Cryptosulidae Vigneaux, 1949

Cryptosula pallasiana (Moll, 1803)

Location: Antrim, Cork, Dublin, Galway, Kerry, Mayo, Meath, Wexford

Specimen: W18 Authors collection

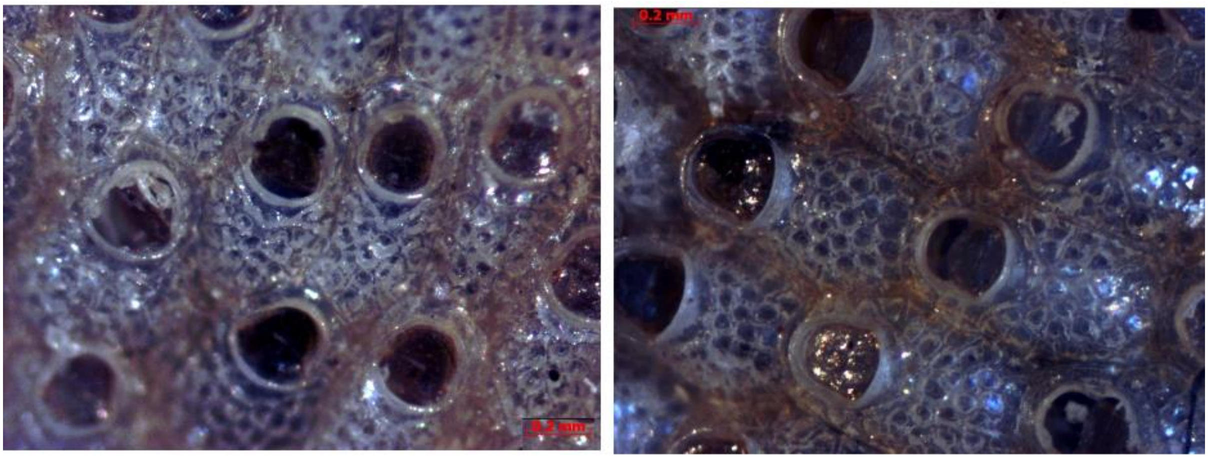


Fig. 4.18. *Cryptosula pallasiana* (Moll, 1803)

Family Schizoporellidae Jullien, 1883

Schizoporella unicornis (Johnston in Wood, 1844)

Location: Antrim, Cork, Down, Dublin, Galway, Kerry, Mayo, Wexford.

Specimen: NHMUK 1899.7.1.2408

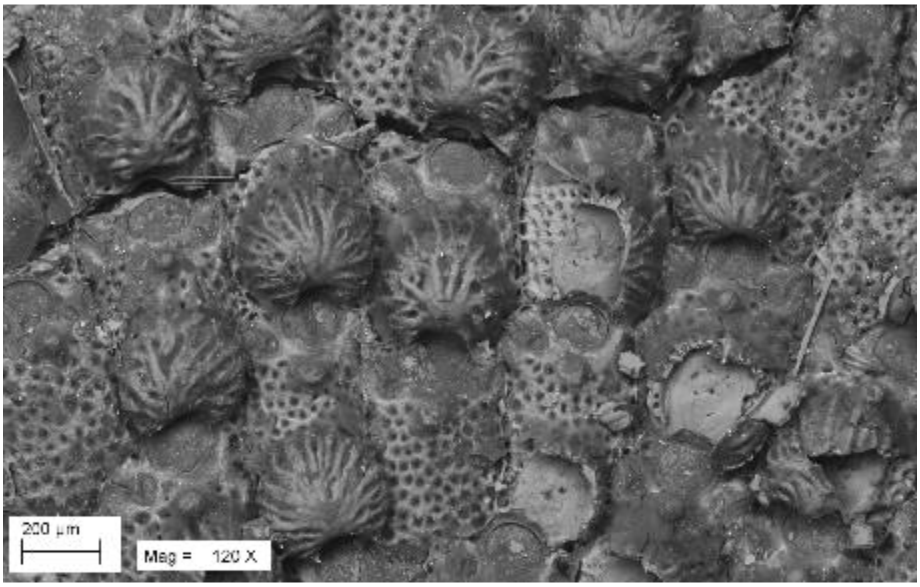


Fig 4.19. *Schizoporella unicornis* (Johnston in Wood, 1844)

Schizoporella dunkerii (Reuss, 1848)

Schizoporella japonica Ortmann, 1890

Schizobrachiella sanguinea (Norman, 1868)

Anthropoma cecilii (Audouin, 1826)

Family Cheiloporinidae Bassler, 1936

Hagiosyndos latus (Busk, 1856)

Cheiloporina circumcinta (Neviani, 1896)

Family Escharinidae Tilbrook, 2006

Escharina dutertrei haywardi Zabala, Maluquer and Harmelin, 1993

Escharina vulgaris (Moll, 1803)

Herentia hyndmanni (Johnston, 1847)

Escharina johnstoni (Quelch, 1884)

Location: Antrim, Down

Specimen: NHMUK 1899.5.1.593

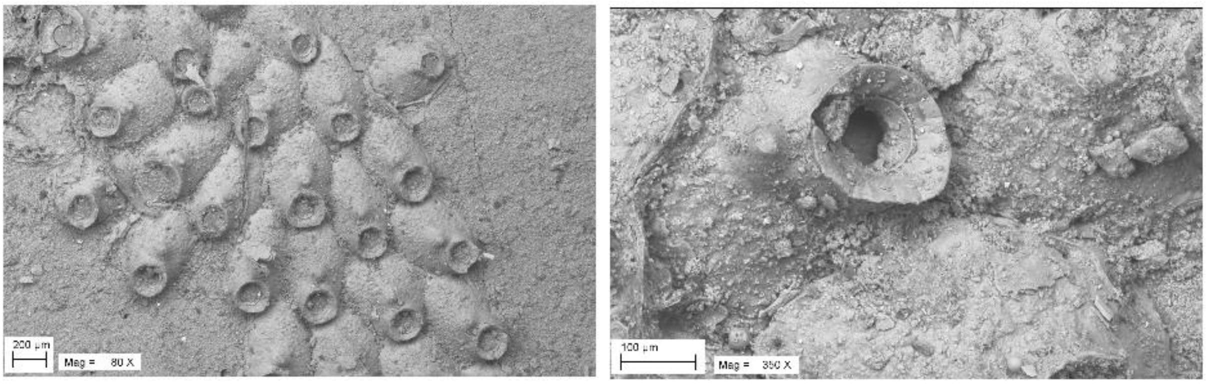


Fig. 4.20. *Escharina johnstoni* (Quelch, 1884)

Phaeostachys spinifera (Johnston, 1847)

Location: Antrim, Cork, Down, Dublin Mayo.

Specimen: NHMUK 1911.10.1.117

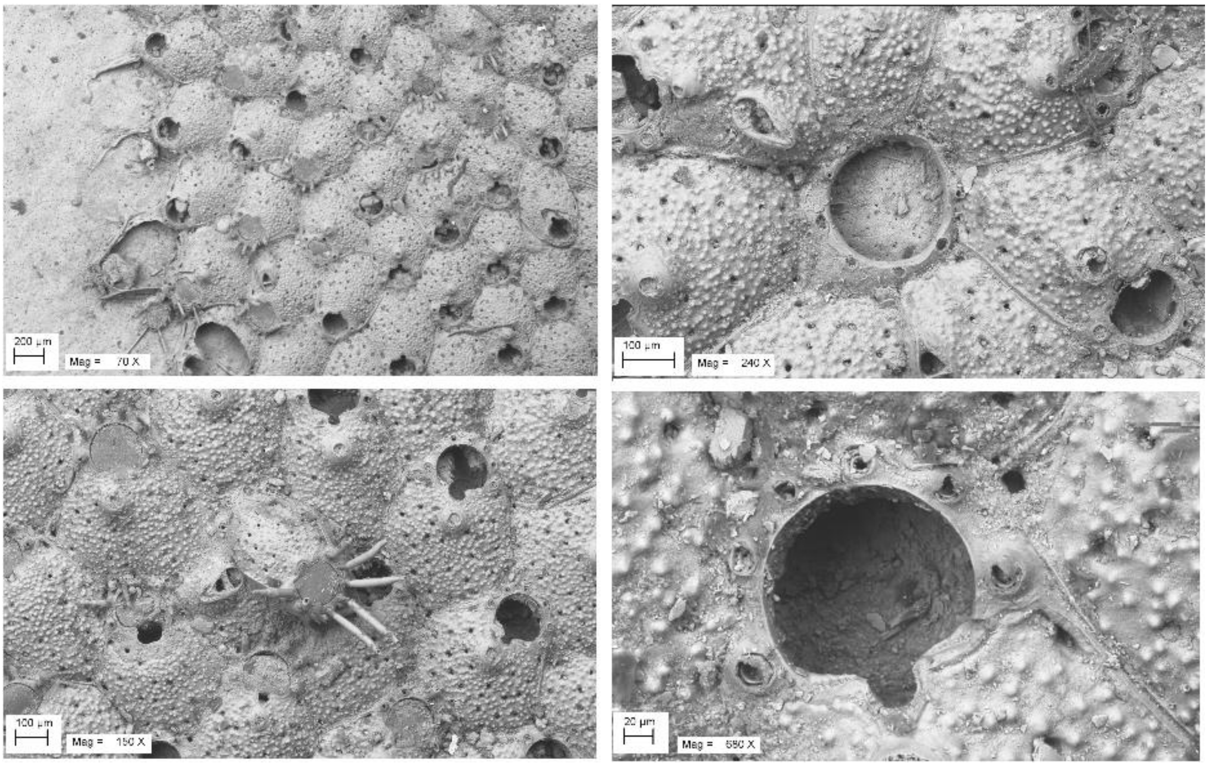


Fig. 4.21. *Phaeostachys spinifera* (Johnston, 1847)

Family Microporellidae Hincks, 1879

Diporula verrucosa (Peach, 1868)

Microporella ciliata (Pallas, 1766)

Fenestrulina malusii (Audouin, 1826)

Location: Antrim, Clare, Down, Dublin, Galway, Kerry, Mayo, Wexford.

Specimen: NHMUK 1899.5.1.851

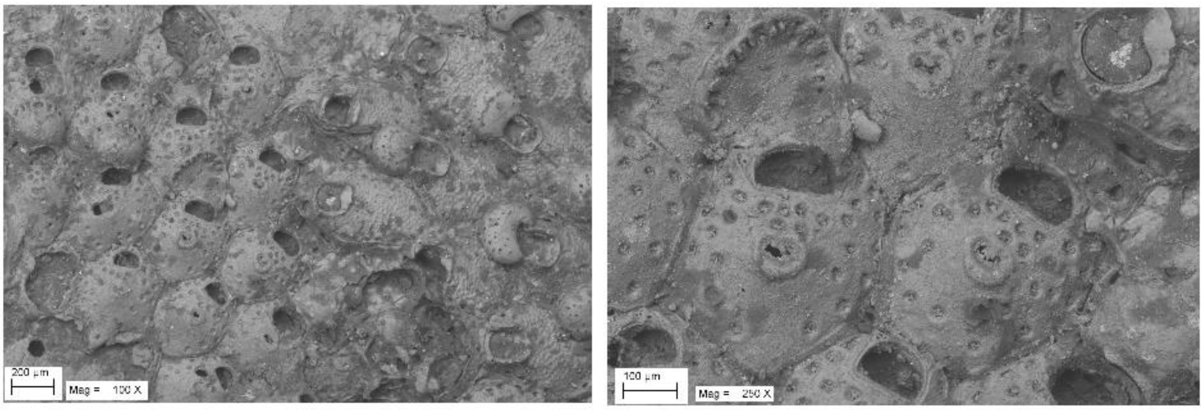


Fig. 4.22. *Fenestrulina malusii* (Audouin, 1826)

Superfamily Smittinoidea Levinsen, 1909

Family Bitechiporidae MacGillivray, 1895

Schizomavella (Calvetomavella) discoidea (Busk, 1859)

Schizomavella (Schizomavella) linearis (Hassall, 1841)

Schizomavella (Schizomavella) auriculata (Hassell, 1842)

Schizomavella (Schizomavella hastata (Hincks, 1862)

Pentapora fascialis (Pallas, 1766)

Pentapora foliacea (Ellis & Solander, 1786)

Family Smittinidae Levinsen, 1909

Smittina landsborovii (Johnston, 1847)

Smittina cervicornis (Pallas, 1766)

Smittina bella (Busk, 1860)

Smittoidea reticulata (MacGillivray, 1842)

Parasmittina trispinosa (Johnston, 1838)

Phylactella labrosa (Busk, 1854)

Prenantia cheilostoma (Manzoni, 1869)

