Foras na Mara
Marine Institute

CHAPTER 6

COMMERCIAL FISHERIES

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6.1 INTRODUCTION

Fish are a key component of marine ecosystems contributing to food webs as both consumers and prey items. As such they interact closely with their biological, physical and chemical environments. These interactions make them particularly vulnerable to potential impacts of climate change. Sea-surface temperatures in the Northeast Atlantic have risen by between 0.1 and 0.5°C per decade in the past century (Pinnegar *et al.*, 2017). A detailed climate risk assessment carried out across the European marine fisheries sector placed Irish fisheries in the categories of low-medium risk (Payne *et al.*, 2021). As warming is expected to continue, however, more detailed information is required to truly understand the effects of climate change on our marine fish communities.

Around €382M worth of quota fish and shellfish species are caught in the Irish EEZ annually.

This chapter provides an overview of commercial fish stocks in Irish marine waters and highlights a range of stocks, including (a) stocks of economic importance such as Atlantic mackerel, (b) potential stocks such as European anchovy and (c) historically important stocks such as cod. Potential impacts of climate change on fish communities are investigated here. Where there is little information on Irish stocks, we present information from geographically adjacent stocks to identify potential effects on Irish stocks arising from climate change. It can be difficult to disentangle climate change effects from anthropogenic activities most notably the effects of fishing. We present possible methodologies for detecting climate change including a simple community analysis approach and the use of indicator species.

Important commercial species by value include Atlantic mackerel (*Scomber scombrus*), Norway lobster (*Nephrops norvegicus*), monkfish (*Lophius spp.*) and horse mackerel (*Trachurus trachurus*).

6.2 ECONOMIC IMPORTANCE OF IRISH FISHERIES

Marine fishing is of significant importance to the Irish economy with an average number of 500 fishing vessels active daily within Irelands Exclusive Economic Zone (EEZ) (Gerritsen and Kelly, 2019). Ireland has some of the most biologically sensitive and important sea areas in EU waters with major spawning areas of Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), hake (*Merluccius merluccius*) and cod (*Gadus morhua*). Ireland's marine territory is approximately 500,000 km^2 (Government of Ireland, 2020) (Figure 6.1). Ireland's fishing waters are part of the FAO (Food and Agriculture Organization of the United Nations) Northeast Atlantic major fishing area 27 (FAO, 2021) and is further subdivided into ICES (International Council for the Exploration of the Sea) fishing areas (Figure 6.1). Fisheries stocks in Irish waters come under the remit of the EU Common Fisheries Policy (CFP) (EU 380/2013). Except for inshore fisheries, the CFP is enforced through total allowable catches (TAC) with a catch limit set for a particular fishery generally for a year or a fishing season. Around €382M worth of quota species are caught in the Irish EEZ annually (€254M by foreign vessels and €128M by Irish vessels). Irish vessels catch

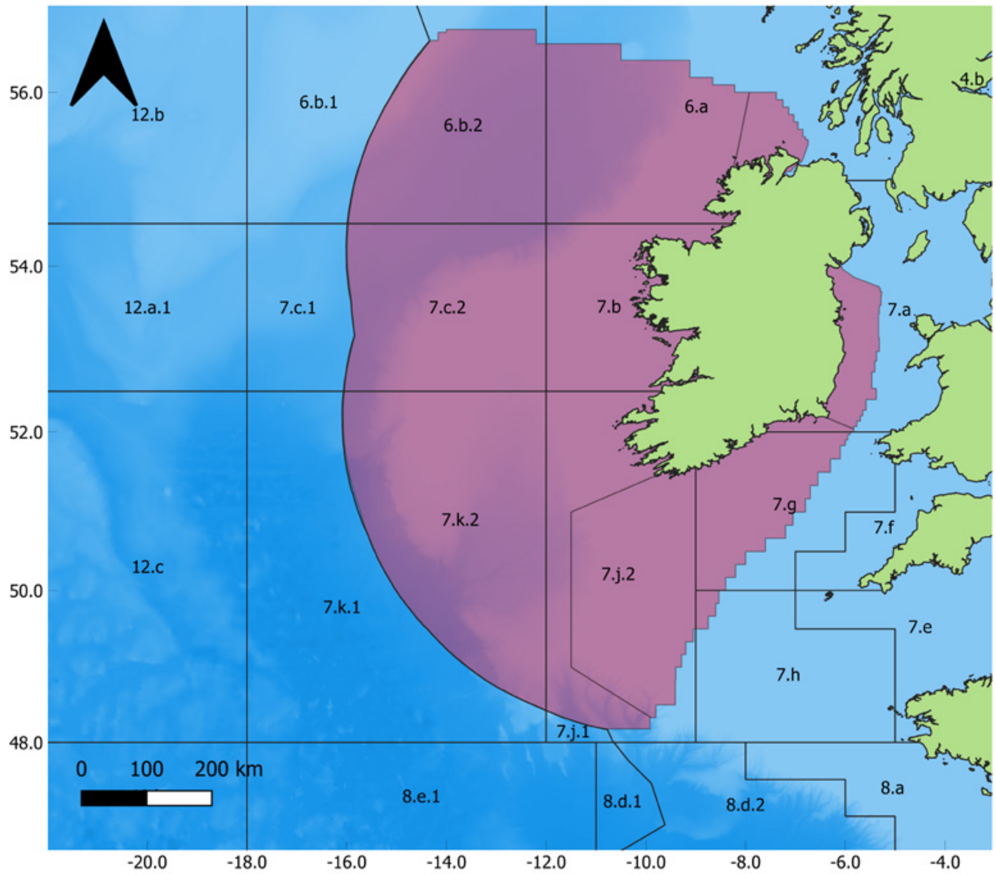

Figure 6.1 Marine waters surrounding Ireland, showing ICES fishing areas and subdivisions and Ireland's exclusive economic zone (EEZ) highlighted in purple.

around €250M worth of quota species annually (Department of Agriculture Food and the Marine, 2022). Figure 6.2 shows (a) live weight in thousand tonnes and (b) values of landings (million euros) of marine species into Irish ports from 1973 to 2020. The value of landings has shown an increasing trend since records began. This general upward trend is also evident after values were adjusted for inflation (Figure 6.2(c)). In 2019, four species; Atlantic mackerel, Norway lobster (*Nephrops norvegicus*), monkfish (*Lophius spp.*) and horse mackerel accounted for 60% of the landed value of fish into Irish ports by Irish vessels with Atlantic mackerel and Norway lobster making up approximately 50% (€118M) of this value (Central Statistics Office, 2020).

