WORKSHOP TO DEVELOP A RESEARCH ROADMAP FOR CHANNEL AND CELTIC SEAS SPRAT (WKRRCCSS)

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Contents

i Executive summary

Stock assessors, researchers, survey experts, and industry and NGO stakeholders met in the ICES workshop to develop a research roadmap for Channel and Celtic Seas sprat (WKRRCCSS).The goal of the workshop was to produce a roadmap for the delivery of future research needs for the management of fisheries on sprat in ICES Subareas 6 and 7.

Currently ICES recognizes two sprat (*Sprattus sprattus*) stocks in the region, namely Channel sprat (ICES division 7.de) and sprat in the Celtic Seas (ICES divisions 6.a and 7.a-c,f-k). The Channel sprat is subject to a Category 3 assessment with advice based on a Constant Harvest Rate but the Celtic Seas sprat is not assessed, with ICES providing precautionary advice every second year. The stock structure of sprat found all around the British Isles is uncertain and where, if at all, stock boundaries are unknown. At present there is insufficient understanding, information and data on the sprat populations in the Celtic Seas region to be able to provide robust advice on the current stocks or on potential changes in productivity in the short to medium time frames. Sprat are a key forage fish in these ecosystems, forming an important part of the food chain for key predatory species, including mackerel (*Scomber scombrus*), whiting (*Merlangius merlangus*), Atlantic cod (*Gadus morhua*), horse mackerel (*Trachurus trachurus*), marine mammals and birds. Therefore, there is a need for advice which takes their role in ecosystem functioning into account.

The main aims of the workshop were therefore to:

a) Identify methods and data available for the identification of sprat stock boundaries in the Channel and Celtic Seas.
b) Identify and prioritize potential and existing datasets (including environmental parameters), and assessment methods of utility for these sprat stocks.
c) Identify the advice needs of fisheries managers and stakeholders for sprat in the Channel and Celtic Seas.
d) Produce a roadmap for the delivery of the future research needed to underpin the scientific advice on management of the sprat fisheries in the Channel and Celtic Seas.

Participants were given presentations from a range of subject experts such as geneticists, survey coordinators, environmental NGOs and fisheries managers. The resulting discussions focused on pragmatic steps that should be taken to ensure that the resource can be used sustainably. The time frame for these steps range from immediate to 3 - 5 years. This prioritized list includes recommendations to workshop attendees, national fisheries institutes, future research projects, and assessment and ecosystem modelling working groups in ICES. Key areas include the gathering of genetic and biological evidence for stock identification, ecosystem modelling tailored to forage fish in the Celtic Seas, continued development of management strategy evaluations, and the investigation of survey adaptations and in-year advice. Many of the recommendations can progress in parallel. Attendees have drafted a roadmap for the delivery of future research needs for the scientific advice that underpins management of the sprat fisheries in the Channel and Celtic Seas. This roadmap is considered live and will be adapted as required.

ii Expert group information

Expert group name	Workshop to Develop a Research Roadmap for Channel and Celtic Seas Sprat (WKRRCCSS)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chair(s)	Campbell Pert, Scotland
	Cormac Nolan, Ireland
Meeting venue(s) and dates	Galway, Ireland and Online

1 Introduction

European sprat *Sprattus sprattus* (Linnaeus, 1758) (Order: Clupeiformes, Family: Clupeidae) is one of five clupeids occurring in the North Sea. Three subspecies have been defined, namely *S. sprattus sprattus* in the North-East Atlantic and North Sea, *S. sprattus balticus* in the Baltic Sea and *S. sprattus phalericus* in the Mediterranean and Black Seas.

Sprat is short-lived and rarely attains an age of more than five years or a length of >16 cm. Sprat generally first spawn at 2 years of age, though a small proportion of the population spawn at 1 year of age, and are multiple batch spawners, with females spawning repeatedly throughout the spawning season producing up to 100 - 400 eggs per gram body weight. Spawning occurs in both coastal and offshore waters, during spring and late summer, with peak spawning between May and June, depending on water temperature.

Currently ICES recognizes two sprat (*Sprattus sprattus*) 'stocks' outside the North Sea (Sub-area 4) and Division 3a, namely sprat in Divisions 7.d and 7.e (Channel sprat) and sprat in the Celtic Seas (subarea 6 and divisions 7.a-c and 7.f-k). The Channel sprat is subject to a Category 3 assessment with advice based on a constant harvest rate but the Celtic Seas sprat is not assessed, with ICES providing precautionary advice every second year. The stock structure of sprat found all around the British Isles is uncertain and where, if at all, stock boundaries exist are unknown. Catch data are collated for all areas where sprat are caught either in targeted fisheries or as a bycatch. In addition, there are a number of surveys (acoustic and bottom trawl) where catches of sprat occur and in some cases the abundance/biomass is estimated.

1.1 Background

Sprat is the subject of a targeted fishery in Divisions 7.d and e, currently mainly in Lyme Bay along the south coast of England in Division 7e. Recently there has been interest in developing targeted fisheries for sprat in the Celtic Sea (7aS, f-j), and in inshore waters of 6a. In recent years there have been increased landings of sprat from the Celtic Sea with the uptake thought to be due to the recent low biomass of Celtic Sea herring.

Currently there is insufficient understanding, information and data on the sprat populations in the Celtic Sea region to be able to provide robust advice on the current 'stocks' or on potential changes in productivity in the short to medium time frames. Sprat are a key forage fish in these ecosystems forming an important part of the food chain for key predatory species, including mackerel (*Scomber scombrus),* whiting (*Merlangius merlangus*), Atlantic cod (*Gadus morhua*), horse mackerel (*Trachurus trachurus*), marine mammals and birds to name a few. Therefore, there is a need for advice which takes their role in ecosystem functioning into account.

After discussion between Marine Scotland Science (MSS), the Marine Institute (MI) and the Centre for Environment, Fisheries and Aquaculture (CEFAS) it was decided to hold this workshop to develop a Research Roadmap for Channel and Celtic Seas Sprat (WKRRCCSS). The main aims of this workshop are to:

a) Identify methods and data available for the identification of sprat stock boundaries in the Channel and Celtic Seas.
b) Identify potential and existing datasets (including environmental parameters) for the assessment and management advice for western sprat stocks.

c) Identify the aspirations and concerns of fisheries managers and stakeholders in the development of sprat fisheries in the Channel and Celtic Seas.

d) Produce a roadmap for the delivery of future research needs for the scientific advice that underpins management of the sprat fisheries in the Channel and Celtic Seas.