Location: Cork

Specimen: NHMUK 1899.5.1.897

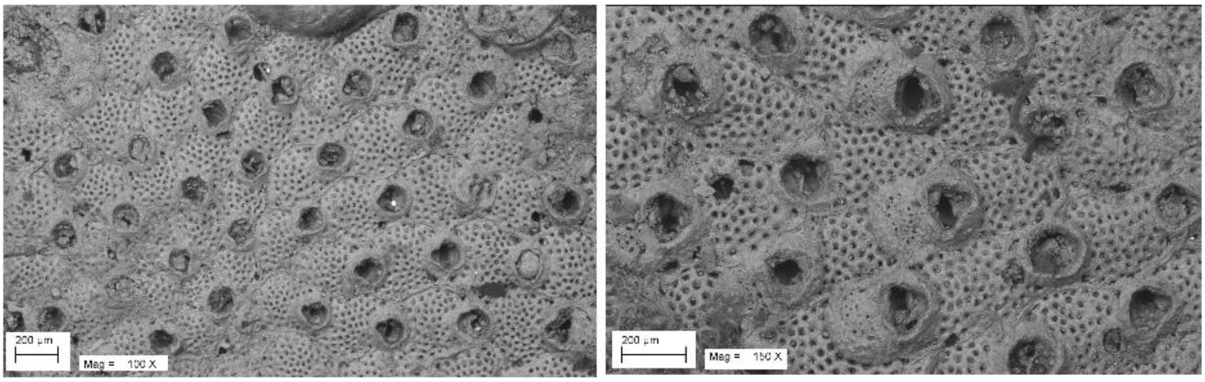


Fig.4.23. *Prenantia cheilostoma* (Manzoni, 1869)

Family Watersiporidae Vigneaux, 1949

Watersipora subatra (Ortmann, 1890)

Location: Dublin

Specimen: M11 Authors collection

Fig. 4.24. *Watersipora subatra* (Ortmann, 1890)

Superfamily Celleporoidea Johnston, 1838

Family Celleporidae Johnston, 1838

Buskea dichotoma (Hincks, 1862)

Cellepora pumicosa (Pallas, 1766)

Celleporina costazii (Audoun, 1826)

Celleporina caliciformis (Lamouroux, 1816)

Celleporina decipiens Hayward, 1976

Celleporina tubulosa (Hincks, 1880)

Lagenipora lapralioides (Norman, 1868)

Omalosecosa ramulosa (Linnaeus, 1767)

Osthimosia eatonensis (Busk, 1881)

Palmicellaria aviculifera Canu & Bassler, 1928

Turbicellepora avicularis (Hincks, 1860)

Location: Antrim, Cork, Down, Dublin, Galway, Kerry, Mayo, Meath.

Specimen: 1890.4.15.46-47

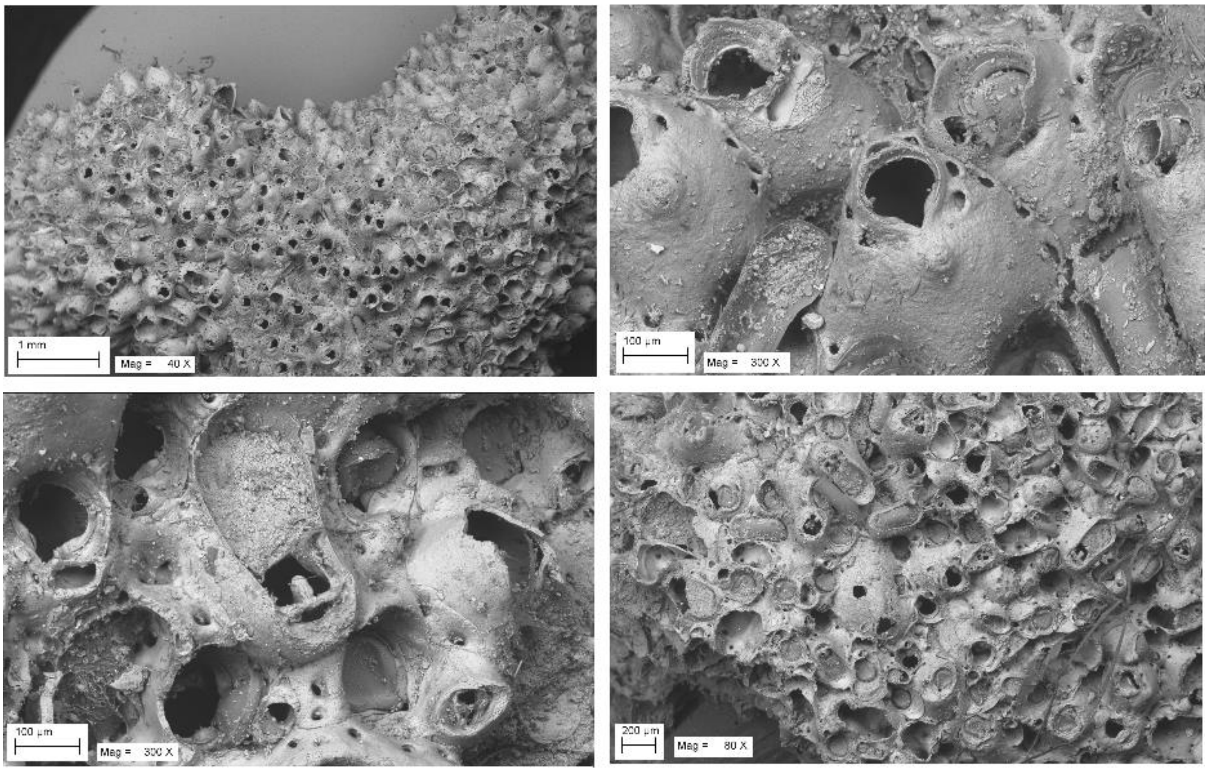


Fig. 4.25. *Turbicellepora avicularis* (Hincks, 1860)

Turbicellepora armata (Hincks, 1860)

Turbicellepora boreale Hayward & Hansen, 1999

Turbicellepora avicularis (Hincks, 1860)

Family Hippoporidridae Vigneaux, 1949

Hippoporidra lusitania Taylor & Cook, 1891

Family Phidoloporidae Gabb & Horn, 1862

Schizotheca fissa (Busk, 1856)

Schizotheca divisa (Norman, 1864)

Rhynchozoon bispinosum (Johnston, 1847)

Reteporella couchii (Hincks, 1878)

Reteporella grimaldii (Jullien, 1903)

Reteporella beaniana (King, 1846)

Order Ctenostomatida Busk, 1852

Suborder Alcyonidiina Busk, 1852

Infraorder Alcyonidioidea Johnston, 1838

Family Alcyonidiidae Johnston, 1838

Alcyonidioides mytili (Dalyell, 1848)

Alcyonidium albidum Alder, 1857

Alcyonidium diaphanum (Hudson, 1778)

Alcyonidium mammillatum Alder, 1857

Alcyonidium gelatinosum (Linnaeus, 1761)

Alcyonidium hirsutum (Fleming, 1828)

Alcyonidium parasiticum (Fleming, 1828)

Suborder Flustrellidrina

Superfamily Flustrellidroidea

Family Flustrellidridae Bassler, 1953

Flustrellidra hispida (O. Fabricius, 1780)

Suborder Stoloniferina Ehlers, 1876

Superfamily Aeverrillioidea d’Hondt

Family Farrellidae d’Hondt, 1983

Farella reptans (Farre, 1837)

Superfamily Arachnidioidea Hincks, 1880

Family Arachnidiidae Hinck, 1880

Arachnidium simplex Hincks, 1880

Arachnidium fabrosum Hincks, 1880

Superfamily Penetrantioidea Silén, 1946

Family Penetrantiidae Silén, 1946

Penetrantia densa Silén, 1946

Superfamily Triticelloidea Sars, 1873

Family Tritcellidae Sars, 1873

Triticella flava Dalyell, 1848

Triticella pedicellata (Alder, 1857)

Superfamily Walkerioidea Hincks, 1880

Family Walkeriidae Hinck, 1880

Walkeria tremula Hinck, 1862

Walkeria uva (Linnaeus, 1758)

Family Hypophorellidae Prenant & Bobin, 1956

Hypophorella expansa Ehlers, 1876

Suborder Vesicularina Hincks, 1880

Superfamily Vesicularioidea Hincks, 1880

Family Vesiculariidae Hincks, 1880

Amathia lendigera (Linnaeus, 1758)

Amathia imbricata (Adams, 1798)

Amathia pustulosa (Ellis & Solander, 1786)

Amathia citrina (Hincks, 1877)

Amathia gracilis (Leidy, 1855)

Vesicularia spinosa (Linnaeus, 1758)

Suborder Victorellina Jebram, 1973

Superfamily Victorelloidea Hincks, 1880

Family Nolellidae Harmer, 1915

Nolella dilatata (Hincks, 1860)

Class Stenolaemata Borg, 1926

Order Cyclostomatida Busk, 1852

Suborder Articulina

Family Crisiidae Johnston, 1838

Crisia eburnea (Linnaeus, 1758)

Crisia ramosa Harmer, 1891

Crisia aculeata Hassall, 1841

Crisia denticulata (Lamarck, 1816)

Crisidia cornuta (Linnaeus, 1758)

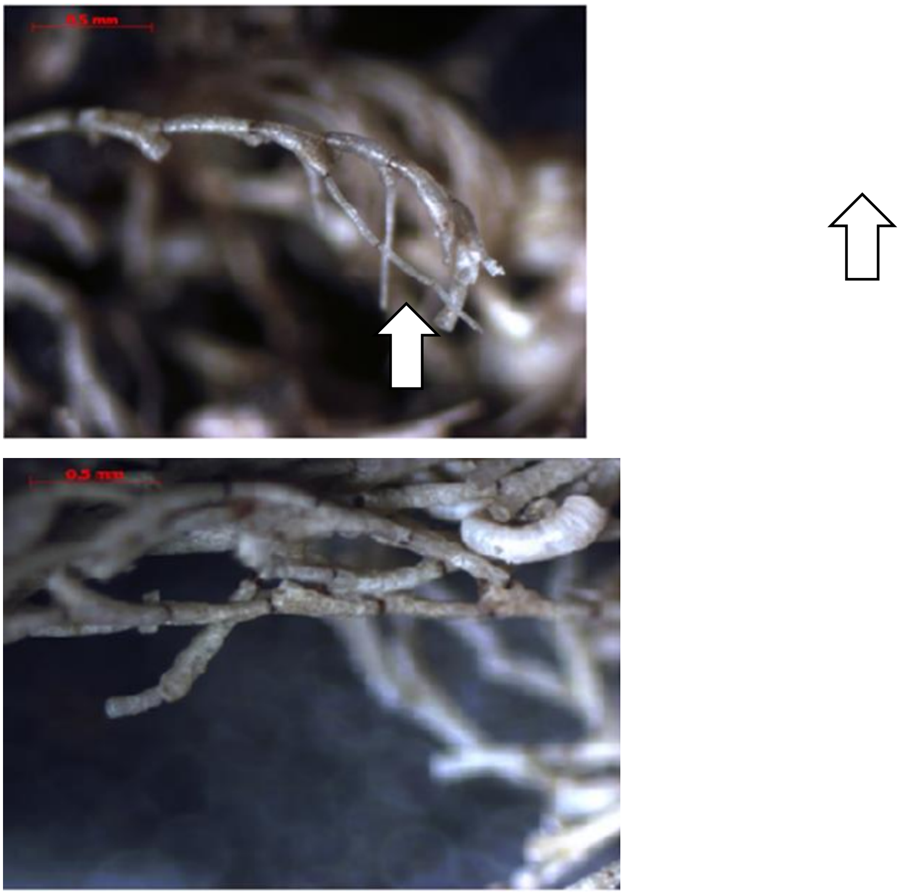


Fig 4.26 *Crisidia cornuta* (Linnaeus, 1758) Photo with arrows indicating the curved spines and joints.