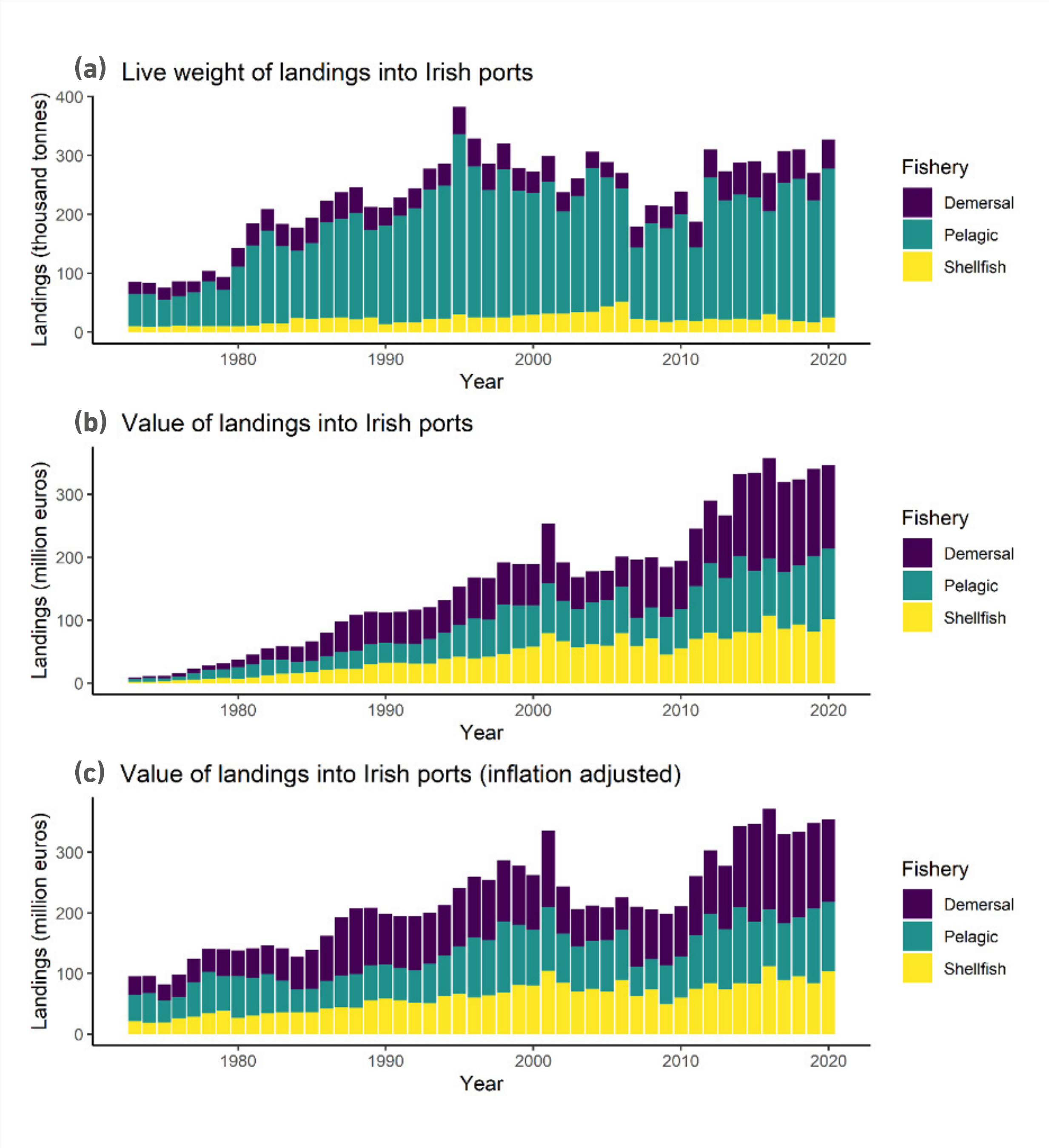

Figure 6.2 Landings into Irish ports of marine species (pelagic, demersal and shellfish[1]) (a) live weights of landings (thousand tonnes), (b) value of landings (million Euros) and (c) value of landings (million Euros) after adjustment for inflation. Data sources: 1973-2004: https://data.gov.ie/dataset/ata04-sea-fish-landings, 2005-2020: https://www.cso.ie/en/statistics/environmentstatistics/fishlandings[2], inflation rates taken from https://visual.cso.ie/?body=entity/cpicalculator.

[1]For further information on species groupings of Irish Commercial fish, please refer to the Appendix 2 in Anon. Atlas of the commercial Fisheries around Ireland, 2009.

[2]Data collected from the Sea Fisheries Protection Authority (SFPA). The SFPA Statistics Unit is responsible for collating all sea-fisheries data, particularly domestic and foreign landings by Irish vessels. Data for Irish fishing vessels of 10 m or longer was obtained from logbooks. Fishing vessels of less than <10 m are not generally required to complete a fishing logbook; landing statistics were gathered using sales notes and gatherers documents. Aquaculture and angling data are not included in this dataset.

6.3 CLIMATE EFFECTS ON FISH COMMUNITIES

Climate change is already affecting marine taxa through changes in ranges, abundance, productivity, mortality, maturity and growth (Pinnegar *et al.*, 2017: Rijnsdorp *et al.*, 2010). Climate models predict that the impact of climate change will differ between geographic areas. In Irish waters, climate change is projected to cause changes in wave height, sea surface temperature (SST), near bottom temperature (NBT), salinity and primary productivity (Chapter 9, this report). Impacts to fish communities will vary not only between geographic areas, but also between species. How a fish species responds to climate change will depend on their ability to adapt (Rijnsdorp *et al.*, 2010). Climate change may impact all stages of the fish lifecycle including (i) size and location of suitable habitat; (ii) retention of eggs and larvae; (iii) match in timing of the fish larvae and their food; (iv) connectivity between habitats of successive life stages; (v) growth; and (vi) predation mortality (Rijnsdorp *et al.*, 2010).

There is a mixture of stock trajectories within the Irish EEZ, with some stocks rebuilding well following overexploitation by fisheries. Average overall fishing mortality rates have declined in the Celtic Seas ecoregion since around the year 2000 with subsequent increases in spawning stock biomasses. Some stocks remain at levels of exploitation above current scientific advice. Declines in over-exploited fish stocks may be exacerbated by climate change.

6.3.1 RECRUITMENT/PRODUCTIVITY

The number of young fish recruited to a stock is dependent on egg production along with survival rates from eggs to juveniles. Fish eggs and spawning adults are particularly vulnerable to environmental processes most notably warming due to climate change (Dahlke *et al.*, 2020). Recruitment can be difficult to predict, with spawning behaviour and environmental conditions all influencing recruitment rates (Brosset *et al.*, 2020). Climate change can affect recruitment through changes to the physical environment or through fluctuations in the abundance and range of prey items such as zooplankton (Brunel and Boucher, 2007). In the North Sea declines in recruitment of cod has been linked to warming induced declines in zooplankton prey species (Brander, 2010). Changes in recruitment may lead to range shifts due to the decreased recruitment success of populations at the southernmost edge of their ranges (Rijnsdorp *et al.*, 2009). A study of 40 fish stocks in the Northeast Atlantic demonstrated that a long-term decline in recruitment was linked to warming SST (Brunel and Boucher, 2007). Conversely warming at the poleward edges of a population range may allow spawning areas to expand northwards.

6.3.2 DISTRIBUTION SHIFTS

A common population response to ocean warming involves the changing distribution of marine fish toward cooler waters and thus frequently poleward. The SST and NBT off southwest Ireland are projected to increase in the next couple of decades (Nagy *et al.*, 2021). Simpson *et al.* (2011) analysed fish species in the Northeast Atlantic and found that 50 common species responded to warming waters by changing distribution and abundance, with smaller bodied warm-water Lusitanian species increasing in abundance while cold-water Boreal large bodied species decreased (Rijnsdorp *et al.*, 2010). This may be a response to recruitment variations and to changes in suitable habitats. Atlantic mackerel is an example of highly publicised commercial fish stock that has expanded its range in the past decade. From the mid-2000s summer feeding populations expanded westward towards south Iceland and east Greenland and northward toward Svalbard (Olafsdottir *et al.*, 2019). The range expansion of the population can be attributed to several factors including an increased stock size, changes in zooplankton biomass and increasing ocean temperatures providing favourable conditions for fish (Overholtz *et al.*, 2011; Kvaavik *et al.*, 2020; Payne *et al.*, 2022). While expansion of a stock's range can provide novel opportunities for fisheries it can also lead to management challenges particularly for stocks like Atlantic mackerel that span several management areas. The range expansion of Atlantic mackerel allowed for the fisheries from Iceland, Faroe Islands and Greenland to begin exploiting the stock (Baudron *et al.*, 2020). Disputes over quota allocations between countries led to the so-called "mackerel wars" in the early 2010s. This study highlights the need for forecasting models that could potentially predict changes in fish distribution. Payne *et al.*, (2022) demonstrated that decadal-scale climate prediction can be applied to the habitat distribution of three fish species (mackerel, blue whiting and blue fin tuna). The study showed that the current conflicts between the European Union, Faroe Islands, Norway and Iceland over Atlantic mackerel fishing quotas (Spijkers and Boonstra, 2017) could have been foreseen using predictive models (Payne *et al.*, 2022).