1.2 Methods and Approach

A number of meetings, including HAWG 2021, identified a range of knowledge gaps regarding sprat (*Sprattus sprattus*) stocks in Divisions 7.d,e (Channel sprat) and sprat in the Celtic Seas i.e. Sub-Areas 6 and 7. Following discussion between CEFAS, Marine Institute (MI) and Marine Scotland Science (MSS) a proposal and outline ToR's we're submitted to ICES and this was accepted as well as identifying co-chairs Cormac Nolan (MI) and Campbell Pert (MSS). An e-mail for WKRRCCSS was sent out in December of 2021 via the HAWG mailing list as well as to other stakeholders with additional advertising via the Internet and social media undertaken by our ICES supporting officer Jette Fredslund. Initially, the workshop was going to be held in Dublin, Ireland from 25-27 April 2022 with 28 delegates attending in person and online but due to ongoing issues around Covid-19 restrictions throughout Europe the meeting was postponed. Further issues due to the Ukraine war and the temporary cessation of all ICES meetings meant that the workshop was held in the Marine Institute in Galway on 12–14 September 2022 with 26 delegates attending in person and online. A short follow-up meeting, WKRRCCSS2, was held in ICES immediately following the HAWG (23/03/2023) to collate catch data, produce maps and discuss progress. A subset of the first workshop attended WKRRCCSS2.

1.2.1 Invited Statements and Presentations

The following expert presentations were given, each followed by a questions and discussions session.

Term of Reference A - Identify methods and data available for the identification of sprat stock boundaries in the Channel and Celtic Seas.

Presentation Title: A switch from sprat to herring in a recovering pelagic ecosystem

Authors: Joshua Lawrence and Paul Fernandes (Heriot Watt University)

Although many marine ecosystems have been adversely impacted by human activities, some are now recovering due to reductions in fishing pressure. Here, we document the recovery of an ecosystem subjected to intense anthropogenic activity for over 200 years, the Clyde Sea. This region once had productive fisheries for herring (*Clupea harengus*) and other fish, but these disappeared at the turn of the century. Using acoustic surveys of the pelagic ecosystem, we found that the Clyde Sea supports 100 times as many forage fish as in the late 1980s. However, herring has now been replaced by sprat (*Sprattus sprattus*), despite virtually no fishing on herring for 20 years. A combination of a warming sea, bycatch of herring in the prawn (*Nephrops norvegicus*) fishery, and susceptibility of herring to poor recruitment may have contributed to this unexpected recovery. The lack of a current sprat fishery in the Clyde presents a unique opportunity to develop an alternative industry for its seafaring community: ecotourism. Charismatic megafauna (whales, dolphins and seabirds) that people will pay to see, will, in time - if not already - be drawn in by the abundance of forage fish now present, further restoring the biodiversity of the region after centuries of overexploitation.

Lawrence, J. M., and Fernandes, P. G. 2021. A switch in species dominance of a recovering pelagic ecosystem. Current Biology, 31: 4354-4360.e3.

Presentation Title: Marine Scotland Science West of Scotland (6aN) Survey 2022

Author: Steven O'Connell (MSS)

Sprat (*Sprattus sprattus* L., 1758) is a minor species for the Scottish pelagic fleet as a whole, but holds more importance on the west coast, with a small fishery operating out of Mallaig. Their effort being focused in ICES Subarea 6.a. This fishery is worth approximately €4.7 million a year and represents a valuable resource for the local community. There has been no acoustic survey targeting sprat specifically in this area at the time during which the fishery takes place. In the absence of a directed survey on shore sampling has been taking place at varying levels since 2012. In 2019 a high resolution on shore sampling programme was initiated. This was facilitated by a collaboration between International Fish Canners (IFC) and Marine Scotland and involved the sampling of every haul in each season since. In October 2022 Marine Scotland will undertake an acoustic survey for sprat in this area. The location of transects for this survey will be informed by historic fishing activity. Methods will be closely aligned with those adopted for HERAS and WESPAS in terms of acoustic and biological sampling strategies where possible. Going forward we would look to analyse these data in order to derive appropriate abundance and biomass indices for the inshore sprat fishery in subarea 6.a. This index could be applied to a stock assessment framework to ensure sprat in this area are sustainably exploited. Additionally, we would look to expand the scope of the sprat survey to investigate unresolved stock identity issues using similar methods to recent herring stock identity studies mainly using genetic analysis with a concurrent study looking at parasites as biological tags – these are likely longer term aims which would be beneficial to do in a larger collaboration covering the Channel and Celtic seas.

ToR b - Identify and prioritize potential and existing datasets (including environmental parameters), and assessment methods of utility for these sprat stocks.

Presentation Title: The Mallaig Sprat Fishery – Addressing Data Limitations and Implications for Assessment and Future Management

Author: Eleanor MacLeod (MSS) and Campbell Pert (MSS)

In sea lochs neighbouring Mallaig on the West Coast of Scotland (subarea 6a), a seasonal fishery for sprats takes place in the winter months. There is currently no management plan for sprat in subarea 6a, and no assessment of these inshore fisheries on sprat populations is in place. Data limitations for this fishery relate to the suitability of available survey data and a limited series of market samples from the fishery. This has implications on the suitable stock assessment options and the future management of sprat to the West of Scotland. Continued detailed landings sampling and the inclusion of sprat into acoustic survey planning would allow stock assessment methods to be applied more confidently to this fishery.

Title: Celtic Sea Sprat: Management Strategy Evaluation

Author: Laurie Kell and Jacob Bentley (MRAG)

Sprat is a target species in the Celtic Sea; however, current harvest advice is based on landings, and there is insufficient information to estimate stock status, trends, or target and limit reference points. As well as being a valuable commercial species, sprat are a major predator on zooplankton, an abundant prey for piscivorous fish and a competitor for herring. Ensuring the sustainable exploitation of sprat is therefore important for both the health of the Celtic Sea's marine ecosystem and for the wider fisheries sector in Ireland. To develop robust advice, we conduct Management Strategy Evaluation using a multistock single species sprat operating model conditioned on life history theory and linked to an Ecosystem Model of Intermediate Complexity. We show how ecosystem understanding can be incorporated within the existing precautionary and maximum sustainable yield frameworks. This novel approach allows environmental drivers, such as sea surface temperature, to more complex emergent foodweb indicators, to be simulated and the benefits of alternative harvest control rules to be evaluated. As a result, we identify key improvements that could be made to current data collection, surveys, biological knowledge, and assessments and management to provide advice for sprat harvest in the Celtic Seas that is robust to uncertainty.

Title: An Overview of Spr.27.7de and Spr.27.67a–cf–k, Their Respective Assessments and the Data Limited Guidelines for Short Lived Stocks.