Filicrisia genticulata (Milne Edwards, 1838)

Suborder Cancellata

Family Horneridae Smitt, 1867

Hornera lichenoides (Linnaeus, 1758)

Hornera foliacea (MacGillvray, 1869)

Hornera frondiculata (Lamarck, 1816)

Family Stigmatoechidae Brood, 1972

Stigmatoechos violacea (M. Sars, 1863)

Suborder Fasciculina

Family Frondiporidae Busk, 1875

Filifascigera fascicultа (Hincks, 1880)

Frondipora verrucosa (Lamouroux, 1821)

Suborder Rectangulata

Family Lichenoporidae Smitt, 1867

Coronopora truncata (Fleming, 1828)

Patinella verrucaria (Linnaeus, 1758)

Patinella radiata (Audouin, 1826)

Disporella hispida

Location: Antrim, Cork, Dublin, Kerry, Galway, Mayo, Meath, Wexford

Specimen: NMHUK 1911.10.1.1547A

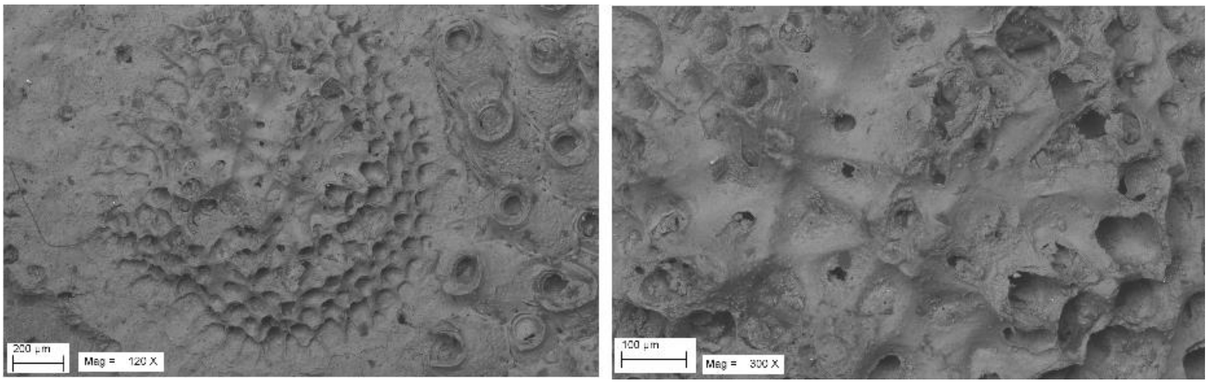


Fig. 4.27. *Disporella hispida* (Fleming, 1828)

Suborder Tubuliporina

Family Annectocymidae Hayward & Ryland, 1985

Annectocyma major (Johnston, 1847)

Entalophoroecia deflexa (Couch, 1842)

Family Oncousoeciidae Canu, 1918

Oncousoecia dilitans (Johnston, 1847)

Oncousoecia diastoporides (Norman, 1896)

Family Plagioeciidae Canu, 1918

Diplosolen obelium (Johnston, 1838)

Plagioecia patina (Lamarck, 1816)

Plagioecia sarniensis (Norman, 1864)

Family Stomatoporidae Pergens & Meunier, 1886

Stomatoporina incurvata (Hincks, 1859)

Family Tubuliporidae Johnston, 1838

Exidmonea atlantica (Forbes in Johnston, 1847)

Tubulipora liliacea (Pallas, 1766)

Tubulipora flabellaris (Fabricius, 1780)

Tubulipora plumosa Thompson in Harmer, 1898

Tubulipora expansa (Packard, 1863)

Tubulipora lobifera Hastings, 1963

Tubulipora phalangea Couch, 1844

Penciletta penicillata (Fabricius, 1780)

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Chapter 5

Non-indigenous and invasive Bryozoa in Ireland

Contents

Abstract

Europe has exhibited an increase in marine non-indigenous species (NIS) recently (Tsiamis *et al. 2018).* In recent years an increased number of non-indigenous aquatic species such as the Asian clam (*Corbicula fluminea*), Bloody-red shrimp (*Hemimysis anomala*) and the fish Chub (*Squalius cephalus*) have been recorded in Ireland and are now established (ISI 2019). Four invasive bryozoan species have been discovered in Ireland during bryozoan surveys that have been carried out from 2011-2015. *Watersipora subatra* (Ortmann, 1890), *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985 and *Bugula neritina* (Linnaeus, 1758) were discovered in Dun Laoghaire marina, Dublin during this time and the presence of *Schizoporella japonica* Ortmann, 1890 has recently been recorded by Loxton *et al.* (2017). The presence of these species primarily within marina locations suggests that they have been spread via shipping activities by attaching to boat hulls and boating equipment. Very little research has been carried out on Ireland's non-indigenous bryozoans and this chapter will assess the relevant literature and records from 43 sites around Ireland which were surveyed on dates in 2011-2015. Significant legislation which protects the biodiversity in Ireland's Marine environment is in place which requires non-indigenous species to be monitored and any impacts they may cause needs to be assessed.

5.1 Introduction

Continents, temperature gradients, water currents and substrate availability are no longer the natural barriers they once were in the defence against the spread of non-indiginous species (NIS) in marine ecosystems (Carlton 1996). In Europe there is a growing concern about the number of non-native species being reported (Commission of European Communities 2008). Legislation such as EC Directive 2008/56/EC (EC 2008), the biodiversity strategy (EC 2014), the convention on biological diversity (CBD 2014) and the assigning of locations as Special Protected Areas (SPA) or RAMSAR sites are in place to achieve the ultimate aim of maintaining biodiversity. As part of the EU, Ireland is also subject to these directives but dispite this, there have been increasing numbers of aquatic NIS which have been reported around Ireland in recent years (ISI 2019). Not all NIS will negatively affect the community they are present in (Bruno *et al.* 2005), but a small number can have a detrimental effect on the native biodiversity of the ecosystem in which they occur (Carlton and Geller 1993; Caffrey *et al.* 2011, Loxton *et al.* 2017) and could potentially change the community structure and function and potentially modify the food chain of a habitat (Vitousek 1990, Pratt and Grason 2007).

Globally the cost to biodiversity due to the introduction and spread of invasive species can amount to millions of euro per annum (Oreska and Aldridge 2011) and damage can be caused to marine infrastructures and resources such as aquaculture and fisheries (Bax *et al.* 2003). In Ireland it has been estimated that there is a direct annual loss of over 200 million to Ireland's economy (NPWS 2017). This is obviously problematic, but it is also worth recognizing that although aquaculture has suffered, aquaculture related activities have been important drivers in the spread of NIS in the past (Savini *et al.* 2010). *Crassostrea gigas* is a commonly imported oyster into many European countries for aquaculture purposes. This oyster has brought with it unwanted NIS such as *Watersipora subatra* (Ryland *et al.* 2009) which can quickly change the ecosystem dynamics of an area.

While habitat destruction is considered the greatest threat to biodiversity (Fahrig 2003, Klausmeier 1998, Tittensor *et al.* 2010), competition from NIS constitutes a serious threat to native species (Bax *et al.* 2003). Ryland *et al.* (2009a) discovered that the non-indigenous bryozoan *Watersipora subatra* spread from the oyster beds where it originated from to nearby areas and dominated the available rocky substratum with 80% coverage over a 5 year period in St-Jacut de la Mer, France (Ryland *et al.* 2009a, 2011). As with most NIS introductions, this introduction was unintentional and resulted in a quick alteration to the biodiversity of this location.

Harbours, ports and marina are now often used as locations in targeted surveys as they are recognized as being significant primary introduction sites (Bishop *et al.* 2015, Cook *et al.* 2013, Kelso & Wyse Jackson 2012). Pontoons and other man-made surfaces in these ports and marinas often act as a suitable alternative environment to both native and non-native biota with a notable alteration of species composition often recorded. Marine surveys have discovered that quite often, the species found on man made surfaces are non-native species (Glasby & Connell 2001, Arena *et al.* 2006, Kelso & Wyse Jackson 2012). A number of factors have been suggested to contribute to this differentiation of surfaces, including the presence of more shaded areas such as the under-surfaces of pontoons, walkways and pilings; distance from the seabed and the constant shallow depth which is maintained during the falling and rising of pontoons with the changing tides (Glasby 1999b, Connell 2000, 2001, Arenas *et al.* 2006).

There is a possiblity that some of the non-indigenous bryozoan species recently recorded in Ireland may have been present for a number of years but due little recording of bryozoan distribution around Ireland until most recently they have not been recorded before. In the last fifteen years non-native bryozoans at other locations in Europe have been recorded more frequently with publications recording instances from France (Ryland *et al.* 2009a), Italy (Occhipinti Ambrogi *et al.* 2010, Lodola *et al.* 2012), Norway (Porter *et al.* 2015), United Kingdom (Bishop *et al.* 2015, Loxton *et al.* 2017), while for the same period there have been four publications with records from Ireland (Kelso and Wyse Jackson 2012, Cook *et al.* 2013, [Nunn 2013], Loxton 2017). These records will help with understanding the biogeography and possible dispersal methods for each species. It is presumed that the introductions to these new areas are unintentional with many species colonising ship hulls at ports and marinas (Ryland *et al.* 2009b).

Legislation regarding NIS in Ireland's marine environment

There are a number of EU directives and regulations to assist in the monitoring and prevention of NIS in Europe and Ireland as a member state has commited to adhere to these regulations. The European Union Marine Strategy Framework Directive (EC 2008) is a directive designed to guide member states in maintaining biodiversity, and achieving and conserving clean and productive marine ecosystems. In this directive member states have agreed to establish and implement suitable monitoring programmes to determine the status of their marine environments with an approach that includes areas of protection and investigations into antropogenic activites that could impact the environment. Environmental status is determined by utilizing qualitative descriptors such as biodiversity levels and the presence of NIS introduced antropogenically. In this directive it is noted that members should recognize NIS as a possible biological disturbance that could cause undue pressure on an ecosystem and cause alteration to the ecosystem.

EU Regulation 1143/2014 (EU 2014) came into force on 3rd August 2016 and deals with the handling of alien species that have been placed on a list known as the 'Union List' which lists the species that have the potential to adversely impact ecosystems within a member state. The list currently comprises of 14 plant species and 23 animal species, none of which are Bryozoa but this list is continually updated. One of the aims of The EU Biodiversity Strategy (EU 2014) is to identify alien species and their pathways. These species should be priorised and where appropriate a plan to eradicate or control the NIS to prevent harmful NIS from becoming established and to prevent the introduction of new NIS across the EU.

The Convention on Biological Diversity (CBD 2014) has been in force since 1993 with Ireland signing up in 1992 and ratifying it in 1996. This convention aims to conserve biological diversity by halting biodiversity loss, encourage the sustainable use of biological components and sharing the benefits between members achieved from the use of genetic resources. This convention requires Ireland together with Northern Ireland to prepare strategies to prevent, control and minimise introductions of NIS that could threaten our biodiversity.

Ireland has approached the commitments it made in the above directives and regulations by establishing The National Biodiversity Plan (NPWS 2017) which was first established on 2002 and is now on its third version which plans for the period 2017-2021. This plan has been legislated using the Wildlife Act, 1976 and the Wildlife (Amendment) Act, 2000. It recognises that aside from habitat destruction, the introduction of harmful NIS is one of the primary pressures exherted upon our biodiversity. NIS overall, are currently increasing in Ireland and there is a concern that they could cause displacement of native species and alter the current biodiversity levels by affecting ecosystem processes and services.

5.2 Dispersal mechanisms - Bryozoan hitch hikers of the sea

Anthropogenic dispersal of non-indigenous species (NIS) has occurred for thousands of years (Carlton & Geller 1993) and they can often cause harmful effects at the introduced location. Non-native bryozoans have been recorded more frequently in recent years in Irish waters (Kelso & Wyse Jackson 2012, [Nunn 2012], Cook *et al.* 2013, Loxton *et al.* 2017). Natural dispersal is possible but anthropogenic dispersal through shipping, fisheries activities (Carlton and Geller 1993) and leisure craft movement has been reported as the cause of this wide spread dispersal which in many species would not be possible naturally due to short living larval stages (Cook *et al*. 2013) There are two primary mechanisms through which bryozoans are transported from one location to the other, transportation by vessel, either fouling or ballast water exchange, and aquaculture (Minchin *et al.* 2006). NIS can exhibit behaviours that are considered invasive such as alterations to the ecosystem structure and the provision of ecosystem services (Molner et al. 2008). Smaller NIS such as bryozoans can be transported with unintended human assistance through aquaculture, on ships hulls, sea chests, ballast water and semi-submersible platforms. The increasing amounts of plasic debris in water bodies can provide more opportunities for NIS attachment and transportation to new locations (Carlton and Fowler 2018). Algae is a common substrate for bryozoans to settle on, this is a further vector for non-indigenous bryozoans to be transported. A number of years can pass by before NIS are detected, especially smaller marine species which may need to be targeted to be found if they are not causing any obvious problems during this period or they may be discovered during a survey of a targeted area (Kelso and Wyse Jackson 2012).

Anthropogenic dispersal of bryozoans can now enable the crossing of natural barriers such as temperature gradients, current regimes and land masses (Cook *et al.* 2013). Increased human movement around the globe has, either intentionally or unintentionally, allowed non-native species to spread and inhabit new areas (Cohen & Carlton 1998). Non-indigenous marine species are usually recorded first in Britain before being recorded in Irish waters (Ryland *et al.* 2011, Bishop *et al.* 2015) where they are initially recorded from ports or marinas (Kelso and Wyse Jackson 2012, Minchin 2007). Increased knowledge of natural biogeographic regions for species has increased with the advent of the study of taxonomy (See Minchin *et al.* 2013) and the increased use of more defined biogeographic regions such as those listed in Spalding et al. (2007) has allowed for more uniform reporting of NIS locations.

Risk assessments of NIS

To assist with meeting the obligations set forth by the above directives, members will carry out risk assessments to ensure the appropriate monitoring measures are taking place. During risk assessments information such as introduction vectors, dispersal methods, demonstrated impacts at other locations and the strength and type of interactions with other species is gathered and evaluated to decipher if a species is a high risk species for introduction if it is not already present or if it has the potential to cause harmful effects to an ecosystem if it has already been introduced. Non-indigenous bryozoans are one of the many marine groups which have appeared in Irish waters; they are known to be introduced by both natural dispersal and man-made dispersal through shipping (fouling and ballast water) and fisheries activities (Carlton and Geller 1993). Gathering the information for risk assessments on Bryozoa in Ireland can be difficult due to the shortage of records on non-indigenous bryozoa but the recent papers on our non-indigenous bryozoa (Kelso and Wyse Jackson 2012, Cook *et al.* 2013, Nunn 2013, Loxton 2017), will assist in producing risk assessments for these species.