While fish may experience northward range shifts with the advent of warming waters, there is some evidence that certain species may change their distribution vertically in the water column. Atlantic cod off the Norwegian Skagerrak coast were shown to select shallower vegetated habitats with better feeding opportunities at cooler temperatures while at higher temperatures they showed a preference for non-vegetated rocky bottoms and sand habitats that provided deeper, colder conditions (Freitas *et al.*, 2016; Freitas *et al.*, 2021). With increasing sea temperatures, species may be forced to inhabit deeper habitats with suboptimal feeding conditions as a trade-off for favourable temperature conditions (Freitas *et al.*, 2016). The availability of habitats at suitable depths may constrain the adaptability of demersal fish in particular (Rutterford *et al.*, 2015). As there is commonly a decoupling between SST and NBT, either due to lateral current flow or seasonal stratification (Rheuban *et al.*, 2017), it is vital to understand the projected spatial and temporal variability of the water column for future management of fisheries (Rheuban *et al.*, 2017).

Disentangling long-term fishing effects from the impacts of climate change is difficult. Climate change cannot be examined in isolation of these effects.

6.3.3 BODY SIZE AND GROWTH

As oceans warm they will also experience deoxygenation which can have consequences for fish metabolism and physiology. Marine fish as ectotherms are expected to develop faster but reach smaller adult body sizes due to the interactive effects of temperature and oxygen availability (Ohlberger *et al.*, 2011). Evidence of body size changes has already been noted in certain fish species found in Irish waters. Decreases in size at age for herring in the Celtic Seas ecoregion was noted since the mid-1980s (Lynch, 2011). Lyashevska *et al.*, (2020) related this decline in adult size to increases in sea surface temperature during the first growing season. Negative relationships between growth and temperature were noted in other fish stocks including haddock in the North Sea (Baudron *et al.*, 2011) and Mediterranean fish populations (Shapiro Goldberg *et al.*, 2019). Declines in growth can also be attributed to food availability, density dependant and fishing effects (van Walraven *et al.*, 2010; Lyashevska *et al.*, 2020).

Warming waters may allow for new fishing opportunities (e.g. boarfish and anchovy), but it is imperative that new opportunities are managed effectively and sustainably.

CASE STUDY

THE CASE OF SNAKE PIPEFISH (*ENTELERUS AEQUORAEUS*)

Increases in rare migrant species from more southerly waters is one of the expected outcomes of warming waters, however, scientists and policy makers must be careful not to attribute all unexpected changes in distributions to climate change. The increase of snake pipefish (*Entelerus aequoraeus*) in the North Sea in 2003 and subsequently in Irish waters was attributed at the time to rising sea surface temperatures facilitating increased fecundity of the species (Kirby *et al.*, 2007). Since 2008 however, numbers of this species have declined in the Irish Groundfish Survey (IGFS) despite a continuing upward trend in sea surface temperature (SST) (Figure CS6.1). This decline in abundance was seen throughout its geographic range (Heath *et al.*, 2012). There is some anecdotal evidence of mass mortality events of this species in the Atlantic Ocean and North Sea previously (Brongersma-Sanders, 1957). Whether these mass mortality events were linked to previous population explosions is unknown. Natural fluctuations in fish populations, such as snake pipefish, highlight the importance of long-term monitoring if we are to accurately model the impacts of climate change on marine ecosystems.

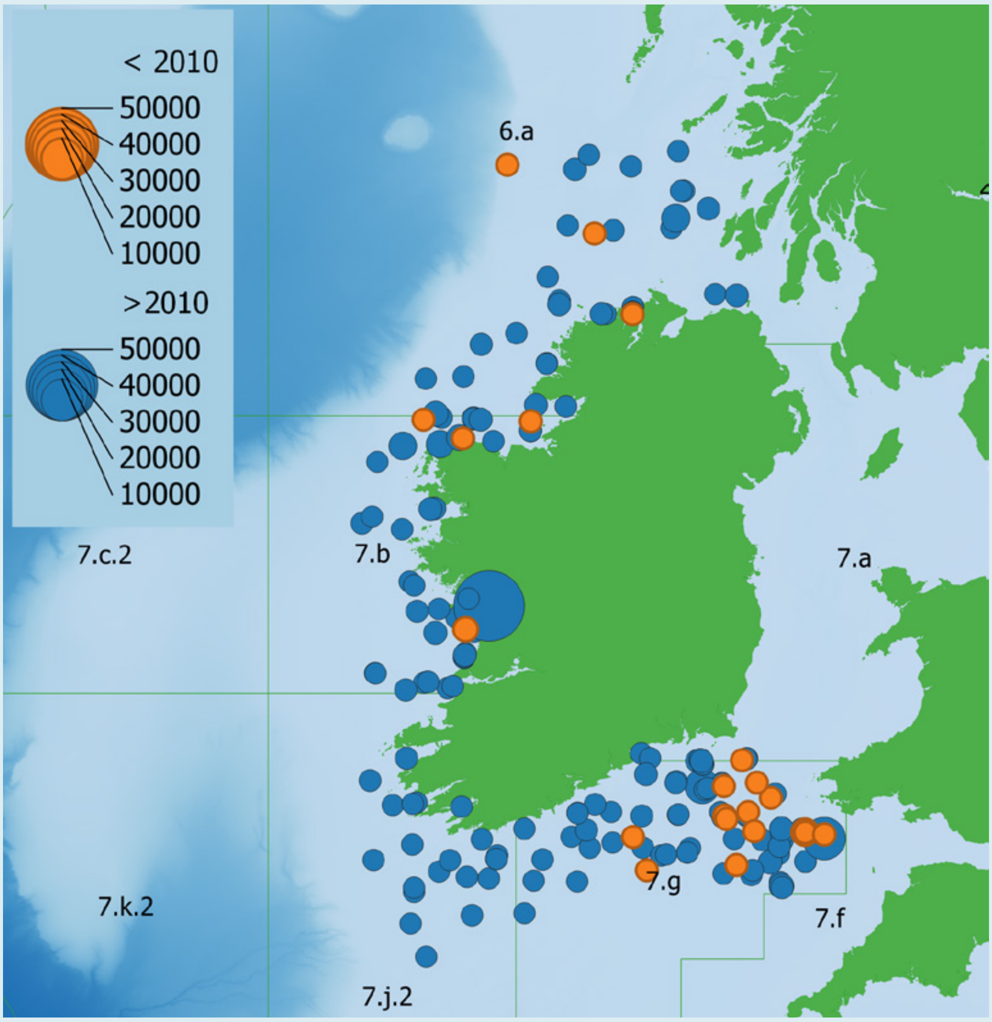

Figure CS6.1 The distribution (no/km^2) of Snake Pipefish (*Trisopterus minutus*) from the Irish Groundfish Survey from 2003–2008 (orange circles) and 2009–2020 (blue circles).