Author: Johnathan Ball (CEFAS)

The European sprat is found all around the UK in the warm summer months and is the focus of a number of targeted fisheries around the UK. During my presentation I will give an overview of Spr.27.7de and Spr.27.67a–cf–k, their respective assessments, the currently available data to ICES, a brief summary of the technical guidelines for data-limited short lived species, some examples and discussion of how they have been implemented since WKLIFE X and their pros and cons for Spr.27.67a–cf–k.

Title: Evidence from French surveys sampling sprat in the English Channel

Author: Paul Marchal (IFREMER)

Sprat in the English Channel (7d and 7e) is assessed primarily on the basis of information coming from Division 7e. The Channel Groundfish Survey (CGFS) has operated with a GOV bottom trawl in Division 7d since 1988, and in Division 7e since 2015. We provide here survey evidence that sprat abundance in 7d should not be neglected.

High densities of sprat are found in the Baie de Seine, particularly off the estuary, a shallow area that may not easily be accessed by large survey vessels. An abundance index could be derived for sprat in 7d by applying a two-tiered delta-GAM to CGFS catches (linear year effect and non-linear spatial effect as explanatory variables; gamma distribution in the GAM analysis of non-zero values).

Sprat abundance has varied without trend over the period 1988 - 2014. From 2015 - 2022 abundance indices were slightly above average, which might reflect the change of research vessel that occurred in 2015. Mean sprat sizes were analysed with a GAM (linear year effect and non-linear spatial effect as explanatory variables; normal distribution). Mean sizes have varied without trend around 9.5 cm over the period 1988 - 2009, and they have declined consistently over the period 2010 - 2022. While the reasons for this decline remain to be investigated, they bear out similar observations reported for other small pelagics (anchovy, sardine) in other areas (Mediterranean, Bay of Biscay) suggesting a possible change in ecosystem functioning. Time series were still too short or incomplete to provide an abundance index for sprat in Division 7e.

ToR c - Identify the advice needs of fisheries managers and stakeholders for sprat in the Channel and Celtic Seas.

Title: Why Fish Forage Fish?

Author: Simon Berrow (IWDG)

Sprat as a "forage fish" are a critical food source for a wide range of predators from whales, dolphins, seabirds, sharks, tuna and commercially exploited fish species. Forage fish are small, schooling species that are an essential link between two trophic levels. Sprat is one of the most important forage fish in inshore Irish waters.

Sprat is an important component of the diet of a suite of predators. Age 0 sprat and herring comprised a large proportion of the diet of fin and humpback whales in the Celtic Sea (Ryan et al. 2014). The importance of sprat in the diet of seabirds is not known but is consider a key component of the diet of terns and auks, including puffins. There has been an increase in bluefin tuna in the Celtic Sea in recent years (Horton et al. 2021) caused by seasonal migrations into higher latitude waters of the North Atlantic to forage on a wide variety of caloric-rich pelagic prey such as sprat. All these species are highly protected under a suite of international legislation.

Landings of sprat are increasing in Ireland. Biomass estimates implied from Celtic Sea herring acoustic surveys, which target herring not sprat, suggest large fluctuations in SSB occur. Large fluctuations can lead to population crashes, especially locally if subpopulations faithful to an area exist.

Knowledge of the importance of sprat to key marine predators is essential including to inform Fn in fishery models to ensure enough sprat is available to not only maintain current populations of key predators but to facilitate population increases as many of these species are under pressure and declining. A moratorium on fishing sprat should be considered

Most sprat fishing by Irish boats occurs within the 12nml territorial waters and thus are managed by the Irish state without having recourse to the EU. We would argue that forage fish such as sprat should be left to be foraged and no extraction is permitted within 12nmls. If quotas are to be set they should be highly precautionary until sufficient data on their life history especially fecundity, recruitment, longevity and stock structure (movements) have been carried out.

***Title: The importance to the Cornish Sardine Management Association (CSMA) of Developing a Research and Management Plan for Sardines in the Channel*.**

Author: Gus Caslake (Seafish)

The importance to the Cornish Sardine Management Association (CSMA) of developing a research and management plan for Sardines in the channel. How scientific work carried out by skippers and processors has help filled data gaps in the fishery, building relationships with fisheries scientists and managers and supporting the ongoing MSC certification of Cornish Sardines.

Title: International Fish Canners (IFC) and the West of Scotland Sprat Fishery

Author: Alan McRobb (IFC)

International Fish Canners (IFC) have built a trusted relationship with fishers at Mallaig, located on Scotland’s west coast, where we buy all the sprat that the local boats land. The Mallaig sprat fishery is typically targeted by small vessels (<15 m) that usually target Nephrops through most of the year, but switch to pair trawls to fish sprat typically in November and December. These vessels tow pair trawls, with fishing for sprat normally occurring at night, with catches discharged into lorries the following morning for transportation to the processing facility located in North East Scotland. In recent years, a single pair team has been operating and landing into Mallaig. During this presentation I intend to encapsulate a short explanation of who IFC are, their involvement with the Mallaig sprat fishery over time and our client’s expectations. I will also explain how IFC work with the local fishermen to organize and conduct the fishery. Finally, I will provide an outline of what steps we, as a company, are taking in order to put the fishery on a pathway to a sustainable future to ensure its long term viability.

ToR d - Produce a roadmap for the delivery of future research needs for the scientific advice that underpins management of the sprat fisheries in the Channel and Celtic Seas.

1.3 ICES Code of Conduct/Conflict of Interest

WKRRCCSS is seen as a scoping workshop and participants were expected and encouraged to speak from their own experiences and positions. Thus this workshop is considered to be covered by the code of conduct as *'ICES may run meetings which are intended to solicit stakeholder views. For these meetings, … participants will be asked to represent specific professional interests*.'

1.4 Nature of Consensus in this Report

The workshop was tasked with developing a research roadmap for sprat in the Channel and Celtic Seas. The level of consensus among all workshop participants on the various issues discussed was very high. With such a broad range of experts in attendance, many different aspects of the research needs were discussed in detail and the knowledge shared by the invited speakers was instrumental in sparking debate and coming to a common understanding. The roadmap presented here can therefore be considered broadly supported with the caveat that there may be views held by other stakeholders that were not involved in the meeting.

1.5 Scope of the Workshop

The workshop focused on the scientific research needs for the specific sprat stocks. Issues of management policy arose during various conversations but they are, in the main, not reported here.