This chapter aims to determine which non-indigenous bryozoan species have been recorded in Ireland by assessing specimens collected by the author between 2011-2015 and also by reviewing the relevant literature. The possible vectors of dispersal will be assessed for these species along potential impacts these species could cause to the native fauna and ecosystem. Risk assessment will be carried out for the non-indigenous bryozoans recorded and other non-indigenous bryozoans that have the potential to be introduced be in the near future. This will be achieved by examining and adapting current risk assessments used for NIS in Ireland.

5.3 Materials and Methods

A survey of the bryozoans was conducted between 27/07/2011 and 27/08/2015 from 43 locations in Ireland (fig 5.1). Bryozoa were collected by hand from the forty three locations (Table 5.1) in 0-1 meters of water, at as close to low tide as possible to ensure the recovery of the maximum number of species. Samples were also collected from depths up to 27m by means of a grab sample, from 10-20m by scuba diving and from 6m with the use of settlement panels. Eight harbour locations were targeted and the remaining 34 locations were beachs and bays. The survey area ranged from the most North location at Belfast Harbour, Antrim and the most south location being Slade Harbour, Wexford
The survey method was carried out by taking samples from both artificial surfaces such as marina pontoons and platforms, buoys and ship hulls, and natural substrates such as algae, rock and sediment. A number of sampling methods were used and these have been assigned to 6 categories, shore sampling in intertidal areas, settlement panels, scuba diving, dredges, grabs and harbour.

Marina and harbour surfaces were checked visually first followed by taking a sample carefully, using a scrapper if required. If algae was present on the pontoon a sample of this was collected including the root. Shore sampling in intertidal areas was achieved by walking along the shoreline at low tide of the chosen location and collecting samples from both natural and artificial substrates such as rocks, shells, drift plastic and algae. Data was collected describing the beach habitat type (sandy, stoney etc.), the tide level and time of day, sampling carried out in 2011 at Dun Laoghaire, Dublin was done as part of a MSc thesis (Kelso 2011) and information about the sample and location was collected on a survey made specifically for the location (appendix 5.2).

Specimens were stored initially in sample tubes filled with seawater, and subsequently either air-dried or preserved in 70% alcohol. Very small colonies which were not attached to a substrate were placed into cavity slides. Bryozoans were examined with a binocular microscope, photographed and identified using the standard taxonomic keys (Hayward and Ryland 1998, 1999) and relevant literature (De Blauwe 2009; Hayward 1985; Hayward and Ryland 1985; Ryland *et al.* 2009a). The sample of *T. inopinata* was identified using De Blauwe (2009) and kindly confirmed by Hans De Blauwe (Bruges). Possible dispersal vectors for each species was investigated by evaluating the relevant literature and the possible introduction methods at previously established sites elsewhere.

Fig 5.1 Forty three sampling locations surveyed for non-indigenous bryozoans.

Biodiversity risk assessment have been carried out to determine if each of the four species is low, medium or high risk of becoming established and possibly impacting its new distribution site. The risk assessment used herein for the four non-indigenous bryozoans found to be present in Ireland is adapted from the risk assessment used by the organisation Invasive Species Ireland when they are required to prioritize species which may cause harm to the ecosystem. The assessment used will offer important questions about the species and potential impact and these are scored. Species with a score of 18-24 are high risk, 14-17 medium risk and 0-13 low risk. These scores will allow the surveyor to recommend which species should be targeted either preventative measures or future monitoring programmes.

Table 5.1 Location and co-ordinates of the 43 sample sites surveyed for NIS

	Location	Co-ordinates	Date first surveyed
1	Baginbun bay, Wexford	52.173620, -6.833490	25/02/2012
2	Balbriggan beach, near Hampton Cove, Dublin	53.605140, -6.165040	11/03/2012
3	Ballyhenry, Strangford Lough, Down	54.560520, -5.697600	20/08/2013
4	Belfast Harbour, Antrim	54.628596, -5.883376	02/08/2013
5	Bettystown Beach, Meath	53.692490, -6.241420	15/07/2012
6	Booley Bay, Wexford	52.137070, -6.928560	26/02/2012
7	Camp Beach, Dingle Peninsula, Co. Kerry	52.229590, -9.907400	04/08/2012
8	Carnsore point, Co. Wexford	52.172460, -6.365070	25/02/2012
9	Dingle Marina, Co. Kerry	52.138160, -10.276330	04/08/2012
10	Dublin bay (site 1), Dublin	53.300420, -6.051370	26/10/2011
11	Dublin bay (site 2), Dublin	53.355470, -6.084850	26/10/2011
12	Dublin bay (site 3), Dublin	53.322980, -6.104760	26/10/2011
13	Dublin Bay, (3BR) , Dublin	53.302570, -6.065070	26/10/2011
14	Dublin Bay, near Rosberg Bank (1NB), Dublin	53.364070, -6.100780	21/10/2011
15	Dun Laoghaire Marina, Dublin	53.296850, -6.134770	15/06/2011
16	Dun Laoghaire, Dublin, Dublin	53.292000, -6.128690	15/10/2012
17	Fahamore Pier, Co. Kerry	52.302180, -10.040630	05/08/2012
18	Garrahies, Camp beach, Kerry	52.229590, -9.907400	11/01/2014
19	Hampton Cove, Balbriggan, Dublin	53.603830, -6.164352	22/06/2014
20	Holm Bay, Strangford Lough, Down	54.406090, -5.642230	21/08/2013
21	Horse Island, Strangford Lough, Down	54.465070, -5.543580	26/08/2013
22	Inner Lee's Wreck, Ballyhenry Strangford Lough, Down	54.388450, -5.571580	20/08/2013

23	Islandacorr, Strangford Lough, Down	54.392630, -5.576630	25/08/2013
24	Kilbaha harbour, Clare	52.570770, -9.861668	14/10/2011
25	Kilkee, Clare	52.682706, -9.647571	15/10/2011
26	Killiney, Dublin	53.263147, -6.107423	01/06/2014
27	Kilmore Harbour, Wexford	52.173790, -6.587350	25/02/2012
28	Portaferry Marina, Strangford Lough, Down	54.380310, -5.549300	23/08/2013
29	Portmarnock beach, Dublin	53.420480, -6.119280	07/03/2012
30	Ross Bay, Clare	52.594710, -9.854670	14/10/2011
31	Sand eel bay, Wexford	52.161190, -6.881530	27/02/2012
32	Sandycove beach, Dublin	53.288500, -6.114470	27/07/2011
33	Shanganagh, Dublin	53.238720, -6.111380	04/10/2012
34	Skerries beach, Dublin	53.582160, -6.107950	11/03/2012
35	Sketrick Island, Strangford Lough, Down	54.483500, -5.628570	21/08/2013
36	Slade Beach, Wexford	52.134760, -6.910240	26/02/2012
37	Slade Harbour, Wexford	52.134520, -6.909530	28/02/2012
38	South of Abby Rock, Strangford Lough, Down	54.522970, -5.579580	21/08/2013
39	Strangford Lough, Down	54.418530, -5.597400	21/08/2013
40	The Dam, Strangford Lough, Down	54.447290, -5.540820	24/09/2012
41	The Dorn, Strangford Lough (near Ardkeen), Down	54.434260, -5.544900	23/08/2013
42	Wine Strand, Smerwick Harbour, Kerry	52.177620, -10.368480	25/06/2013
43	Zara Shoal, Strangford Lough, Down	54.370940, -5.552860	21/08/2013

5.4 Results and Discussion

Non-indigenous bryozoans found in Ireland

In this survey a total of 54 species (Appendix 5.1) were identified from 250 specimens from 43 locations in Ireland (Table 5.1). *Schizoporella japonica* was recorded by Loxton *et al.* (2017) from Greystones harbour, Dublin and not detected during the survey carried out of the current study. *Watersipora subtorquata* which was later reassigned as *W. subatra* by Vieira *et al.* (*2014*) (Fig. 5.3) (Kelso & Wyse Jackson 2012), *Tricellaria inopinata* (Fig. 5.4) (Kelso & Wyse Jackson 2012, Cook *et al.* 2013) and *Schizoporella japonica* (Loxton *et al.* 2017) have been recorded from Ireland during this survey and in additional relevant recent publications. *W. subatra* has only been detected at its original location in Dun Laoghaire, Dublin in 2011 and subsequentially in Ardglass, Down in 2013 (Porter *et al.* 2017). *T. inopinata* has been reported from two marinas in Dublin, Dun Laoghaire (Kelso & Wyse Jackson 2012) and Malahide (see Cook *et al.* 2013), and two other locations in Ireland, Cork and Louth (See Cook *et al.* 2013). *Bugula neritina* is reported herein as the first recording of the species for Ireland in July 2013 at Dun Laoghaire marina, Dublin with a second report from Strangford Lough in August 2013 during the Blitz the Lough 2013 event [Julia Nunn 2013 unpublished]. There have been no published recordings of this species since in Ireland although this species is highly invasive so it is likely at other location. The first occurrence of *Watersipora subatra* (Ortmann, 1890) was published by the author in 2012 (Kelso & Wyse Jackson 2012) but has not been reported again in any subsequent publications. These NIS are discussed in more detail below.

5.4.1 *Watersipora subatra* (Ortmann, 1890) (Fig. 5.2)

On the 23/06/2011 and 01/07/2013 red encrusting samples of *W. subatra* were collected from permanent floating dock pontoon and concrete supports in Dun Laoghaire Marina. The colonies were identified as *Watersipora subtorquata* at the time (Kelso and Wyse-Jackson 2012) and later reassigned to *W. subatra* by Vierra *et al.* (2014). This bryozoan was found to be covering a large area of a shaded pleasure craft pontoon in one site (n=8) of the marina in 2011 but not found in the remaining 19 marina sites. In 2013 the same marina was surveyed again but this time *W.subatra* was specifically targeted along with *Tricellaria inopinata* which had been found in the 2011 survey also.

Fig 5.2 Red dots mark the sites surveyed. Red circle marks the marina area. Marina sites (n=8), Total Dun Laoghaire harbour sites (n=20)

The specimens were initially identified using the morphological characters and dimensions described in Ryland *et al.* (2009a) and subsequently this identification was confirmed by Prof. John Ryland (University of Swansea). As mentioned above this identification was reassigned when Vierra *et al.* (2014) investigated the identity of *W. subtorquata* to resolve the mix up between a number of the species within the genus. *W. subatra* originates from Japan and has been recorded from Europe in the Bay of Arcachon, Bordeaux, France by d'Hondt (1984) where it is thought to have arrived sometime between 1968 and 1973 on the shells of the oyster – *Crassostrea gigas* which were imported from Japan. This invasive bryozoan species was then recorded from 1999 in other locations in Brittany, France such as St Jacut de la Mer (1999, 2005), Iles Chausey (2002), near Gujan-Mestras (2003), St-Lunaire (2005), Golfe de Morbinan (2006) and Erquy (2008). In 2007 *W. subatra* was recorded from the QEII Marina, Guernsey and from both Queen Anne's Battery marina in Plymouth, England and Poole harbour in southeast England (Ryland *et al.* 2009a). Ryland *et al.* (2009a) reported on the current enlarged distribution of a number of *Watersipora spp*. in Western Europe.

Watersipora subatra is a persistently aggressive invasive bryozoan species which has also been introduced globally to Australia, New Zealand and USA (California) (Porter *et al.* 2014, Bishop *et al.*2015). It was discovered for the first time in New Zealand in 1982 on experimental panels in Victoria Wharf, Dunedin and Carey's Bay, Port Chalmers but was not found at the same location in 1977 which indicates the arrival time to be between these dates (Gordon and Mawatari 1992). *W. subatra* is an encrusting species coloured dark orange/red in Dublin but has been found in other locations in other darkly pigmented shades. As per the description in Vieira *et al.* (2014) this species can be distinguished by the U-shaped sinus in the orifice and the narrow, bar-shaped condyles. The opercula is broad and the calcified frontal shield possesses circular pseudopores which are 18-30 um in diameter and 2 latero-oral interzooidal septula. Scanning electron images of this species displaying these morphological features can be seen in Vieira *et al.* (2014).

This group of bryozoans can be difficult to identify to species level correctly due to the lack of morphological features such as avicularia, spines and ovicells which are used to identify other bryozoan species. This has inevitably caused much confusion and incorrect identification of many of the Watersiporid species. These species are capable of quickly becoming the most prevalent bryozoan in a short time with it becoming the most common bryozoan at St-Jacut-de-la-Mer Beach, Brittany within 5 years of introduction (Ryland *et al.* 2009a). Species of this kind can quickly cause a near monocultured ecosystem as they compete with other sessile organisms for settlement space on hard substrates. *W. subatra* has also been found in the QE II marina in Guernsey, Channel Islands in 2007 in very similar conditions to that of the Dun Laoghaire marina samples from this study, in both locations the bryozoan was found on floating pontoons and in the shade, away from direct sunlight (Ryland *et al.* 2009a, Kelso and Wyse-Jackson 2012).