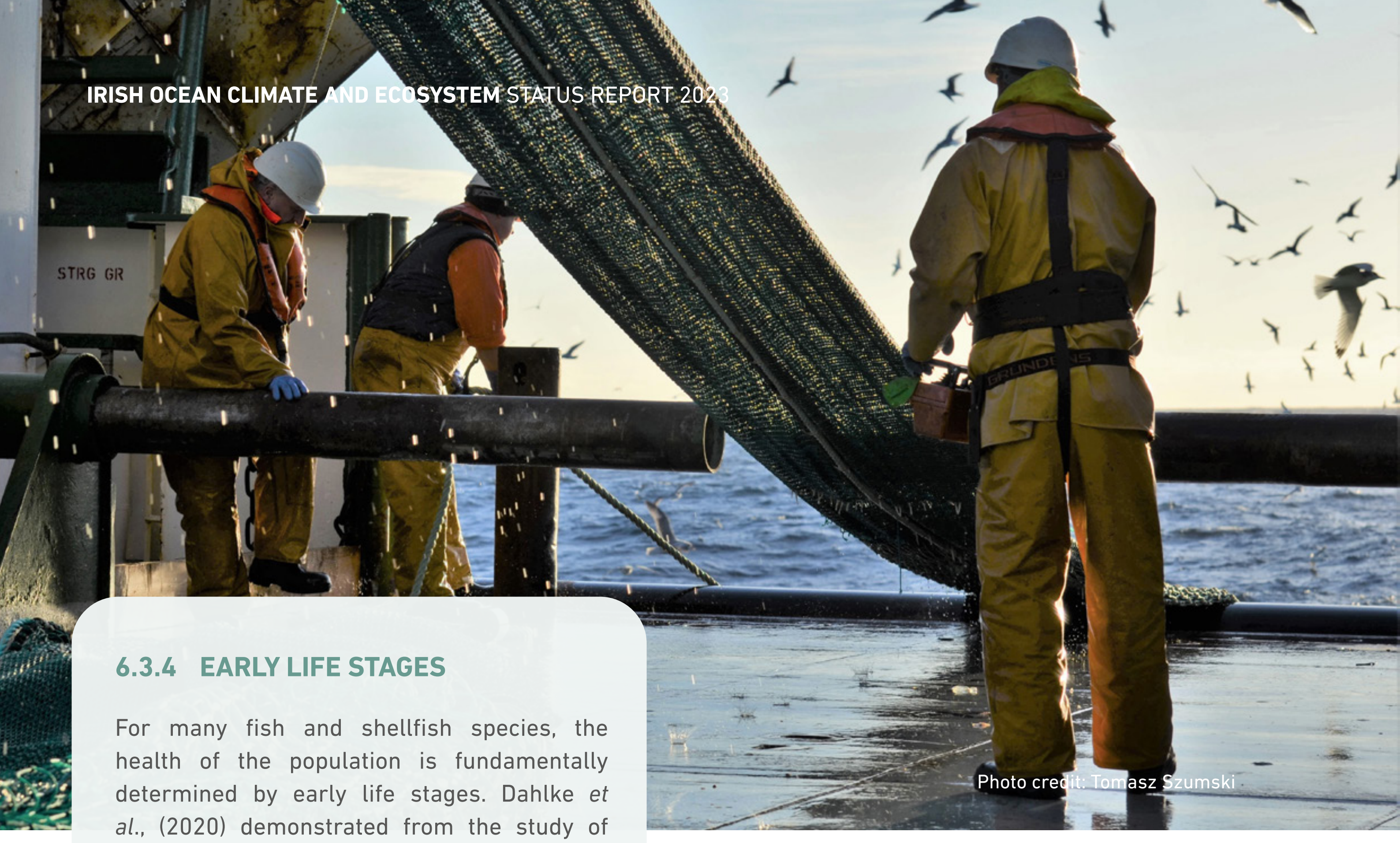

Photo credit: Tomasz Szumski

6.3.4 EARLY LIFE STAGES

For many fish and shellfish species, the health of the population is fundamentally determined by early life stages. Dahlke *et al.*, (2020) demonstrated from the study of 694 marine and freshwater fish species that spawning adults and embryos have narrower thermal tolerance ranges than other life stages. They hypothesised that the "thermal bottlenecks" may define the vulnerability of fish to thermal changes caused by climate change. Physiology and growth rates of larvae are also affected by environmental temperatures (McGeady *et al.*, 2021). McGeady *et al.* (2021) modelled larval transport of the Norway lobster (*Nephrops norvegicus*) in the Irish Sea and, demonstrated that embryo incubation and release of larvae occurred 17.2 days earlier in the period of 2000–2010 than in 1982–1995. The 17.2 day earlier release time accompanied a 0.9°C increase in surface water temperature coinciding with the incubation period (McGeady *et al.*, 2021).

Oceanographic environments are complex with many physical and biological interactions. This can make it difficult to estimate the effects of parameters on early life stages, demonstrated particularly when examining the abundance of the mesopelagic gadoid blue whiting (*Micromesistius poutassou*). Stocks of blue whiting in the Northeast Atlantic show fluctuations in abundance over time. Payne *et al.* (2012) postulated several hypotheses to explain the variations in abundance including large mackerel feeding on blue whiting pre-recruits and variations in the physical environment affecting the food type available to larvae. When the sub-polar gyre (See Chapter 3 of this report for more information) is strong (large in size), cold fresh water spreads east over the Rockall plateau limiting blue whiting spawning to a narrow area along the European continental slope and to the south of the Porcupine Bank (Hátún *et al.*, 2009). When the gyre is weak (constricted) blue whiting spawning spreads northwards and westwards along the continental slope over the Rockall plateau (Hátún *et al.*, 2009). Spawning of blue whiting appears limited to a salinity window of 35.3 to 35.5 (Miesner and Payne, 2018). Weak gyre conditions are associated with more saline, warm water conditions (Hátún *et al.*, 2009). Spatial overlap between blue whiting pre-recruits and their mackerel predators may be regulated by the sub-polar gyre (Payne *et al.*, 2012). Mackerel spawning distribution is limited to the continental shelf edge during March to April and covers more of the blue whiting spawning area from April to May (ICES, 2011). In years with strong gyres, the spatial overlap between spawning distribution of both species is limited, restricting opportunities for mackerel to prey on blue whiting. Hydrographic surveys have indicated that the Northeast Atlantic is currently in a period of freshening (González-Pola *et al.*, 2020) constricting the habitat typically associated with blue whiting. Future climate model projections, up to 2035, estimate that surface and bottom waters off southwest Ireland will continue to freshen (Nagy *et al.*, 2021).

6.4 STATUS OF MAJOR STOCKS

Overall, fishing mortality rates have declined in the Celtic Seas ecoregion since around the year 2000 with subsequent increases in spawning stock biomasses on average (ICES, 2021a). Forty-seven percent of stocks are fished below F_{MSY}, but not all stocks are currently fished at fishing mortality rates commensurate with long-term maximum sustainable yield (MSY), with 15% fished above this rate and 37% with unknown or not defined exploitation rates in 2021 (Marine Institute, 2021). While overexploitation was significantly addressed within the region, there are stocks that are still overfished. The effects of climate change on a stock will depend not only on the biology and ability to adapt to change, but also on the current stock status. The health of stocks is monitored through implementation of the CFP and collection of data under the data collection framework (DCF) Directive (EC 665/2008; 2010/93/EU). Data collected from these programmes also feeds into the EU Marine Strategy Framework Directive (MSFD) (2008/56/EC), which was instigated in 2008 in an effort to protect the marine environment across Europe (Marine Strategy Framework Directive, 2008). The Directive requires Member States to take appropriate action to maintain or achieve Good Ecological Status (GES) by 2020. In terms of commercial fisheries, it aims to restore and maintain populations of harvested species to levels that can produce the MSY and minimise wider impacts of fishing on the ecosystem (Department of Housing Planning and Local Government, 2019). In the latest assessment, GES was achieved for five of the eleven qualitative descriptors used to assess the quality of marine waters. Commercial fisheries are covered under Descriptor 3 – Commercially Exploited Fish and Shellfish and GES was not fully achieved. A total of 34 stocks (18%) have achieved GES, while the environmental status of 99 stocks (60%) is currently unknown. GES was not achieved for 44 of the remaining stocks (Department of Housing, Local Government and Heritage, 2021).