2 Where are we now?

There are currently two stocks in the Celtic Sea ecoregion, sprat in 7de and sprat in 6 and 7a-cf-k. The two stocks are contrasted in both their advice category and relative exploitation. Sprat 7de was recently moved to a category 3 data-limited assessment that applies a constant harvest rate (ICES. 2021b, ICES 2021c) and is lightly exploited, while sprat in the wider Celtic Seas ecoregion is a category 5.2.6 data poor stock (ICES 2012) and while the exploitation of the stock cannot be determined (extant biomass is unknown) is caught at a level exceeding current ICES catch advice. The two stocks are both assessed as part of the Herring Assessment Working Group (HAWG) in March, with sprat in 7de assessed annually and giving seasonal advice and with advice given biannually for sprat in 6 and 7a-cf-k.

2.1 Sprat in 27.7.de

Spr.27.7de is centred on a distinct population of sprat inhabiting Lyme Bay off the south coast of England (Figure 2.2.1). Although the stock itself covers areas 7d and 7e the principal fishery takes place in Lyme Bay, with some landings on the French side of the English Channel. The stock is covered by the PELTIC acoustic survey, which has provided a biomass estimate of the stock's core area (Lyme Bay) since 2013.

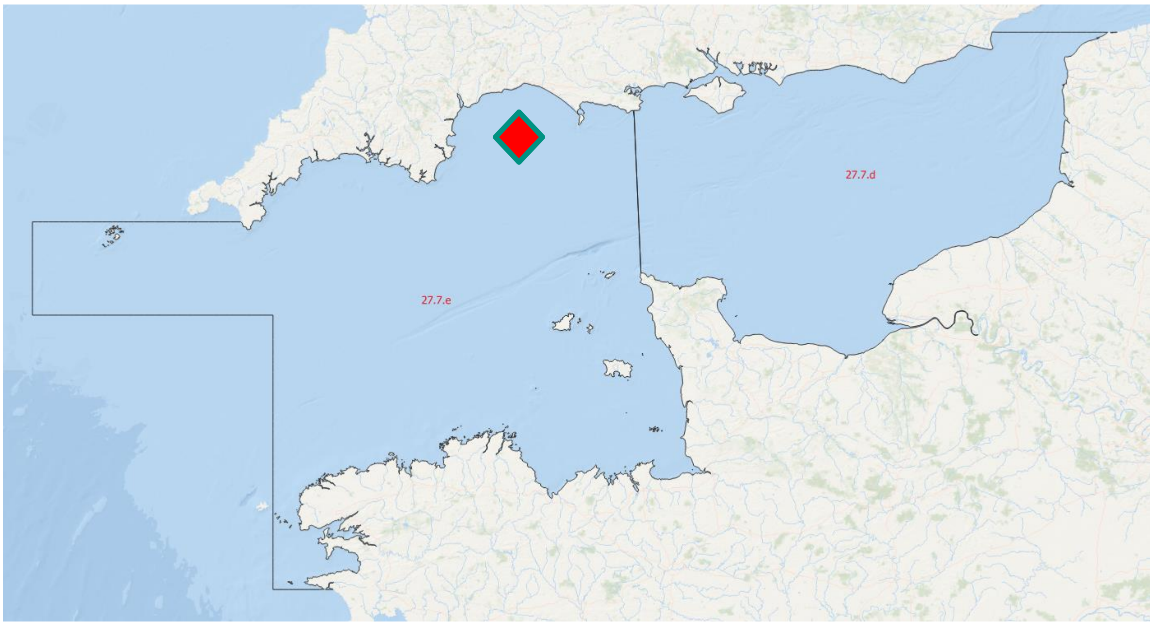

Figure 2.1.1 Area 27.7.de, red diamond denotes the location of fishery and stock biomass.

Historically landings for the stock have been high (Figure2.1.2), however in recent years landings have decreased (table 2.1.1), partly due to reduced advice, but also due to changes in demand. The fishery is considered to be processor driven, with the most recent landings attributed to the high volume of small age 0 sprat in the stock. The stock is currently assessed via a management strategy evaluation derived constant harvest rate, determined to allow exploitation of the stock while keeping it above its biomass safeguard. The CHR is a percentage (8.57%) applied directly to the most recent survey biomass.

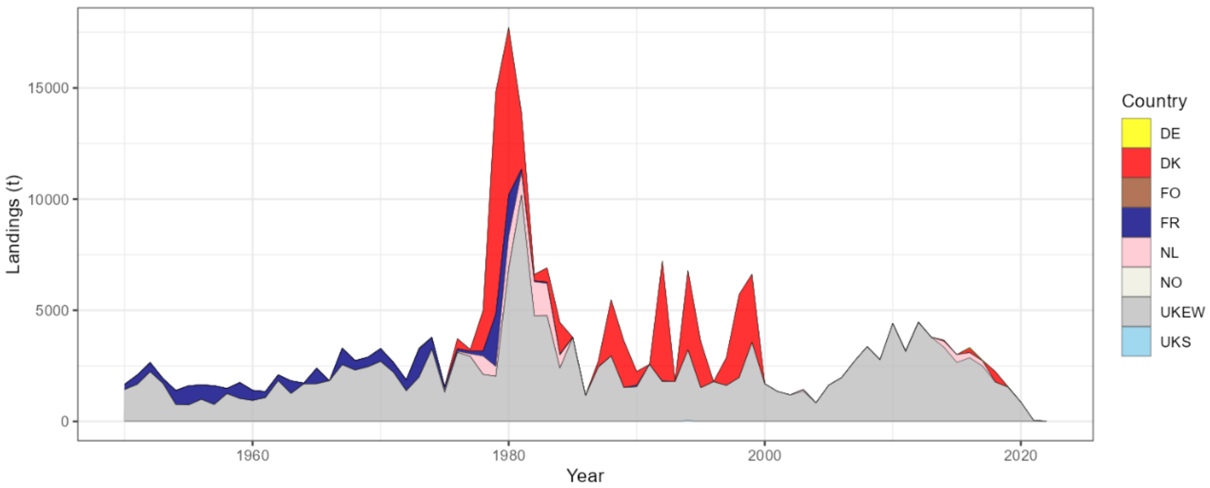

Figure 2.1.2. Sprat landings for 7de (ICES 2023)

Table 2.1.1. Biomass and landings of sprat in 7de (ICES 2023)

Year	Biomass	Catches	Harvest
2013	70,680	3793	0.054
2014	85,184	3658	0.043
2015	65,219	3012	0.046
2016	9,826	3339	0.340
2017	32,751	2733	0.083
2018	21,772	2252	0.103
2019	36,789	1573	0.043
2020	33,798	873	0.025
2021	107,355	49	0.0005
2022	28,439	12	0.0004

2.2 Sprat in 27.67a–c,f–k

Sprat in 67a-cf-k covers a large stock area running from the coast of Cornwall to the northern most islands of the Hebrides and as far west as Rockall and the west coast of Ireland extending out past the shelf (Figure 2.2.1).