The primary type of location that this species has been introduced into and recorded from has been marina's and harbours which indicates that the vector of dispersal is associated with pleasure crafts and shipping. This species thrives in these locations and spreads quickly within the marina location. During visits to Dun Laoghaire Marina, Dublin in 2011 and 2013 the author recorded the *W. subatra* had increased its distribution within marina to 3 sample site (n=20) from 1 sample site on the 2011 visit.

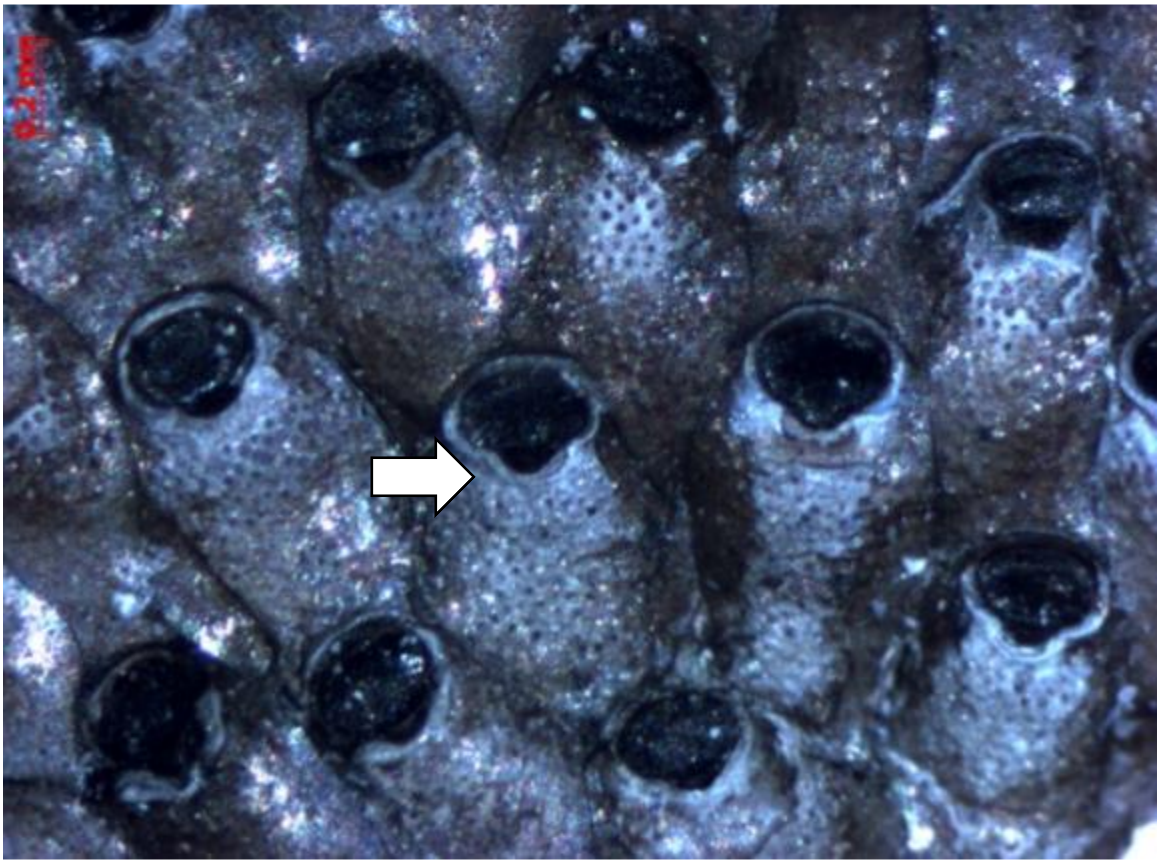

Fig. 5.3. *Watersipora subatra* (Ortmann, 1890) (photo) from Dun Laoghaire Harbour, Dublin (M11 Author's collection), collected 23rd June 2011. The U-shaped sinus is highlighted by an arrow.

5.4.2 *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985 (Fig 5.4)

This non-indigenous species was discovered in Dublin, Ireland for the first time in June 2011 as an epiphyte on a number of unrecorded algae species (Kelso and Wyse Jackson 2012). The same sample site was visited in October 2012 and the start of July 2013 during the sampling survey for this study and *T. inopinata* was not detected in these instances.

Tricellaria inopinata was first described in 1985 (d'Hondt and Occhipinti Ambrogi 1985), this description was based on specimens discovered in May 1982 from waterways leading to the central part of the Lagoon of Venice. Earlier surveys had failed to document this species which pointed to it being a recent introduction. It spread rapidly to other parts of the lagoon (Occhipinti Ambrogi 1991) which recently has been found to possess the highest number of marine invasive species in Italy (Occhipinti Ambrogi *et al.* 2010).

Tricellaria inopinata is thought to have originated in the north Pacific Ocean (Dyrynda *et al.* 2000; De Blauwe and Faasse 2001) and was then introduced into Australia, New Zealand, Japan, Taiwan, the West Pacific and Venice (Occhipinti Ambrogi and d'Hondt 1994); it was just a matter of years after these introductions that it was reported from locations on the Atlantic coast such as France (Breton and d'Hondt 2005), Belgium, the Netherlands (De Blauwe and Faasse 2001), the northwest of Spain and Portugal in 2004 (Marchini *et al.* 2007). By 1998 this invasive species was present in central southern England (Dyrynda *et al.* 2000) and in the Netherlands (De Blauwe and Faasse 2001); it was found to be abundant on both natural and artificial surfaces such as ropes, buoys and other sessile fauna. Most recently it was also reported from Eel Pond, Woods Hole, and Massachusetts in September 2010 (Johnson *et al.* 2012). The location of the first European report of this species was from the Lagoon of Venice (d'Hondt and Occhipinti Ambrogi 1985), which is a busy shipping route with ships crossing to Belgium, the UK and other European countries. For this reason it is quite likely that shipping was the cause of accelerated distribution of *T. inopinata* (Occhipinti Ambrogi 1991) with it being found possibly in every port and harbour in Europe (pers comm. H. De Blauwe 2011).

Tricellaria inopinata has a number of characteristics which enable it to colonise many location types. This species is a generalist when it comes to habitat type with wide ranges in temperature (Dyrynda *et al.* 2000) (its location in Venice has a minimum temperature of 2-3°C), salinity (Occhipinti Ambrogi 1991) and levels of sedimentation toleration (De Blauwe and Faasse 2001). This species also has low substrate specificity and can be found on both natural and artificial substrates. Its ability to readily colonise pleasure craft is probably the reason for its introduction to marinas typically providing mooring for such boats (Minchin *et al.* 2006). In Ireland, Ryland *et al.* (2009b) noted the occurrence of this species in Counties Down and Dublin, and at Cork Harbour. *T. inopinata* has since also been found in a number of locations in Northern Ireland during a rapid assessment for marine NIS carried out in 2012 (Minchin and Nunn 2013).

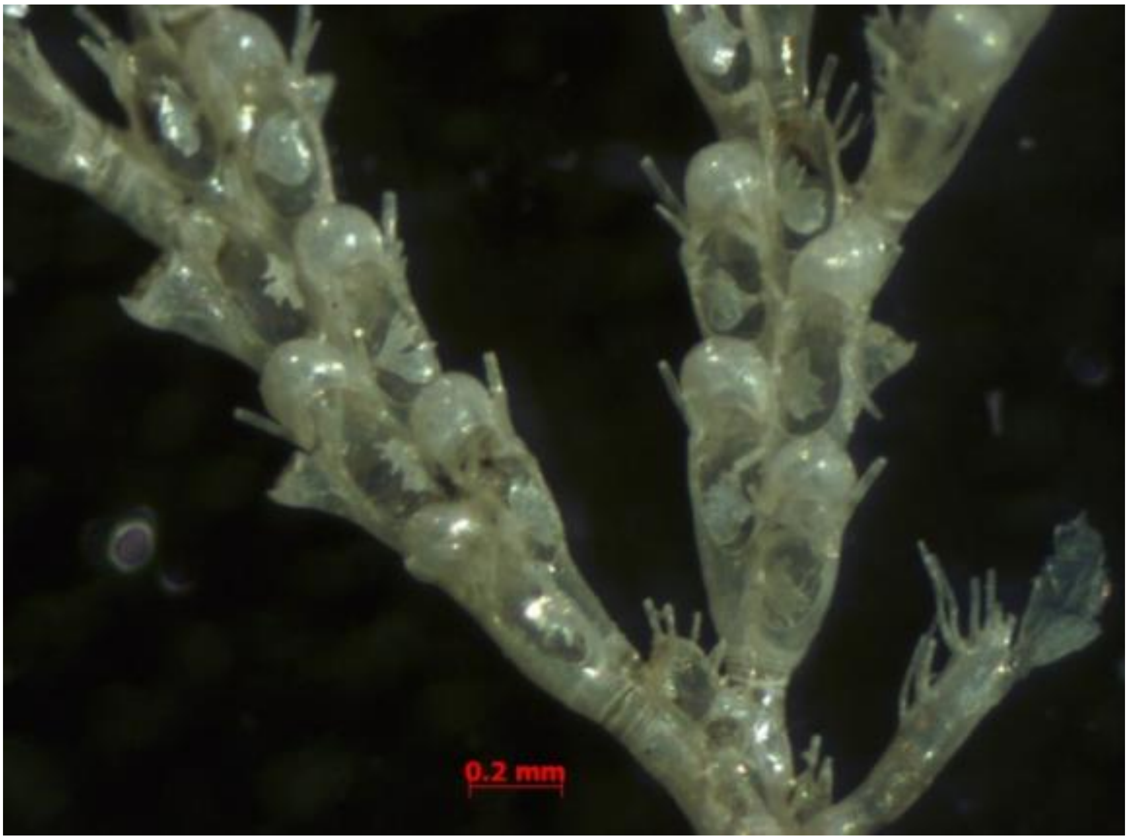

Fig 5.4. *Tricellaria inopinata*, frontal view showing the internode, ovicells, spines, avicularium and scutum, from Dun Laoghaire Harbour, Dublin. (M3 Author's collection).

5.4.3 *Bugula neritina* (Linnaeus, 1758)

This research has recorded the first occurrence of *B. neritina* at Dun Laoghaire Marina, Dublin on 01/07/2013. The specimen was found attached to the concrete of a dock support with an assemblage of other marine fauna such as hydroids, sponges and Pycnogonids. This species has been recorded from a limited number of locations in Ireland in recent years such as Strangford Lough in 2003 [Nunn 2013], Carlingford Lough, Louth in 2008 and Malahide marina, Dublin in 2006, the latter being the first record in Ireland (Ryland *et al.* 2009b). Subsequent visits to Malahide in 2008 showed very little evidence of *B. neritina* as well as other fauna which led Ryland *et al.* to conclude that a marina wide event occurred affecting the assemblage of the marina. *B. neritina* is a warm water species and is found frequently in artificially warmed water. In the right conditions, the larva will settle between May and October and the highest number of colonies are found between July and August (Hayward and Ryland 1998). This species is often found to colonize anthropogenic structures which play an important role in its survival (Dumont *et al.* 2011). In areas where *B. neritina* occurs it can be seen to heavily colonize pilings. Dumont *et al.* (2011) studied the rates of colonization with and without bryozoan predators and found that in locations where predators had access *B. neritina* it exhibited suppressed colonization and determined that predators play an important role in preventing the spread of *B. neritina* on artificial structures. The specimen in this study was found on an artificial structure but too few colonies were found to investigate a link to the substrate.

As with many invasive and non-native marine species *B. neritina* arrived in the United Kingdom before arriving to Ireland. *Bugula neritina* was first reported from Plymouth in 1911 and is now present in locations along the southern North Sea, Ireland and South Scotland (Ryland *et al.* 2011). This species was recorded from Malahide Marina in January 2006 which is only 25km north of Dun Laoghaire where it was recorded during the current study, with the likelihood that it was present in 2005 (Ryland *et al.* 2011). Kelso and Wyse Jackson (2012) warned of its impending presence at Dun Laoghaire, Dublin within a few years and sure enough it was recorded the following summer.