Ireland's position in the Northeast Atlantic supports a wide variety of fish stocks with varying biogeographic affinities (Lusitanian/Boreal/Atlantic). Depending on the life history of the population, potential impacts of climate change can be very different. Due to this diverse nature of marine habitats in Irish waters, numerous stocks of importance are exploited by vessels from more than one country. International cooperation is required to accurately access the health of these stocks. Most scientific assessments and advice for stocks in Irish waters is delivered by the International Council for the Exploration of the Sea (ICES). ICES provides scientific advice to governments and international regulatory bodies that manage fisheries stock assessments. ICES stock assessment data is presented for six stocks found in Irish or adjacent waters with a mixture of biogeographical affinities (Table 6.1, Figure 6.3). Example stocks are highlighted with respect to their biogeography, life history, fisheries and climate vulnerability.

For future management of demersal fisheries such as hake, cod, whiting and haddock, it is vital to understand the projected spatial and temporal variability of both sea surface temperatures and near bottom temperatures.

6.4.1 HERRING AND COD

Herring and cod are cold water (boreal) species and are at the southern limit of their range. Both species demonstrate overall declines in spawning stock biomass (SSB) over their respective time series. This can be attributed to overexploitation in the 1970s and 1980s (Cook *et al*., 1997; Cushing, 2001; Kelly *et al*., 2006). Fishing pressure on the Celtic Sea cod stock is above the reference points FMSY, Fpa, and Flim and spawning-stock biomass is below MSY $B_{trigger}$, B_{pa}, and B_{lim} (ICES, 2021b). Since 2017, cod SSB was below B_{lim} indicating that recruitment has a high likelihood of being "impaired". Forecasting models using a range of projected climate change scenarios predicted declines in abundance of Atlantic cod in the Celtic Seas (Maltby *et al*., 2020).

Historically, herring was one of the most important pelagic species caught by Irish fisheries. Stock collapses in the Celtic Seas ecoregion in the 1970s and early 2000s led to catches dropping from over 150,000 tonnes in the 1970s to present levels of less than 2,000 tonnes. Current assessments of herring stocks in the Celtic Sea and west of Scotland categorise SSB levels to be at the lowest levels seen since the time series began in the 1950s (ICES, 2021c). For 2022, ICES recommendations is for a zero catch where a precautionary approach applies (ICES, 2021c). Herring and cod are highly susceptible to potential ocean warming. As noted in section 6.3.3, herring in the Celtic Seas ecoregion show steady decreases in size at a given fish age from the mid-1980s, which can be partially explained by rising sea temperatures (Lyashevska, *et al*., 2020). This decline in size may lead to an increased vulnerability of herring in the Celtic Seas ecoregion which is already at the southern limit of its range.

6.4.2 ATLANTIC MACKEREL AND BLUE WHITING

Atlantic mackerel (*Scomber scombrus*) in the Northeast Atlantic is a migratory, widely distributed pelagic schooling fish. Atlantic mackerel stocks in the Northeast Atlantic are relatively stable with fishing mortality approximately at F_{MSY} and SSB greater than $MSY\ B_{trigger}$ (ICES, 2021d). From 2010-2019, the value of Atlantic mackerel catches landed into Irish ports amounted to an average of approximately €46M making it the most economically important stock to Ireland. While Atlantic mackerel stocks appear stable, changes in migration and spawning patterns have been evident over the last decade (Astthorsson *et al*., 2012; Bruge *et al*., 2016). Since 2007, large numbers of Atlantic mackerel were observed in the waters around Iceland allowing for the development of a direct fishery in the Icelandic Exclusive Economic Zone (Astthorsson *et al*., 2012; Bruge *et al*., 2016).

Table 6.1 Common characteristics of six stocks from Irish and adjacent waters.

Common Name	Latin Name	Habitat	Biogeographical affinity	Fish Stock Code	Stock Location
Cod	*Gadus morhua*	Demersal	Boreal	cod.27.7e-k	Celtic Sea and west of Scotland
Herring	*Clupea harengus*	Pelagic (Benthopelagic)	Boreal	her.27.6a7bc	Celtic Sea and west of Scotland
Atlantic mackerel	*Scomber scombrus*	Pelagic (Epipelagic)	Atlantic/ Migratory	mac.27.nea	Northeast Atlantic and adjacent waters
Blue whiting	*Micromesistius poutassou*	Pelagic (Mesopelagic)	Atlantic/ Migratory	whb.27.1-91214	Northeast Atlantic and adjacent waters
European hake	*Merluccius merluccius*	Demersal	Lusitanian	hke.27.3a46-8abd	Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay)
European anchovy	*Engraulis encrasicolus*	Pelagic	Lusitanian	ane.27.8	Atlantic Iberian waters