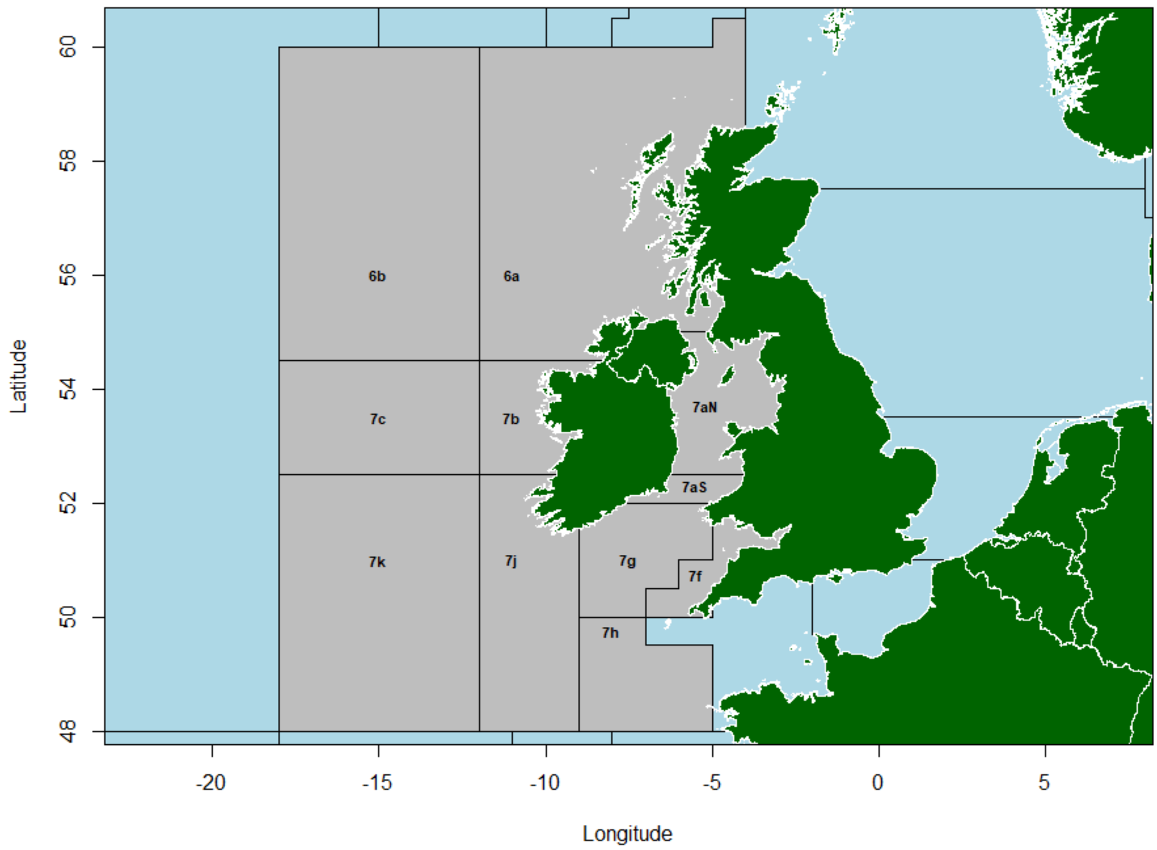

Figure 2.2.1. Celtic sea sprat stock area

The stock is likewise exploited across a wide area, although the bulk of landings come from Ireland (Figure 2.2.2). Landings by ICES division or group of divisions are presented in Figure 5. Landings are mainly taken in divisions 7g and 7j, the south coast of Ireland, 7aS, the southern part of the Irish Sea and 6a, the north and northwest of Ireland and west coast of Scotland. There is also a sprat fishery in 7aN, the Irish Sea and in division 7b, west of Ireland. Small amounts of sprat are taken from the Bristol channel.

Advice was fist given for Celtic Seas sprat in 2012 and was for no increase in catch. In 2013 a 20% reduction of the average catch of the previous 10 years was advised. This advice of 3,500 t was given from 2013-2017. A further 20% reduction was applied in 2018 and 2,800 t advised from 2018-2021. The advice for 2022 and 2023 was reduced by 20% again and was 2,240 t. The 2020 landings of 15,172t and 2021 landings of 14,146 t are well above advice of 2,800t, which is the result of the data poor advice rule for the stock. This category 5 rule is designed to conserve the stock; the precautionary buffer will reduce the advice by 20% every third year. The move to a higher advice category is hampered by the question of stock identity and total-stock biomass.

The total-stock biomass is unknown despite acoustic surveys that cover portions of the stock and provide an estimate of biomass, namely the Celtic Sea Acoustic Survey (A4057), AFBI Acoustic Survey (A4705) and the PELTIC Acoustic survey (A6259). Establishing the biological stock or stocks present in 27.67a-cf-k can be considered a prerequisite to moving the advice to a higher category and will allow biomass estimate from the surveys to be tied to a specific population.

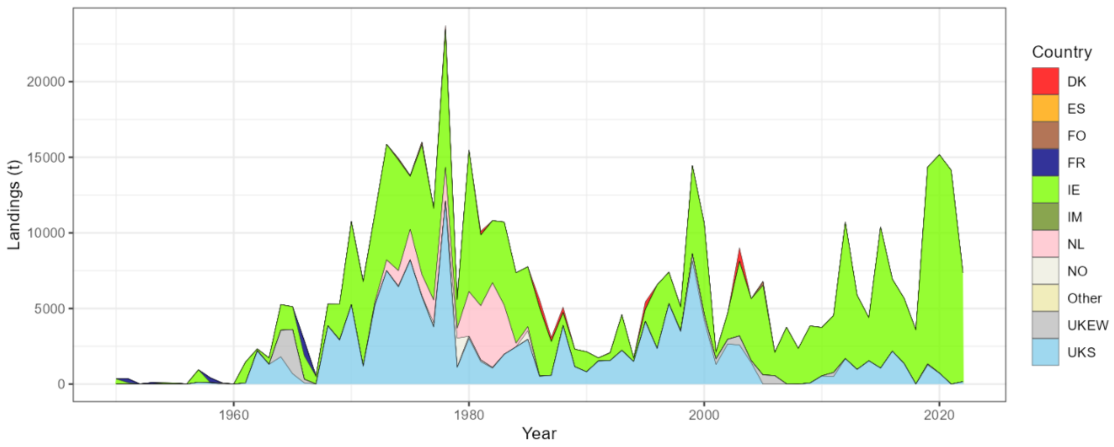

Figure 2.2.2. Total landings for Spr.27.67a–cf–k (ICES 2023)