5.4.4 *Schizoporella japonica* (Ortmann, 1890)

This species was discovered recently from Greystones marina, Wicklow by Loxton *et al.* (2017) but not recorded during sampling in the current surveys. Loxton *et al.* (2017) surveyed twenty eight sites in Republic of Ireland and ten in Northern Ireland, it was recorded from just the one site in Dublin. The first record from Britain was in 2010 from Wales and has since then exhibited a discontinuous distribution in Britain. Loxton *et al.* (2017) examined sites in Norway, France and Portugal also and found *S. japonica* in Norway only. The 2017 record from Wicklow, Ireland is the first record of *S. japonica* from Ireland, although it was also a target species in a rapid marine assessment for Northern Ireland carried out in 2012 (Minchin and Nunn 2013), this species was targeted in this survey due to its establishment and continuous distribution in nearby Scotland (*Loxton et al.* 2017). Twenty seven sites were surveyed over a 12 day period in August – September, but this species was not identified during the survey. Records in Britain show how quickly this species can increase its distribution and needs to be frequently surveyed for in marina locations which have exhibited NIS records previously as it is our responsibility under our Nation Biodiversity plan to monitor for potential NIS. This species has been recorded from a large variety of substrates from plastic, boat hulls, tidal devices and aquaculture equipment (See Loxton et al. 2017) and has the potential to impact commercial and private industry due to the overgrowth on vital equipment.

Other potential invasive Bryozoa to Ireland

Two non-native species of *Bugulina* have recently been reported from Britain and Ireland (Ryland *et al.* 2011). *Bugulina simplex* was recorded in the 1950s from SW England, Belgium and the Netherlands (Ryland *et al.* 2011) but has not yet been reliably reported from any location in Ireland, Boaden *et al.* (1975) recorded it on a list of species found on *Fucus serratus* in Strangford Lough but this is the only report of the species in Ireland and may a misidentification. A second *Bugulina* species, *B. stolonifera* also had very few records with the most recent from ports in Britain and Ireland prior to 1950 (Ryland *et al.* 2011). This species was reported from Cobh harbour, Cork by Ryland (1960) and more recently from Plymouth and Falmouth, U.K. in 2009 (Ryland *et al.* 2011). These two *Bugulina* species have the potential to colonize other sites in Ireland and should be, if possible, targeted during invasive species surveys in marinas and harbours as this is the most likely place for first introduction. These two species are by no means an exhaustive list of potential species but merely an example of the possibilities. As one of these species was last recorded in locations in Ireland over 50 years ago this could indicate that they are either unlikely to spread quickly to other localities or that they are present and have not been recorded as of yet. A study conducted by (Minchin 2007) carried out a rapid marine survey at 29 floating pontoon sites around Ireland but no bryozoans were targeted in this study, this is a familiar situation with many studies in the U.K and *B. simplex* is possibly under reported in areas of the U. K and Ireland (Ryland *et al.* 2011)

The presence of these species could have been indicated if they were targeted by the marine invasive species survey that was carried out in 2005-2006 (Minchin 2007) which encompassed 4 marinas in Dublin, Malahide, Howth, Poolbeg and Dun Laoghaire as well as many more around the country.

Risk Assessments of non-indigenous bryozoans in Ireland

Risk assessments are conducted to assist in monitoring NIS in both marine and terrestrial locations.The EU's Marine Strategy Framework Directive and Ireland's National Biodiversity Plan requires that we provide risk assessments and monitoring for NIS already present and possible NIS .There are many types of risk assessments available that vary in complexity. This study used a method that determines which species are at the highest risk of impacting the ecosystem and rating them with a high, medium or low risk accordingly called prioritisation assessment. In table 5.2 the four non-indigenous bryozoans *Tricellaria inopinata*, *Watersipora subatra*, *Bugula neritina* and *Schizoporella japonica* were assessed by scoring answers regarding their invasion history, potential ability to spread, available habitat, potential impacts and management. Scores between 0-13 are classified as a low risk, 14-17 are medium risk and 18-24 are high risk species. All four bryozoans are rated to be of low risk in this assessment. *T. inopinata* achieved the highest score of 13 which almost places it into the medium risk group. *S. japonica* and *B. neritina* are both very recent introductions to Ireland which is one of the reasons why they scored as low risk. Only a handful of sites in Ireland have been found to have these bryozoans present which opens up a good opportunity to monitor them and record how/if the distribution changes and at what speed and to investigate the pathways further.

Table 5.2 Risk assessment scores for the non-indigenous bryozoans present in Ireland

Factor	**Assessment Criteria**	**Max score**	***Tricellaria Inopinata***	***Watersipora subatra***	***Bugula neritina***	***Schizoporella japonica***
Invasion History	Does the species currently have a widespread recorded distribution in Irish waters?	**3**	*2*	*1*	1	0
	Is the species currently expanding its range in Irish waters?	**2**	2	0	0	0
	Is the species in its present range (including Ireland) known to be invasive i.e. to threaten species, habitats or ecosystems?	**2**	2	2	2	2
Species spread potential	Is there potential for this species to be spread intentionally or unintentionally across Ireland?	**2**	2	2	2	2
Availability of suitable habitats	How widespread are suitable habitats to allow establishment of the species?	**2**	2	2	2	2
Impact assessment	Where the species has become established has it impacted upon the	**4**	1	1	0	1

	conservation objectives for the area?					
	Is the species poisonous, or does it pose a risk to plant and animal health?	**2**	0	0	0	0
	Is the species poisonous, or does it pose a risk to human health due to its parasites, pathogens or other intrinsic factor?	**2**	0	0	0	0
	Has the species directly or indirectly caused economic losses in Ireland or elsewhere?	**3**	0	0	0	0
Management	Are there acceptable and effective control method/s that can be applied? Assessors are asked to consider control methods for similar or related species in their assessment.	**3**	2	2	2	2
Total score		**25**	**13**	**10**	**9**	**9**

5.5 Conclusions

During this study *Tricellaria inopinata*, *Watersipora subatra* and *Bugula neritina* have been collected and *Schizoporella japonica* was recorded by Loxton *et al.* (2017). Examination of the published literature and museum collections have revealed that very few records of these species exist since they were first introduced with no previous records of these species being collected from Ireland, this suggests they have been introduced relatively recently, possibly on leisure or commercial craft travelling to and from the UK and mainland Europe. Increased shipping, use of leisure craft and the import of the oyster *C. gigas* have been blamed as the cause of the spread of non-indigenous species across the coasts of Europe, Britain and Ireland (Watts *et al.* 1998; Minchin *et al.* 2006; Ryland *et al.* 2009a, 2011; Sylvester *et al.* 2011). Ships and leisure craft can introduce non-indigenous Bryozoa in ballast water and also from external areas of the hull which have become fouled with encrusting species (Carlton and Geller 1993; Watts *et al.* 1998; Sylvester *et al.* 2011). Fouling species can then reproduce while the vessel is docked at the port of call (Ruiz and Smith 2005) and if the conditions are favourable for the species it may become establised. Over the last decade vessels have become faster which has cut transit times, increasing the chances that any 'hitchhiking' bryozoan colonies will still be able to reproduce when the vessel arrives in port (Sylvester *et al.* 2011). Considerable legislation has been implemented in Ireland to ensure NIS are correctly monitored and treated where possible (CBD 2014, EU biodiversity strategy 2014, NBP 2017), marine NIS are a further concern as they are more difficult to eradicate once they have been introduced at a location. All four the non-indigenous bryozoans recorded during this study *T. inopinata*, *W. subatra*, *B. neritina* and *S. japonica*, have been reported from marina habitats. This is an indication that boat hulls and possibly ballast water and the main pathways for these species and need to be monitored and assessed in more detail, to determine the type of impact if any they would have if they became established. The impact assessments carried out in this study indicated that the NIS mentioned are low risk. These bryozoans are low risk at the moment but the possibility still exists that they will become a higher risk in the future as that are all very recent introduction to Ireland with very few records, in particular *Tricellaria inopinata* become established very quickly in Scotland (Cook *et al.* 2013).

A further study targeting the four non-indigenous bryozoans in Ireland would be required to determine the full extent of their distribution in Ireland. Locations that have exhibited these species in the past should be surveyed along with nearby harbours or marinas and other sites which show high amputs other marine NIS. Many of the specimens of the non-indidgenous bryozoans that were collected during this study were found to be using other marine fauna or flora as a substrate, the next chapter in this thesis will examine the relationship of both non-indigenous and native Bryozoa with their living substrates.

5.6 Appendices

Appendix 5.1. Bryozoan species identified with the counties they were recorded from.

Order	Species	County recorded
Ctenostomatida	*Alcyonidium diaphanum* (Hudson,1762)	Dublin
	Flustrellidra hispida (Fabricius, 1780)	Dublin
	Amathia imbricata (Adams, 1798)	Down
Cyclostomatida	*Crisidia cornuta* (Linnaeus, 1758)	Down, Wexford
	Crisia eburnea (Linnaeus, 1767)	Down, Dublin, Meath, Wexford
	Plagioecia patina (Lamarck, 1816)	Kerry
	Crisia aculeata Hassall, 1841	Down
	Crisia denticulata (Lamarck, 1816)	Dublin, Down, Meath
	Filicrisia geniculata Milne Edwards, 1838	Down, Kerry
	Tubulipora liliacea (Pallas, 1766)	Kerry, Wexford
Cheilostomatida	*Membranipora membranacea* (Linnaeus, 1767)	Cork, Down, Dublin,Kerry, Meath, Wexford
	Conopeum reticulum (Linnaeus, 1767)	Clare, Dublin, Kerry, Wexford
	Electra pilosa (Linnaeus, 1767)	Antrim, Cork, Clare, Down, Dublin, Kerry, Meath, Wexford,
	Flustra foliacea (Linnaeus, 1758)	Cork, Down, Dublin, Meath, Wexford
	Callopora dumerilli (Audouin, 1826)	Antrim, Clare, Dublin, Kerry,
	Callopora lineata (Linnaeus, 1767)	Dublin, Kerry, Wexford,
	Callopora rylandi Bobin and Prenant, 1965	Clare, Kerry
	Bugulina flabellata (Thompson in Gray, 1848)	Down, Dublin
	**Bugula neritina* (Linnaeus, 1758)	Down, Dublin
	Bicellariella ciliata (Linnaeus, 1767)	Down, Dublin, Wexford

Caberea boryi (Audouin, 1826)	Wexford
Scrupocellaria reptans (Linnaeus, 1767)	Cork, Dublin, Kerry
Scrupocellaria scruposa (Linnaeus, 1758)	Down, Dublin, Wexford
Cradoscrupocellaria ellisi (Vieira & Spencer Jones, 2012)	Down, Dublin, Kerry, Wexford,
**Tricellaria inopinata* d'Hondt & Occhipinti Ambrogi, 1985	Dublin
Chartella papyracea (Ellis & Solander, 1786)	Dublin
Scruparia chelata (Linnaeus, 1758)	Down
Cellaria fistulosa (Linnaeus, 1758)	Down, Wexford
Eucratea loricata (Linnaeus, 1758)	Down
Cauloramphus spiniferum (Johnston, 1832)	Down, Wexford
Cribrilina cryptooecium Norman 1903	Down
Cribrilina annulata (Fabricius, 1780)	Kerry
Celleporella hyalina (Linnaeus, 1767)	Clare, Cork, Down, Dublin, Kerry, Wexford
Escharoides coccinea (Abildgaard, 1806)	Cork, Down, Dublin, Kerry, Wexford
Escharella immersa (Fleming, 1828)	Down, Dublin, Kerry
Escharella variolosa (Johnston, 1838)	Clare, Kerry
Escharella labiosa (Busk, 1856b)	Down
**Watersipora subatra* (Ortmann, 1890)	Dublin
Cryptosula pallasiana (Moll, 1803)	Cork, Down, Dublin, Kerry, Meath, Wexford,
Schizoporella unicornis (Johnston in Wood, 1844)	Cork, Down, Dublin, Kerry
Celleporina calciformis (Lamouroux, 1816)	Cork, Down, Dublin, Kerry
Celleporina decipiens Hayward, 1976	Dublin

Turbicellepora boreale Hayward and Hansen 1999	Wexford
Phaeostachys spinifera (Johnston, 1847)	Down, Dublin
Omalosecosa ramulosa (Linnaeus, 1767)	Wexford
Fenestrulina malusii (Fleming, 1828)	Down, Dublin
Oshurkovia littoralis (Hastings, 1944)	Down
Cellepora pumicosa (Pallas, 1766)	Down, Cork
Microporella ciliata (Pallas, 1766)	Down, Dublin, Wexford
Chorizopora brongniartii (Audouin, 1826)	Clare
Schizomavella (*Schizomavella*) *linearis* (Hassall, 1841)	Dublin
Pyripora catenularia (Fleming, 1828)	Dublin, Kerry
* *Schizoporella japonica* (Ortmann, 1890)	Wicklow
Schizoporella errata (Waters, 1878)	Clare

* Non-native Bryozoa identified

Appendix 5.2

Survey used during 2011 survey of Dun Laoghaire, Dublin

Dun Laoghaire Harbour Bryozoan Survey 2011

Survey number [ ] Surveyor ____________________________

Site number [ ] Date/Time ____________________________

Location

Site Name ____

Survey Area ____

Grid Ref ____

Survey Details

Habitat type ____

Sample method ____

Colony type ___________________ Colony Colour ________________

Colony Size (mm) ________________

Survey number [ ] Surveyor ____________________

Site number [ ] Date/Time ____________________

Location

Site Name ____

Survey Area ____

Grid Ref ____

Survey Details

Habitat type ____

Sample method ____

Colony type ____

Colony Colour ____

Colony Size ____

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Chapter 6

Bryozoans as epiphytes and epizooites

Contents

1.1 Introduction

Epiphytic and epizooitic bryozoans often dominate epibenthic assemblages and will settle, attach and grow on both artificial (López Gappa 1989), and plant and animal species in a non-parasitic manner. Epiphytism of marine algae (Fig 6.1) and epizooitims of sessile fauna such as hydroids (Fig 6.1A) are a common occurrence and often important for the survival and success of both the host plant and the epiphyte/epizooite (Gauna *et al.* 2016). Bryozoans will often use algae and sessile animals as an attachment surface that will provide the bryozoan with increased chances of nutrient availability by being positioned in a suitable flow area where filter feeding is possible (Harlin 1980). On algae, epiphytic Bryozoa can be beneficial for the host plant as they can protect it from desiccation (Guana *et al.* 2016) and can provide a source of CO_2 for phosynthesis (Mercado *et al.* 1998). In Wood and Seed (1980) the bryozoan *Alcyonidium hirsutum* was observed to occupy the broader areas of the *Fucus* plant. The presence of bryozoans on algae also provides a sheltered food source for other species such as nudibranchs and urchins (Vance 1979, Todd 1981). This epiphytic association can also have negative effects on a host plant by affecting the growth and reproduction rates by reducing the opportunity for light to reach the thallus (Muñoz *et al.* 1991) and possibly causing breakage of the algal fronds, defoliation during storms (Saunders Metaxas 2008, Yorke & Metataxas 2011) and possible detachment of the plant from its substrate (Guana *et al.* 2016).