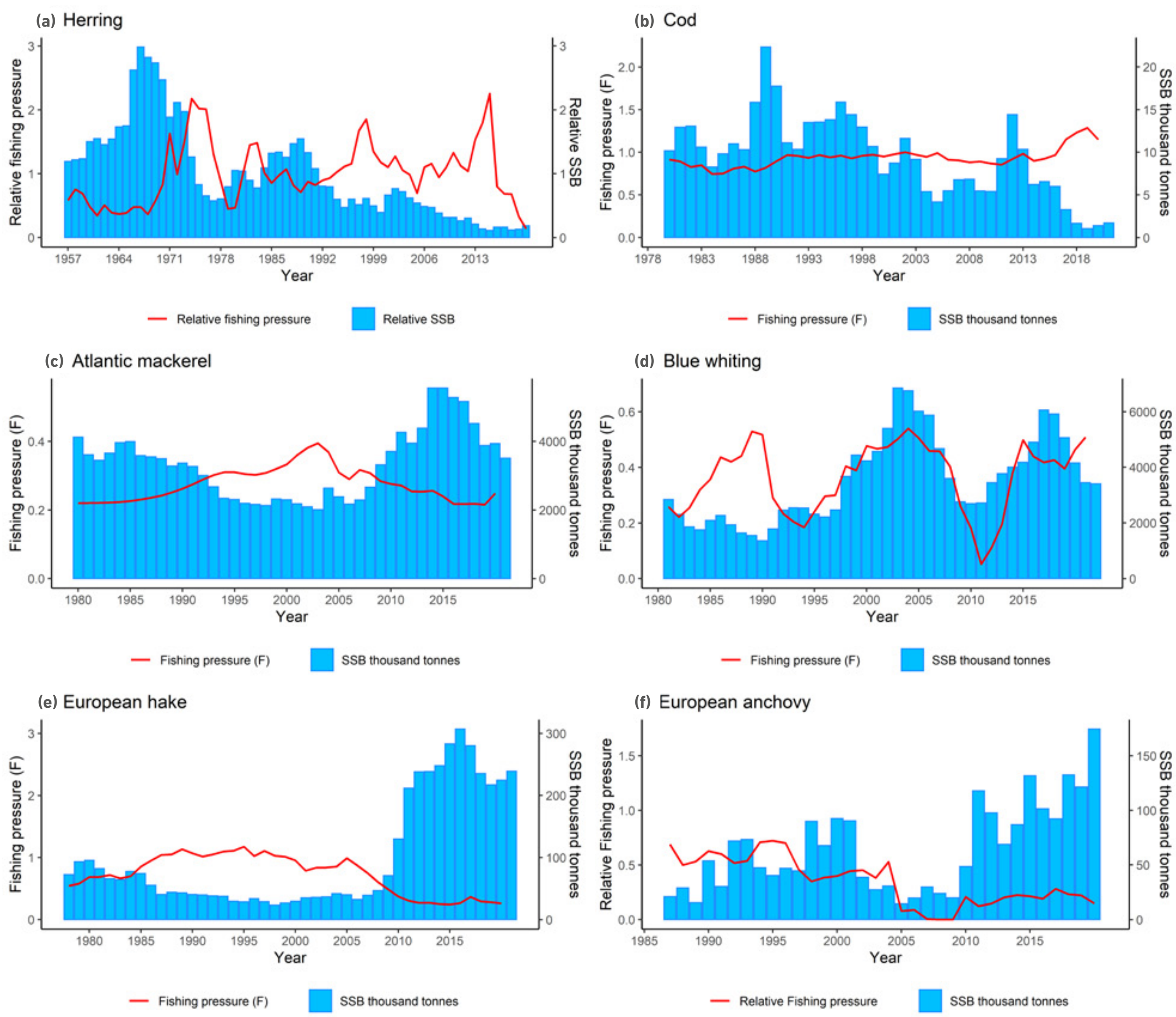

Figure 6.3 Fishing pressure F (blue bars) and spawning stock biomass SSB (red line) of six commercial species in Irish and adjacent waters (data source: http://standardgraphs.ices.dk/stockList.aspx), (a) Herring (*Clupea harengus*), Celtic Sea and west of Scotland stock, (b) Cod (*Gadus morhua*), Celtic Sea and west of Scotland, (c) Atlantic mackerel (*Scomber scombrus*), northeast Atlantic and adjacent waters, (d) Blue whiting (*Micromesistius poutassou*), northeast Atlantic and adjacent waters, (e) European hake (*Merluccius merluccius*), northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay), and (f) European anchovy (*Engraulis encrasicolus*), Atlantic Iberian waters. Note: the different timescales over which the data is available. Fishing pressure in graphs (a) and (f) and SSB in graph (a) are expressed as relative to mean over assessment period.

Blue whiting (*Micromesistius poutassou*) is a pelagic gadoid fish closely related to cod, haddock and hake. Found over the continental slope and shelf to more than 1000 m, it is more commonly found at depths of 300–400 m. Estimates of the spawning stock of blue whiting in the Northeast Atlantic is carried out by the annual international blue whiting spawning stock survey that targets spawning and post-spawning fish. The 2022 survey estimated that the total stock biomass (TSB) of blue whiting in the area was 2.7 million tonnes, representing a 15% increase in biomass from the previous survey (Marine Institute, 2022). While in recent years blue whiting SSB has declined from a high of approximately 6.2 million tonnes in 2018 (Figure 6.3(d)), the stock size remains above B_{lim}. A 4% increase in SSB was noted in 2022 compared to 2021 however, the fishing pressure on the stock remains above F_{MSY} and F_{lim} (ICES, 2022).

There is some evidence of increases in warm water (Lusitanian) species to the south of Ireland (2003-2020). Increased abundance of European anchovy has been noted in both scientific surveys and commercial catches.

6.4.3 EUROPEAN HAKE AND EUROPEAN ANCHOVY

Hake and anchovy are considered Lusitanian (warm water) species. Under a warming ocean scenario, it is expected that Lusitanian species will expand poleward (see Section 6.3.2). Figure 6.3(e) shows fishing pressure and landings from the northern stock of European hake; in general, there is a rising trend in SSB from the mid-2000s to present. In 2009 a recovery plan, was implemented by the European Commission to improve northern hake stocks in European Union waters. This has led to a decrease in fishing mortality and an increase in SSB (Figure 6.3(f)). Increases in hake are mostly attributed to implementation of a more sustainable exploitation regime (Baudron and Fernandes, 2015). However, an increase in suitable habitats due to warming may allow further expansion of this species.

While not yet a major stock in Irish waters, recent evidence indicates that European anchovy may be increasing in numbers. There is no stock assessment data for the European anchovy in Irish waters, however, data from the 2020 Celtic Sea herring acoustic survey indicated high densities of anchovy from Helvick to Waterford harbour within 10 nmi of the coast (O'Donnell *et al.*, 2020). Higher densities of anchovy have also been noted in the groundfish survey carried out in Irish waters annually (Figure 6.4). European anchovy is a pelagic species that forms large schools. and there is some evidence of anchovy increasingly being caught in commercial fishery catches (Siggins, 2020). Figure 6.3(f) presents data from the Atlantic Iberian European anchovy stock to the south of Ireland. The SSB has increased in the last decade. European anchovy has been observed in increasing quantities in northern European and Baltic waters (Alheit *et al.*, 2012). As a small pelagic clupeoid fish, anchovy can respond quickly to changes in climate and can often be used as an indicator of ecosystem change (Lehodey *et al.*, 2006; Checkley *et al.*, 2009; Alheit and Bakun, 2010). To date there is no indication of anchovy spawning in Irish waters. The expansion of anchovy into the Baltic Sea in the mid-1990s has been attributed to a combination of global warming, strengthening of the North Atlantic Oscillation (NAO), the positive phase of the Atlantic Multidecadal Oscillation (AMO) and sub-polar gyre contraction (Alheit *et al.*, 2012). With water temperatures set to continue increasing in the waters surrounding Ireland (Chapter 9, this report) it is reasonable to assume that an increased presence of fish species with southern biogeographic affinities may occur. It is thought that historical changes in the distribution and abundance of these species occurred in response to changes in NAO, AMO and the Subpolar Gyre. Further research is needed to identify what the added effect of climate change will have on these variations and how fisheries managers can respond to maintain sustainable populations.

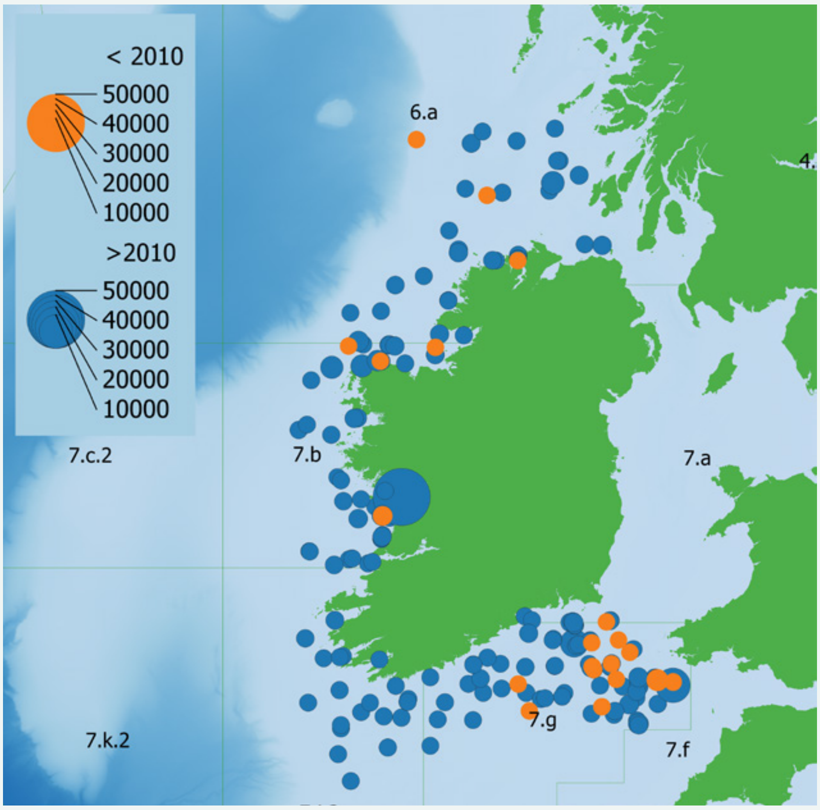

Figure 6.4 The distribution (no/km²) of European anchovy (*Engraulis encrasicolus*) from the Irish Groundfish Survey from 2003–2009 (orange circles) and 2010–2020 (blue circles).

6.4.4 POTENTIAL FOR NOVEL FISHERIES

As the abundance of warm-water species increase in Irish waters, they may become a viable option for exploitation by fisheries. While we have yet to see any significant exploitation of the European anchovy by vessels in Irish waters, other novel fisheries have developed in the last decade. Elevated numbers of boarfish (*Capros aper*) in the early 2000s led to the development of new pelagic trawl fishery targeting this species. Boarfish are small deep bodied fish, growing up to 23 cm in length but are typically smaller up to an average of 12.9 cm (White *et al*., 2011). They are a mesopelagic shoaling species often associated with the continental shelf edge, an area of high productivity (O'Donnell *et al*., 2012). As a Lusitanian species, elevated water temperatures may be contributing to its increased numbers in more northerly waters (Coad *et al*., 2014). The boarfish fishery is conducted in shelf waters to the south and southwest of Ireland and northern Biscay (ICES, 2021e).