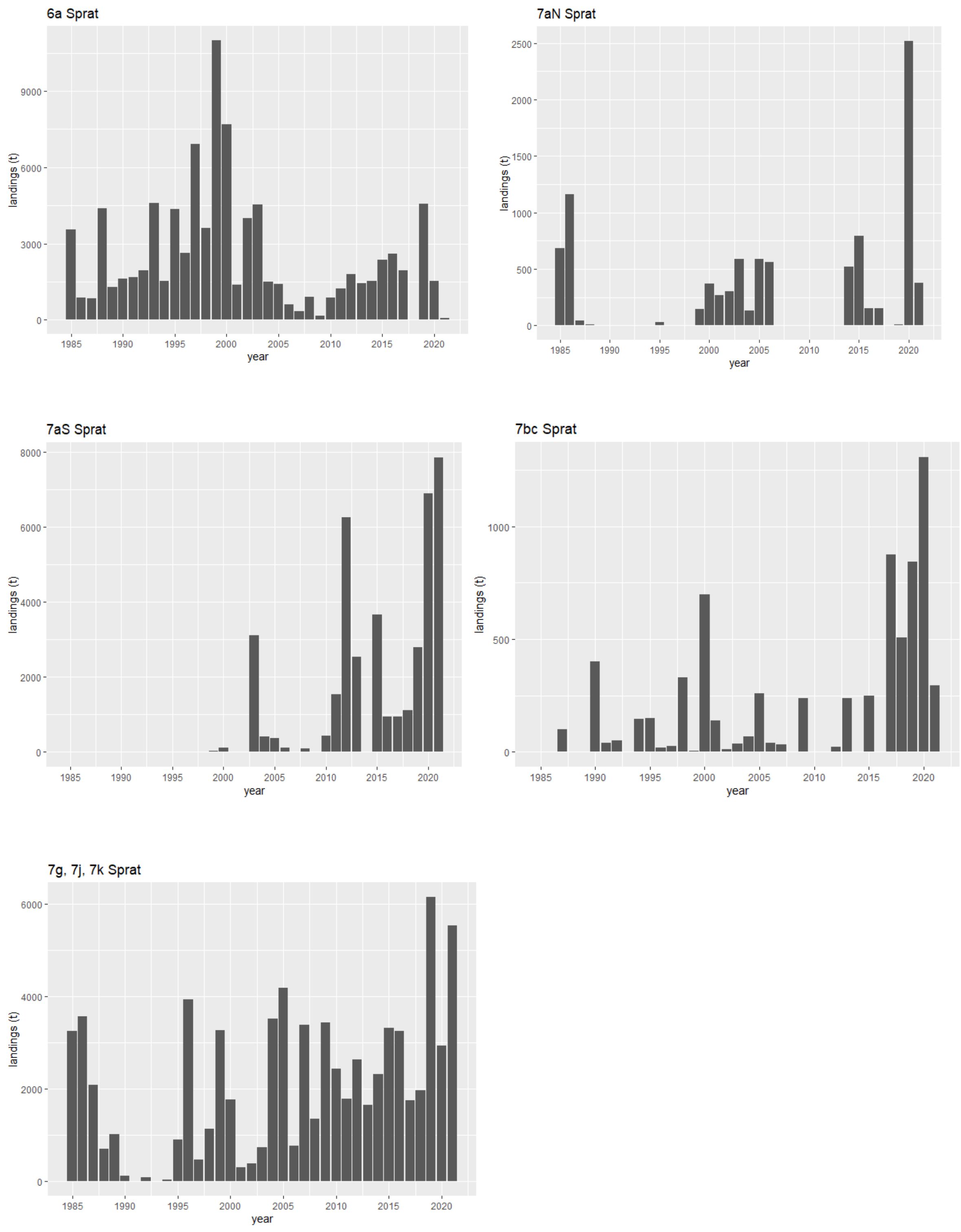

Figure 2.2.3. Landings of Spr.27.67a–cf–k by ICES division or division group.

2.3 Catch by Statistical Rectangle

An informal ICES data request was issued for spatial catch information prior to the WKRRCCSS2 meeting. ICES Member Countries with sprat fisheries in divisions 6 and 7 were requested to provide estimates of catch by quarter and by statistical rectangle for sprat, *Sprattus sprattus*, in the Celtic Seas (subarea 6 and divisions 7 a-c and 7f-k) and English Channel (division 7d and e) for the years 2000-2022 (where available). The data request stated that the data were to be used by the ICES workshop on the Research Roadmap for Channel and Celtic Seas Sprat 2 (WKRRCCSS2) to be held on the 23rd of March 2023 in ICES HQ, Copenhagen and that the end product of the workshop would be an agreed set of data that can be used in future assessments and a set of comprehensive catch maps that will feed into the stock discrimination process.

Data were submitted from Ireland, Scotland, England and Wales, the Netherlands and Denmark. All catch maps are presented in Figure 2.3.1. There are definite breaks in the distribution of catches. As these gaps are a combination of fishing effort distribution and sprat distribution, they could be useful in the both the identification of possible stock boundaries (or at the very least identification of putative populations to target for genetic sampling) and the identification of appropriate boundaries for possible area based advice.

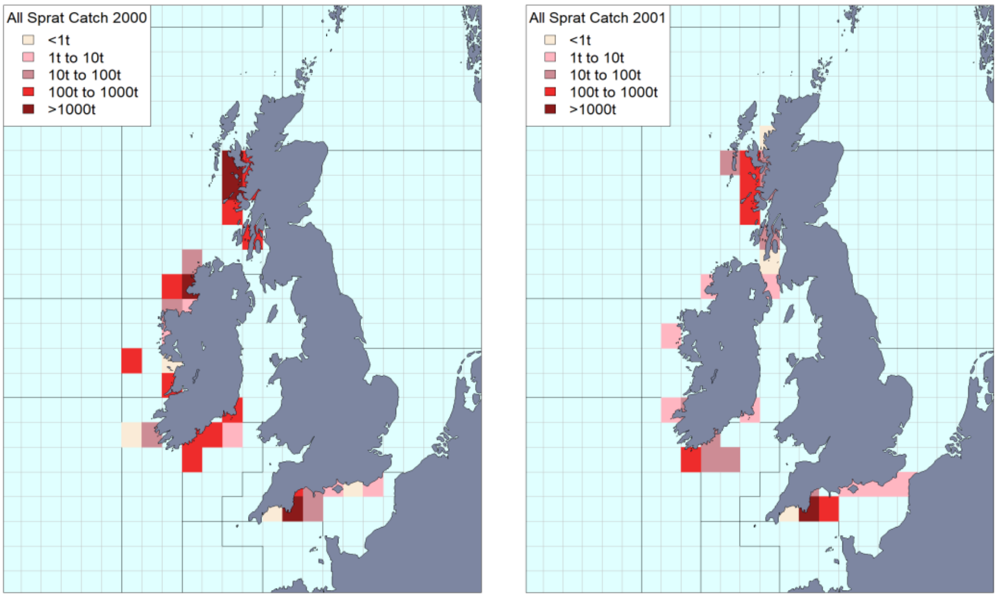

Figure 2.3.1. Sprat catch by statistical rectangle in ICES Subareas 6 and 7, 2000-2022 (Ireland, Scotland, England and Wales, the Netherlands and Denmark).