Previous studies on epiphytic bryozoans

A study carried out by Liuzzi & Gappa (2011) has shown that bryozoan species richness does not increase with algal complexity but instead that related algal will exhibit more epiphytes than unrelated algae. Two common algae settled on by bryozoans are *Laminaria digitata* and *Fucus serratus* (Stebbing 1971, Seed & Stebbing 1979, Wood & Seed 1980, Seed & O'Connor 1981, Seed & Wood 1994). *F. serratus* commonly has an epiphytic community living amongst its fronds. In a study by Seed & O'Connor (1981) eight bryozoan species were found to inhabit this species of algae at a location in Wales. Fucoid algae have a comparably lower growth rate than other algae and very little change in growth rates throughout the year. Fucoids generally have a smaller surface area for epiphytes to attach but still seem to be a preferred species (Yorke & Metataxas 2011). This may be due to the differing substrate types on a single plant. The stipe and holdfast consist of tapered branches with an uneven surface with the area around the holdfast being more sheltered. The blades of the plant usually exhibit a smooth, broad and continuous surface, these areas are more prone to damage but are in an ideal location for its epiphytic bryozoans to filter feed. The diverse surfaces available make this species attractive to a number of sessile species and can help to explain the diverse nature of the epiphyte community often encountered (Seed & O'Connor 1981). In the study carried out by Seed & O'Connor it was recorded that 4 out of 5 of the most dominant taxa found inhabiting this algae were bryozoans. Of the bryozoans present they recorded that *Flustrellidra hispida* often outcompeted other species for space. This was very common distally on the blades where the colonies were less abundant but colony size was larger. Other species such as *Electra pilosa* and *Alcyonidium polyoum* were commonly more abundant in the mid regions of the plant. Seed and Stebbing (1979) also found *E. pilosa* very abundant and found it to be present on every plant that they examined but noted that in more disturbed areas it was less common then the sheltered areas.

L. digitata is commonly present throughout the lower littoral zone where its distribution overlap with *F. serratus* and can potentially provide a vast habitat for a number of diverse epiphytic communities (Seed and Stebbing, 1979). Bryozoans have been recorded to initially settle on the younger parts of the *Laminaria* frond, this will ensure they have substratum availability for the longest possible time (Seed & Stebbing 1979, Hayward & Ryland 1998). *Membranipora membranacea* is common on this plant species. It possesses a number of uncalcified bands in the zooid wall which protect it from damage during wave movement of the algae (Ryland & Hayward 1977, Ryland 1998). Water movement is also a vital factor in the distribution of this species, with the highest abundance being found in moderate flow locations (Kitching & Ebling 1967, Ryland & Nelson-Smith 1975). Other factors important for settlement on *L. digitata* are silt content, frond age and production of anti-fouling compounds (Hayward & Ryland 1998).

Two of the most abundant epiphytic species found in Seed and Harris (1980) were the bryozoans, *Electra pilosa* and *Membranipora membranacea* which usually fare badly in competition with other encrusting bryozoans such as *Alcyonidium sp.* and *F. hispida* as these species attain max abundance on other algal species (Seed & Wood 1994). Laminarians provide a spatial refuge for less successful species of epiphytic communities. An example of this has been observed in *L. digitata* collected from the

Menai Strait, North Wales in 1979 (Seed & Wood 1994). In Seed & Wood (1994) *M. membranacea* was observed to be the only epiphytic species present on this algae.

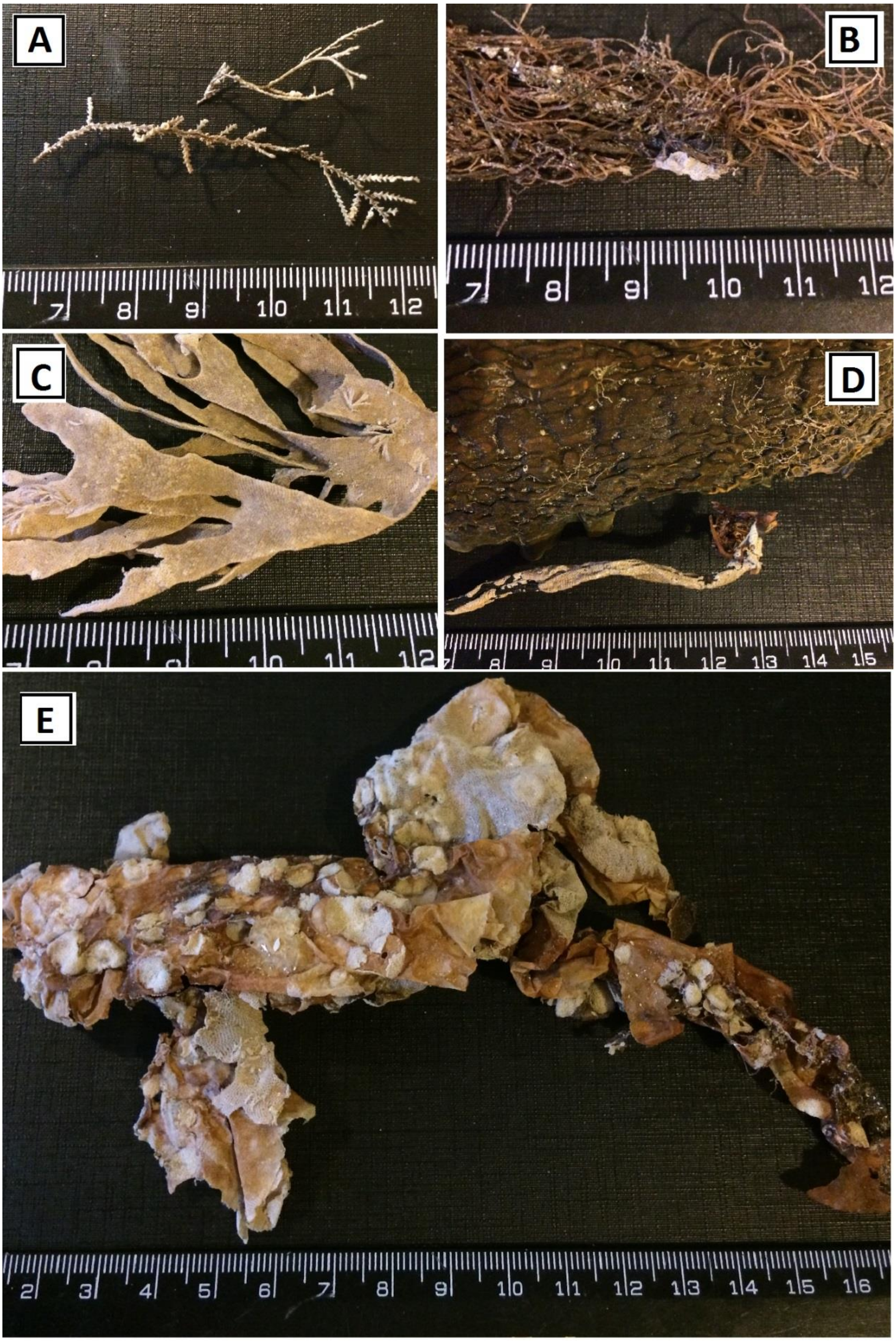

Fig 6.1. Epiphytic and epizooite Bryozoa. **A)** Specimen D53 Authors collection: Hydroid encrusted with *Crisia* sp., a cyclostome and *Electra pilosa*, collected from Portmarnock Beach, Dublin **B)** Specimen MH07 Authors collection: Red algae encrusted with *E. pilosa* collected from Bettystown beach, Meath **C)** Specimen MH05 Authors collection: *Flustra foliacea* with *Bugulina* sp. as an epiphyte collected from Bettytown beach, Meath. **D)** Specimen D43 Authors collection: *Lamininaria sp.* with *Membranipora membranacea* growing on the stipe collected from Balbriggan, Dublin. **E)** Specimen MH04 Authors collection: Brown algae with multiple colonies of *E. pilosa, M. membranacea, Bugulina* sp. and *Cryptosula pallasiana* collected from Bettystown beach, Meath. *All measurements are in cm.

Biodiversity in these epiphytic communities is often regulated by competition from neighbouring colonies (Centurión & López Gappa 2011). Encrusting assemblages can have a limited area on a substratum on which to grow and the growth of a colony is related to space availability (Wood & Seed 1980, Seed & O'Connor 1981), this is regarded as a critical limiting factor (Turner & Todd 1994). Overgrowth is common but this is not a death sentence for the bottommost colony, as overgrowth is often only partial and the overall colony will survive and reproduce (Barnes & Arnold 2001). Often the epiphytes are unevenly distributed along the length of the algal fronds and stipes which could be an indication of location preference from the epiphyte (Seed & O'Connor 1981).

Aims of this study

This study aims to determine which bryozoan species are the most common epiphytes in Ireland's waters. It will also be determined if substrate preference by the epiphytes is exhibited. The Weyman (1997) algal collection will be investigated to determine if collections similar to this might yield important bryozoan records not previously recorded. Substrate use will also be investigated by examining the substrate use records taken during the sampling programme of 43 sites around Ireland.

1.2 Materials and Methods

Sampling and identification

Sampling of bryozoans took place from July 2011 - July 2015, from 43 sites on the Irish coastline (Table 6.1). Bryozoa were recorded and collected from substrata including brown algae, red algae, green algae, shells of many bivalves and gastropods on the shoreline with a small number being collected by scuba, snorkel and dredge from the *R.V*

Celtic Voyager. Where possible bryozoans were collected with its substrata but where this was not possible the information was recorded in the field. Any algae collected was allowed to dry before storage.

Table 6.1. Location bryozoans were collected from during the sampling programme of the current study.

Location	**Co-ordinates**
Baginbun bay, Wexford	52.173620, -6.833490
Balbriggan beach, near Hampton Cove, Dublin	53.605140, -6.165040
Ballyhenry, Strangford Lough, Down	54.560520, -5.697600
Belfast Harbour, Antrim	54.628596, -5.883376
Bettystown Beach, Meath	53.692490, -6.241420
Booley Bay, Wexford	52.137070, -6.928560
Camp Beach, Dingle Peninsula, Co. Kerry	52.229590, -9.907400
Carnsore point, Co. Wexford	52.172460, -6.365070
Dingle Marina, Co. Kerry	52.138160, -10.276330
Dublin bay (site 1), Dublin	53.300420, -6.051370
Dublin bay (site 2), Dublin	53.355470, -6.084850
Dublin bay (site 3), Dublin	53.322980, -6.104760
Dublin Bay, (3BR), Dublin	53.302570, -6.065070
Dublin Bay, near Rosberg Bank (1NB), Dublin	53.364070, -6.100780
Dun Laoghaire Marina, Dublin	53.296850, -6.134770
Dun Laoghaire beach, Dublin	53.292000, -6.128690
Fahamore Pier, Co. Kerry.	52.302180, -10.040630
Garrahies, Camp beach, Kerry	52.229590, -9.907400
Holm Bay, Strangford Lough, Down	54.406090, -5.642230
Horse Island, Strangford Lough, Down	54.465070, -5.543580
Inner Lee's Wreck, Ballyhenry Strangford Lough, Down	54.388450, -5.571580
Islandacorr, Strangford Lough, Down	54.392630, -5.576630
Kilbaha harbour, Clare	52.570770, -9.861668
Kilkee, Clare	52.682706, -9.647571
Killiney, Dublin	53.263147, -6.107423
Kilmore Harbour, Co. Wexford	52.173790, -6.587350

Portaferry Marina, Strangford Lough, Down	54.380310, -5.549300
Portmarnock beach, Dublin	53.420480, -6.119280
Ross Bay, Co. Clare	52.594710, -9.854670
Sand eel bay, Co. Wexford	52.161190, -6.881530
Sandycove beach, Dublin	53.288500, -6.114470
Shanganagh, Dublin	53.238720, -6.111380
Skerries beach, Dublin	53.582160, -6.107950
Sketrick Island, Strangford Lough, Down	54.483500, -5.628570
Slade Beach, Wexford	52.134760, -6.910240
Slade Harbour, Wexford	52.134520, -6.909530
South of Abby Rock, Strangford Lough, Down	54.522970, -5.579580
Strangford Lough, Down	54.418530, -5.597400
The Dam, Strangford Lough, Down	54.447290, -5.540820
The Dorn, Strangford Lough (near Ardkeen), Down	54.434260, -5.544900
Wine Strand, Smerwick Harbour, Kerry	52.177620, -10.368480
Zara Shoal, Strangford Lough, Down	54.370940, -5.552860

Algal substrata were identified to as lowest taxonomic level as possible (i.e. species or genus) but ultimately all algae was recorded as either red, brown or green. Bryozoan colonies were examined under a stereomicroscope and identified to the lowest taxonomic level possible using the identification guides by Hayward and Ryland (1985, 1998, 1999) for Cheilostomatida and Cyclostomatida and Hayward (1985) for the Ctenostomatida. As much bryozoan reclassification is ongoing at present by various researchers, all taxonomic nomenclature was cross-checked and verified using the online resource, the World register of marine species (WoRMS 2017). All bryozoans growing as epiphytes were recorded along with the substrata type.