It is important that any novel fishery that arises from distributional shifts are managed sustainably. The boarfish fishery was unrestricted until 2010 with a total catch of 144,047 tonnes reported that year. The biomass rapidly declined in subsequent years, with a TAC of 33,000 tonnes implemented from 2011 in ICES Subareas 6, 7 and 8. In 2020, Ireland took 14,666 tonnes out of a total catch of 15,649 tonnes (ICES, 2021e). Any exploitation of potential new stocks (e.g. European anchovy) should be approached with caution, allowing for development of effective management strategies. This will ensure species are exploited at a level that will maintain a maximum sustainable yield (MSY) while still contributing to the Irish fishing industry and economy.

Photo credit: Jonathan White

6.5 ASSESSING CLIMATE IMPACTS IN IRISH WATERS

Perhaps the biggest challenge to determining climate change impacts on fish species is disentangling the simultaneous pressure of fishing (ter Hofstede and Rijnsdorp, 2011). Declines in species abundance such as cod and herring in the Celtic Seas ecoregion can be attributed to fishing making it difficult to extract information on the effects of climate change on these stocks. Additionally, an over-exploited stock may be more sensitive to further environmental perturbations (Minto *et al.*, 2008) making them more sensitive to climate change effects.

6.5.1 CLIMATE INDICATOR SPECIES

To investigate climate change effects, Nolan *et al.* (2010) suggested using climate indicator species defining them as species with the following characteristics:

1. A preference for waters generally cooler or warmer than those surrounding Ireland.
2. Resilience to fisheries activities.
3. Generally, well sampled by scientific surveys/observers such that their distributions and abundances are known.

A potential species fitting these criteria is the Lusitanian species poor cod (*Trisopterus minutus*). Poor cod are caught regularly in the Irish Groundfish Survey (IGFS), a fisheries independent scientific survey carried out annually as part of the International Beam Trawl Survey. Poor cod increased in density (number per km^2) to the north of Ireland (VIa) from 2003 to 2010. However, abundance declined from 2011 to 2020 (Figure 6.5). These decreases have been mirrored in other areas to the south of Ireland (VIIj and VIIg). Further research is required to investigate whether the fluctuations in potential indicator fish species can be related to climate change.

6.5.2 COMMUNITY RESPONSE

Likely climate change effects on Irish fish stocks have already been demonstrated in various studies mostly focusing on individual stocks and species (Lyashevska, *et al.*, 2020; McGeady *et al.*, 2021). In order to examine the fish community as whole and following the methods of Lynam *et al.* (2010) we took a community level approach to examine the effect of ocean warming on fish communities in Irish waters. Fish sampled by the IGFS from 2003 to 2020 were grouped by their biogeographic affinity for warmer (Lusitanian) or cooler (Boreal) waters. The temporal trends were evaluated for each species using a Mann–Kendall test with

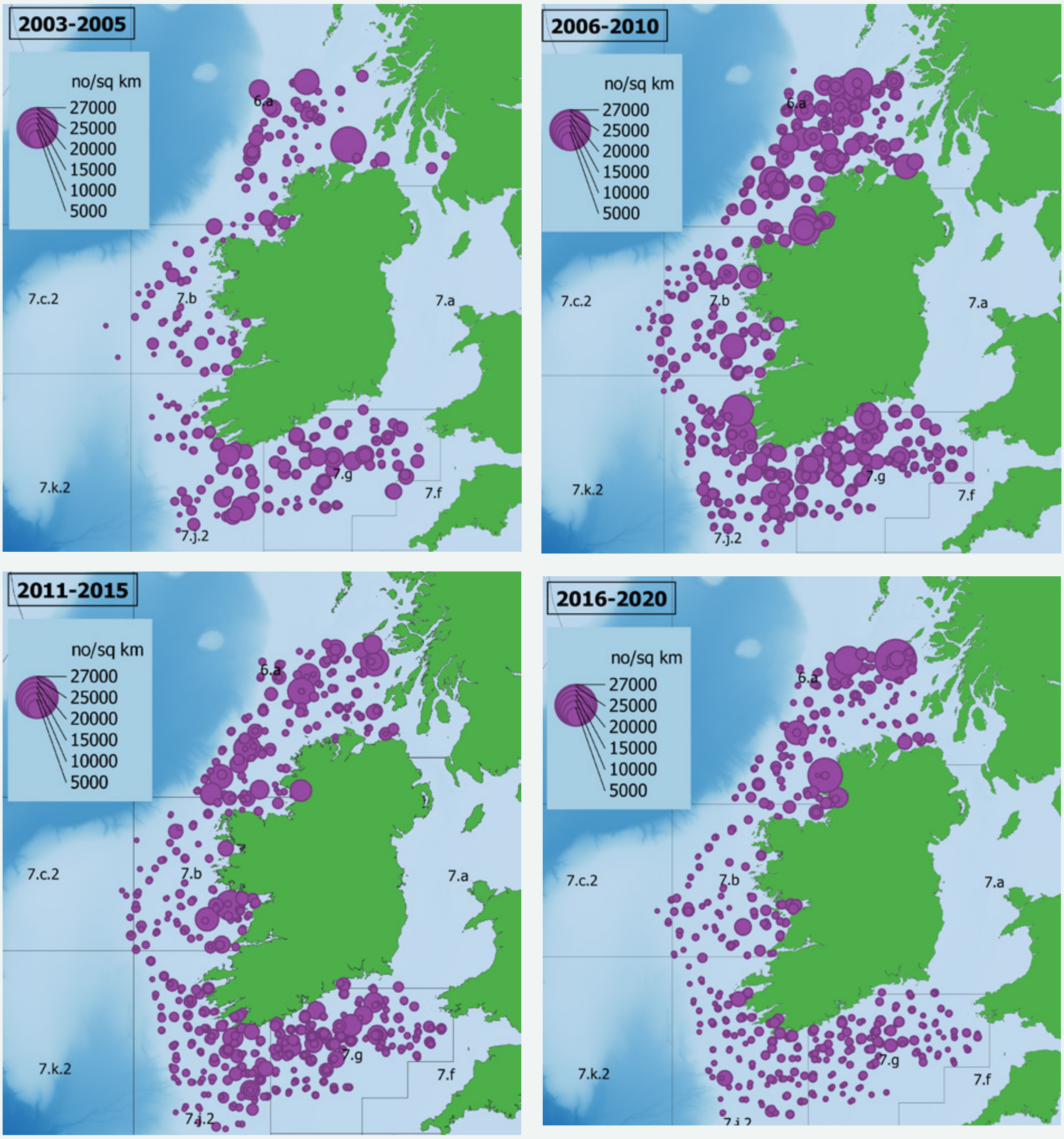

Figure 6.5 The distribution of poor cod (*Trisopterus minutus*), (2003–2020) from the Irish Groundfish Survey, where bubble size indicates density in numbers per km^2.

the resulting distribution of tau coefficients (correlation between relative abundance and time) compared to a null distribution. Deviation from the expected null distribution allows inference on whether taxonomic groups are increasing or decreasing overall in different areas (Figure 6.6). Previous analysis of IGFS data showed Boreal taxa were significantly decreasing in the south while Lusitanian species were increasing in the north and west (Lynam *et al.*, 2010). The current analysis updates the time series adding in the IGFS data from 2008 to 2020. In the updated analysis no significant increasing or decreasing trends were noted in the Boreal communities. The Lusitanian communities in the southeast (ICES division 7g) and southwest (ICES division 7j) showed significantly increasing trends ($p < 0.001$*). While it is difficult to assign changing fish distributions to climate change, increases in Lusitanian species such as anchovy (*Engraulis encrasicolus*) may indicate a response to warming waters. Therefore, although individual species such as anchovy show changes in distribution, there is little evidence at the community level for a broad-scale expansion of warm-water Lusitanian species or a contraction of cold-water Boreal species in the Celtic Seas ecoregion. Further study is needed to analyse these changes in distribution. In particular, it is important that future studies investigate the effects of climate in conjunction with fishing effort. This research was carried out under the ClimFish project ("Impacts of Climate Change on Commercial Fish Stocks in Irish Waters"), a collaboration between the Marine and Freshwater Research Centre at the Atlantic Technological University, Galway and the Marine Institute. The project is carried out with the support of the Marine Institute and is funded under the Marine Research Programme by the Irish Government.