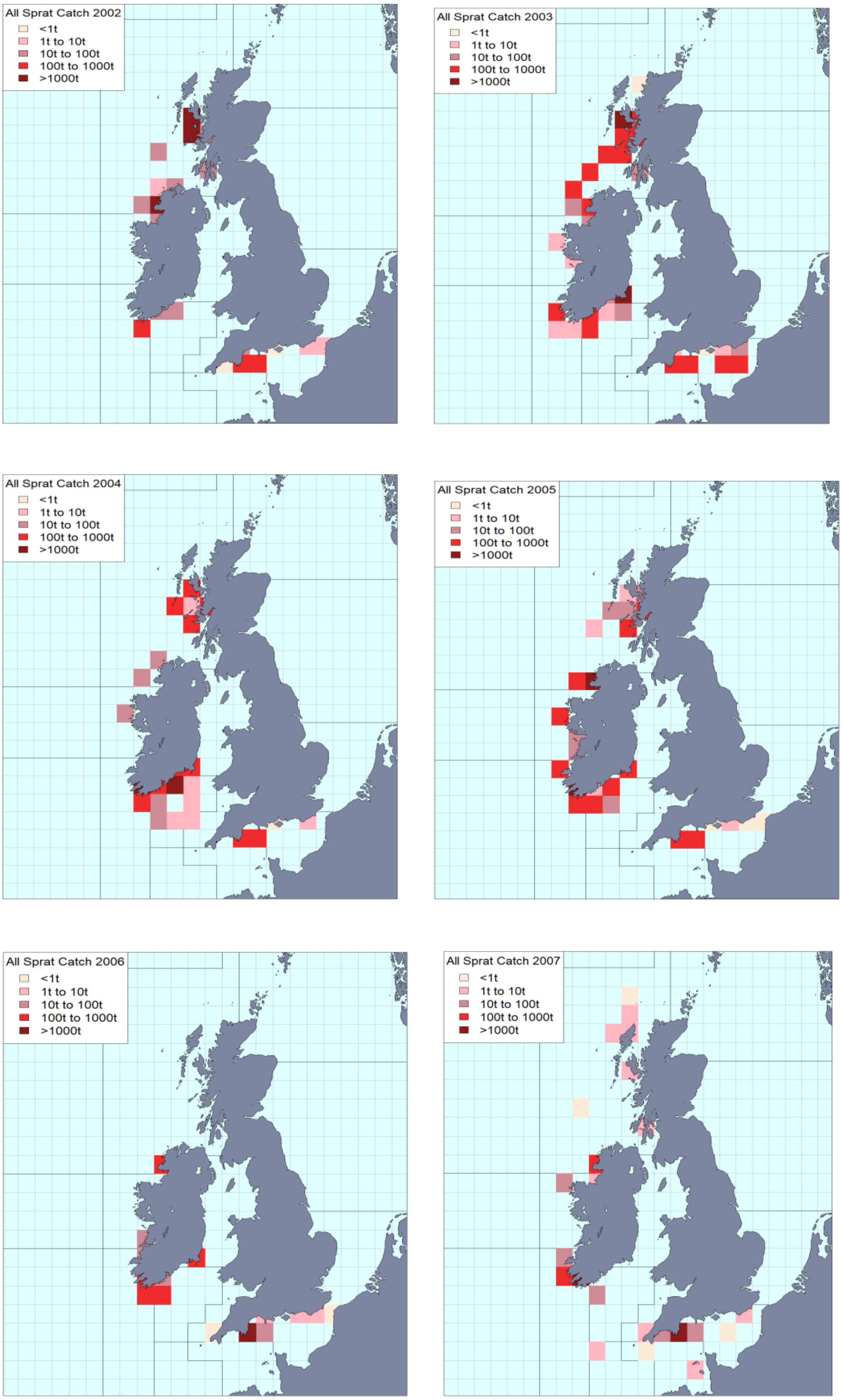

Figure 2.3.1 (continued). Sprat catch by statistical rectangle in ICES Subareas 6 and 7 (Ireland, Scotland, England and Wales, the Netherlands and Denmark), 2000-2022.