Weymen (1997) conducted research around the Howth peninsula, Dublin and identified 99 algal species present. In addition to the material examined and collected by the current author, Weyman's specimens were provided by the National Museum of Ireland, and examined to determine the presence of epiphytes. 99 algal samples were available to examine from this study along with data collected during the study. Weyman's specimens were all dried and pressed.

Bryozoan assemblages

The most common species present in all samples was established by determining all species identified as an epiphyte during this research and the number of times it was recorded as such. Substrata preference was identified by establishing the most utilized substratum by the bryozoans.

1.3 Results

A selection of cryptic bryozoans were found encrusting algal specimens of Weymen (1997) but the total number of bryoans samples was not recorded as it was an algal research project. Six bryozoan species were found during the examination of both the specimens and the raw data. The Cheilostomes, *Electra pilosa* and *Membranipora membranacea;* the Ctenostomes *Alcyonidium gelatinosum*, *Flustrellidra hispida* and *Alcyonidium hirsutum*; and the Cyclostome *Patinella verrucaria* were all recorded by Weymen (1997). During the current re-examination of the specimens, only *E. pilosa* (Fig 6.2) was still present on the dried algal specimens.

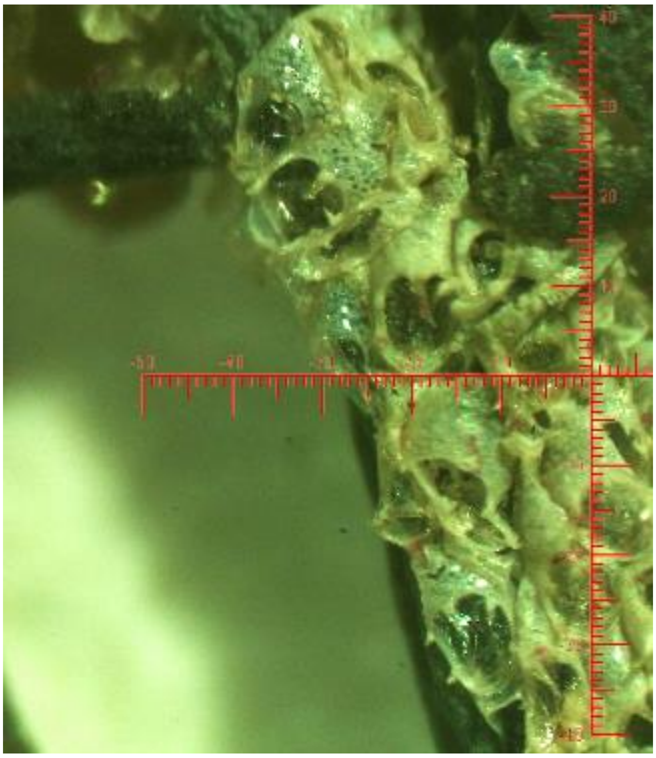

Fig 6.2. Specimen H22 Weyman (1997) collection: *Electra pilosa* on the red algae *Porphyridium purpureum* collected from Howth, Dublin.

In the current study 164 bryoans specimens were found to be either epiphytic or epizooitic. The five most commonly recorded species were *E. pilosa* (22.67%), *C. hyalina* (14%), *C. reticulum* (8.67%), *M. membranacea* (8%) and *C. pallasiana* (6%) were n=164 (Fig. 6.3). Species such as *Amathia imbricata* and *Schizoporella unicornis* were recorded in less than 1% of instances.

In terms of utilization or settlement preference of substrates by the bryozoans (Fig. 6.4) it is observed that Brown algae was the most common substrate settled on with 31.1% of colonies recorded on mostly *Laminaria* and *Fucus.* Bivalves such as oyster, cockle and razor shells were also common substratum in this study with 28% of colonies present on these bivalve shells collected from the shore line. In total 32 species were recorded from 164 spcimens.

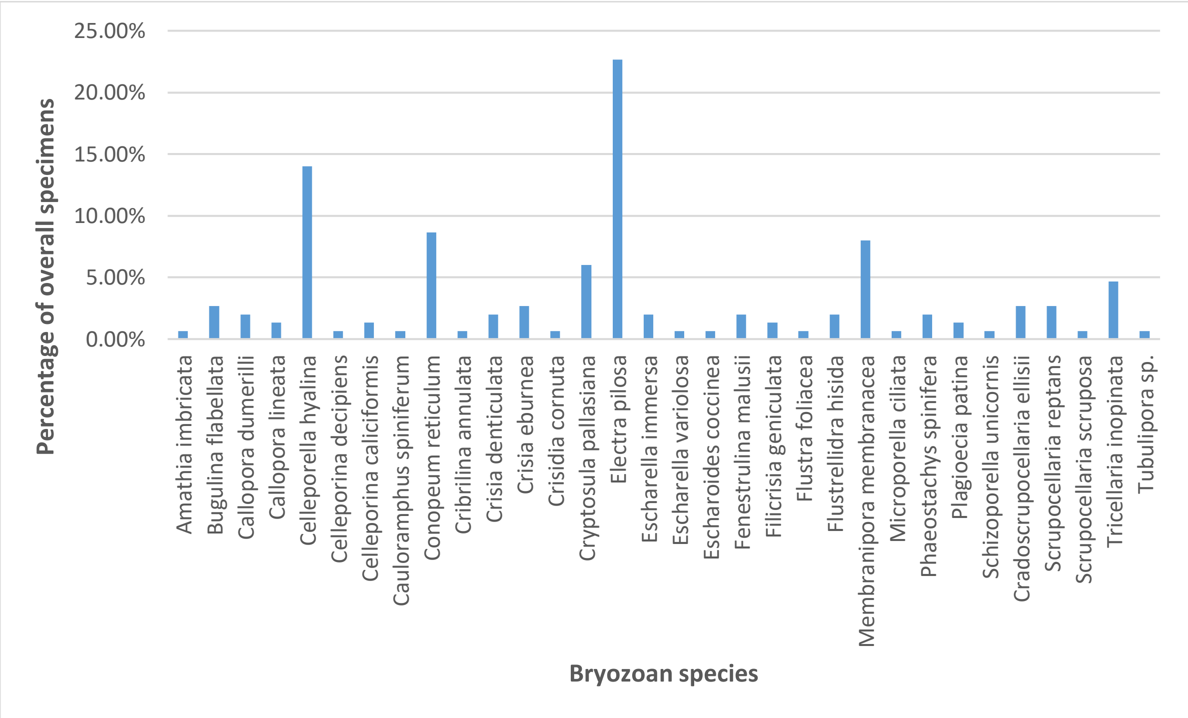

Fig 6.3. Percentage of Bryozoa collected as epiphytes/epizooites on the Irish coast (n=164).

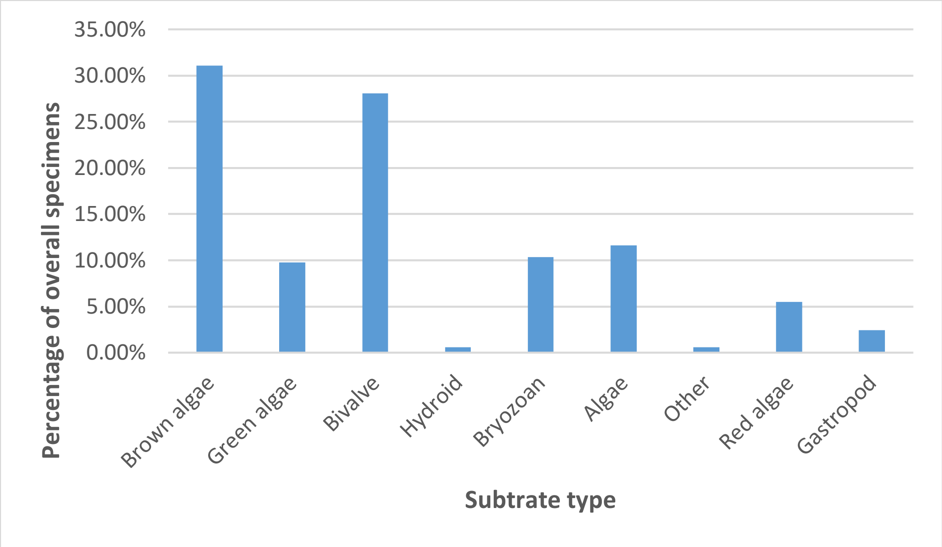

Fig 6.4. Substrate utilization by epiphytic/epizooitic bryozoans from the coast of Ireland (n=164).

Discussion

The six bryozoans identified from the Weymen (1997) specimens were not all present resulting in it being impossible to verify the original taxonomic determination. Half of the species identified were gelatinous species and as the specimens had been dried, these were destroyed during this process. The only species that could be verified was *E. pilosa* encrusting on both red algae (Fig. 6.2) and brown algae. It is expected to find this species on these algal types and consistent with the results from specimens in the present study. *A. hirsutum* and *F. hispida* both breed in alternate seasons with the latter breeding in the summer (Ryland & Porter 2006). In theory this would allow them to be non-competitive in settlement but the location of these species on the thalli was not recorded and could be examined further for this location in a future study.

Identifying *E. pilosa*, *C. hyalina*, *C. reticulum*, *M. membranacea* and *C. pallasiana* as some of the most commonly recorded epiphytic species was similar to findings in studies by Seed & Harris (1980) and Seed & O'Connor (1981) among others. Species of the Order Ctenostomatida were either not recorded, unconsciously ignored during sampling or issues with identification resulted in them not being recorded. As the specimens were not examined for sometime after collection it is probably that ctenostome bryozoans had they been present were desiccated and so undetected or identifiable.

Examination of substratum utilization showed Brown algae and bivalves to be the most common substratum used by the bryozoans in this study although studies have shown that *Flustra foliacea*, included in the bryozoan substrate type here, can have high numbers of epiphytes present (Bitschofsky *et al.* 2011). The bryozoan assemblage of Laminarians and Fucoids has been well documented (O'Connor *et al*. 1980, Seed & O'Connor 1981, Wood & Seed 1992, Stebbing 1979) with comparable results between this study and another carried out in a similar location, Dale, south-west Wales (Seed & O' Connor 1981). Bivalves were collected along the shoreline and the majority were already disarcticulated when collected, there is no way to know if they were home to the bryozoans before or after death or both on many of the bivalve shells as many of the colonies were on the external surface. Studies have observed bryozoans on live bivalves such as commercial oysters and clams (Rodriguez & Ibarra-Obando 2008).

Conclusion

This study aimed to assess the most commonly recorded epiphytes and epizooites from the available records. 32 bryozoan species have been identified as being epiphytic during this study sampling 43 locations in Ireland. *E. pilosa*, *C. hyalina*, *C. reticulum*, *M. membranacea* and *C. pallasiana* were most commonly recorded and this would be be with consistant with information from Hayward and Ryland synopses guides (1998, 1999). The sample set was small (n=164) and a larger scale research project will give more confident results and a better overall picture of Ireland's epiphytes and epizooites. Brown algae was the most commonly utilized algae for epiphyes in this study but more detailed records with algal species names is required to examine this preference any further, this is similar to the epiphytes as species of the host was not recorded. When examining the collection made by Weyman (1998) only *E. pilosa* was found as an epiphyte but as this is just one collection, other algal collections may hold important bryozoan records. Museum collections would be a good source of material for further studies in this area as algae collections have been housed in our museums for many years.

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