Increases in some species may be due to natural long-term fluctuations in abundance (e.g. snake pipefish). This highlights the value of historical documentation and long-term datasets that monitor beyond commercial stocks.

MANN–KENDALL TEST

A Mann–Kendall Test is used to determine whether a time series has a monotonic upward or downward trend. The null hypothesis for this test is that there is no trend. For the time series $x_1, .., x_n$, the MK Test uses the following statistic:

$$s = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_i)$$

Note that if $S > 0$ then later observations in the time series tend to be larger than those that appear earlier in the time series, while the reverse is true if $S < 0$.

* p values from analyses were corrected for multiple tests using a post-hoc Bonferroni correction.

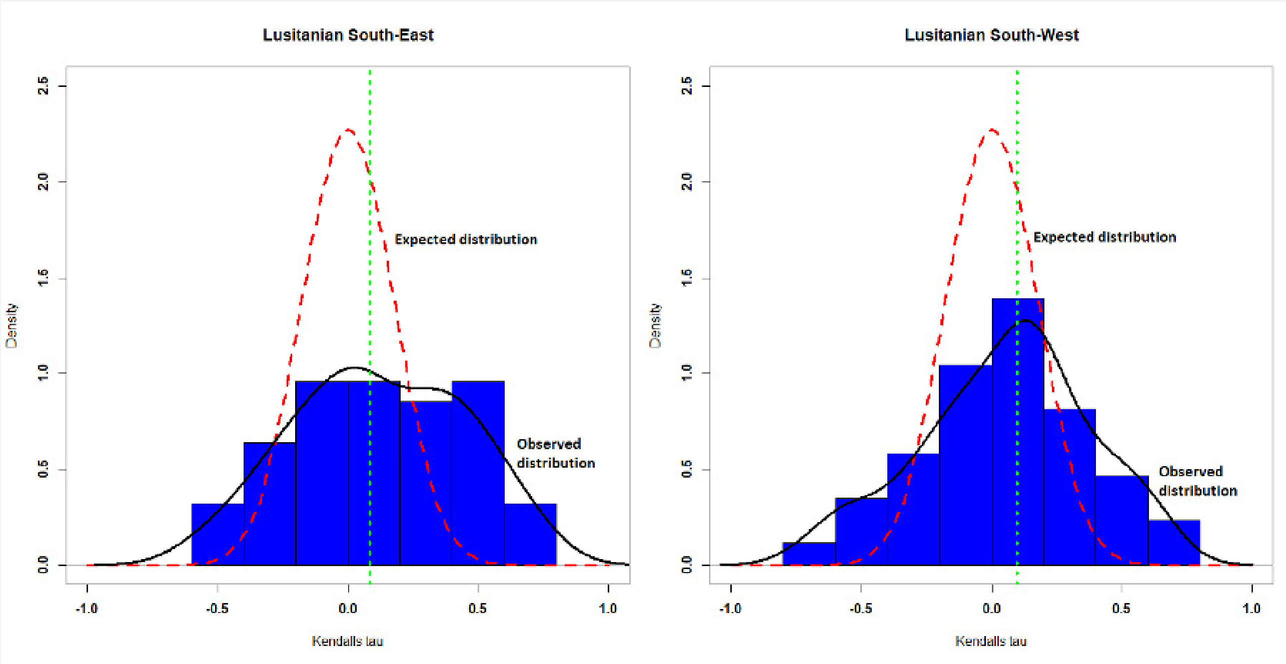

Figure 6.6 Observed histograms (blue bars) with smoother (black lines) of coefficients (Kendall's tau) by area for Lusitanian (warm water species) taxa sampled by the Irish Groundfish Survey, in the southern areas (ICES division 7g and 7j). The red dashed line represents the expected distribution while the green dashed line is the median value of all the observed values. The departure of species to the right of the expected distribution suggests more species are increasing in abundance than expected by chance.

6.6 FISHERIES MANAGEMENT IN A CHANGING CLIMATE

For many fish stocks in Irish waters the primary driver of abundance trends continues to be exploitation by fishing (Kempf *et al.*, 2022). With continued sea warming however, the effects of climate change will likely become more evident. A well-managed fishery will be more resilient to climate change than a degraded stock (Pinnegar *et al.*, 2017). Global climate change poses a significant challenge to fisheries management with models indicating a likely global decline in marine production (Tittensor *et al.*, 2021). However, the regional effects of climate change are less clear (Bahri *et al.*, 2021). An adaptive approach to fisheries management is critical to maintain fish stocks in an uncertain changing environment (Bahri *et al.*, 2021). Current fisheries management is largely based around single species stock assessments and the use of reference points to promote fisheries yields at sustainable levels. Reference points are commonly defined using the Maximum Sustainable Yield (MSY) approach, but, this approach does not commonly allow for fluctuations in ecological processes (FAO, 1995). With the advent of potential ecosystem shifts associated with climate change, a more holistic approach to fisheries management may be needed. In recent years, there has been a move towards implementing an Ecosystem Approach to Fisheries Management (EAFM) in combination with the traditional stock assessment methods (Howell *et al.*, 2021). An ecosystem model of the Irish Sea identified negative correlations between the North Atlantic Oscillation winter index (NAOw) and large zooplankton abundance, and between the Atlantic Multidecadal Oscillation (AMO) and the recruitment of cod (*Gadus morhua*) and whiting

(*Merlangius merlangus*) (Bentley *et al.*, 2020). Knowledge of such ecosystem interactions may highlight potential impacts of climate change. Further development of ecosystem models within Irish waters will support fisheries management. The complexity of ecosystem models is sometimes difficult to translate into targeted management decisions for fisheries. Bentley *et al.* (2021) postulated the use of a F_{eco} value which uses ecosystem indicators to provide ecosystem-based fishing mortality reference points within ICES F_{MSY} ranges. Silvar-Viladomiu *et al.* (2022) postulated the potential use of Peterman's productivity method (PPM) due to its ability to track temporal change of recruitment productivity via the stock-recruitment (SR) relationship (Peterman *et al.*, 2000; Minto *et al.*, 2014; Perälä *et al.*, 2017). These approaches allow the incorporation of ecosystem understanding into existing single species management plans, implementing the first step towards a more ecosystem approach to fisheries management.

The complexity of ecosystem models is sometimes difficult to translate into targeted management decisions for fisheries, however, further development of ecosystem models within Irish waters will support fisheries management. Knowledge of such ecosystem interactions may highlight potential impacts of climate change.

6.7 RECOMMENDATIONS

1. Continue research into the best methods of incorporating ecosystem parameters into current fishery management programmes.
2. Long-term scientific monitoring of fish stocks in the Irish EEZ should be maintained to continue monitoring the stocks health status and to allow further research into the potential impacts of climate change on fisheries.
3. Develop methods to further interrogate data with respect to climate-forcing.
4. Novel fishing opportunities created by species distribution shifts must be managed correctly to ensure a sustainable yield. International cooperation on the management of fish stocks is vital to manage not only novel stocks, but current stocks undergoing distribution shifts.

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