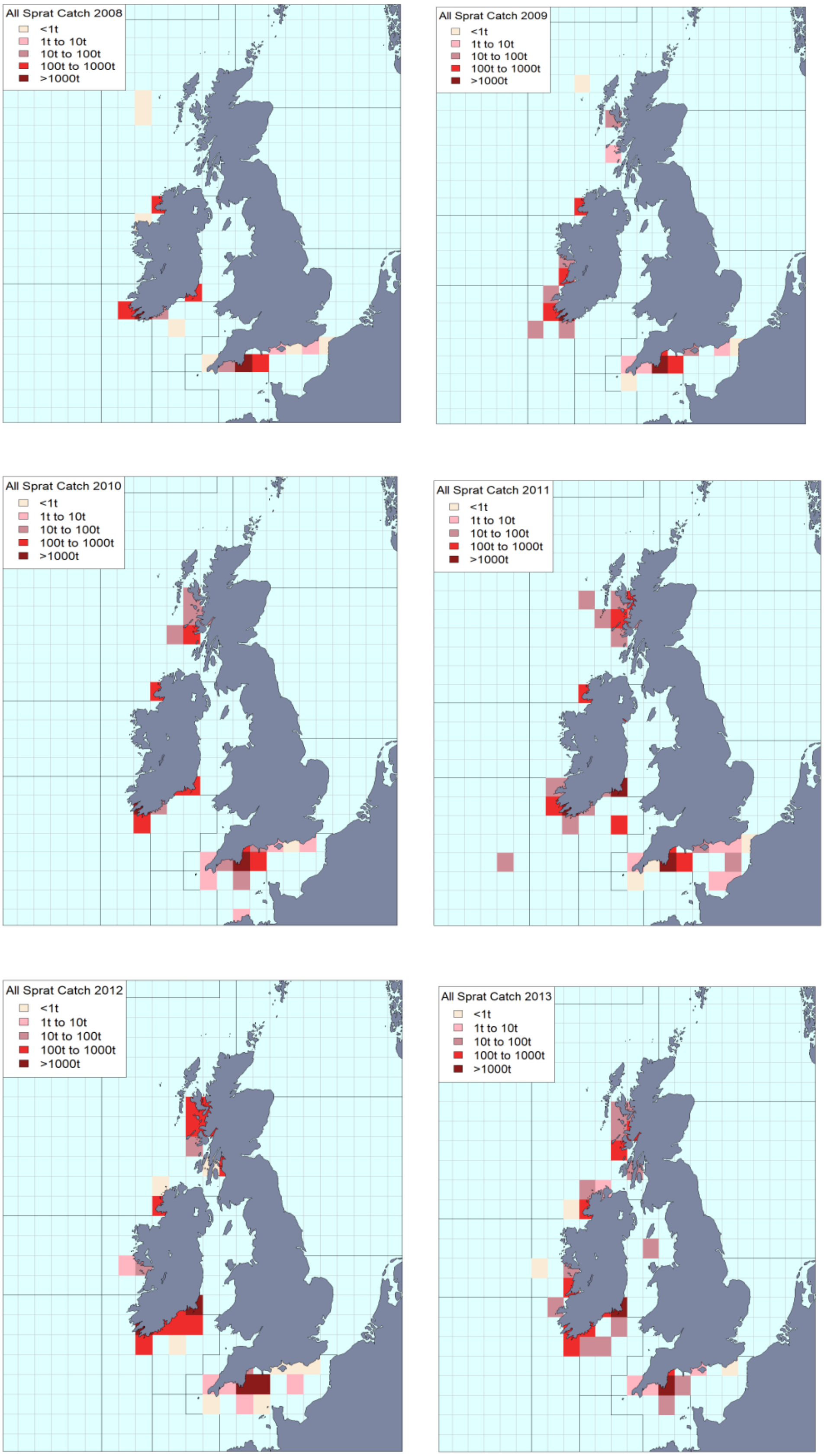

Figure 2.3.1 (continued). Sprat catch by statistical rectangle in ICES Subareas 6 and 7, 2000-2022 (Ireland, Scotland, England and Wales, the Netherlands and Denmark).

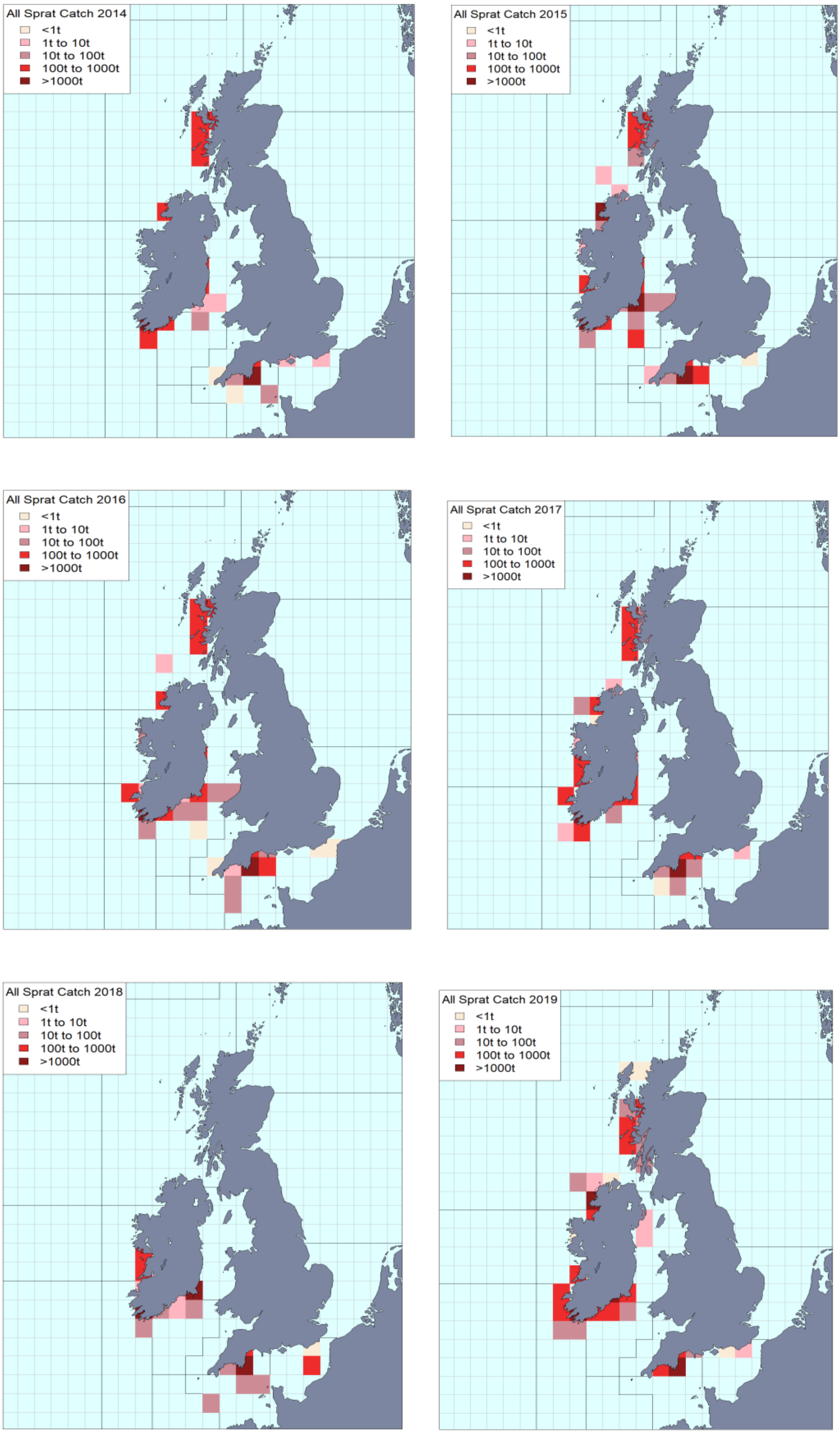

Figure 2.3.1 (continued). Sprat catch by statistical rectangle in ICES Subareas 6 and 7, 2000-2022 (Ireland, Scotland, England and Wales, the Netherlands and Denmark).

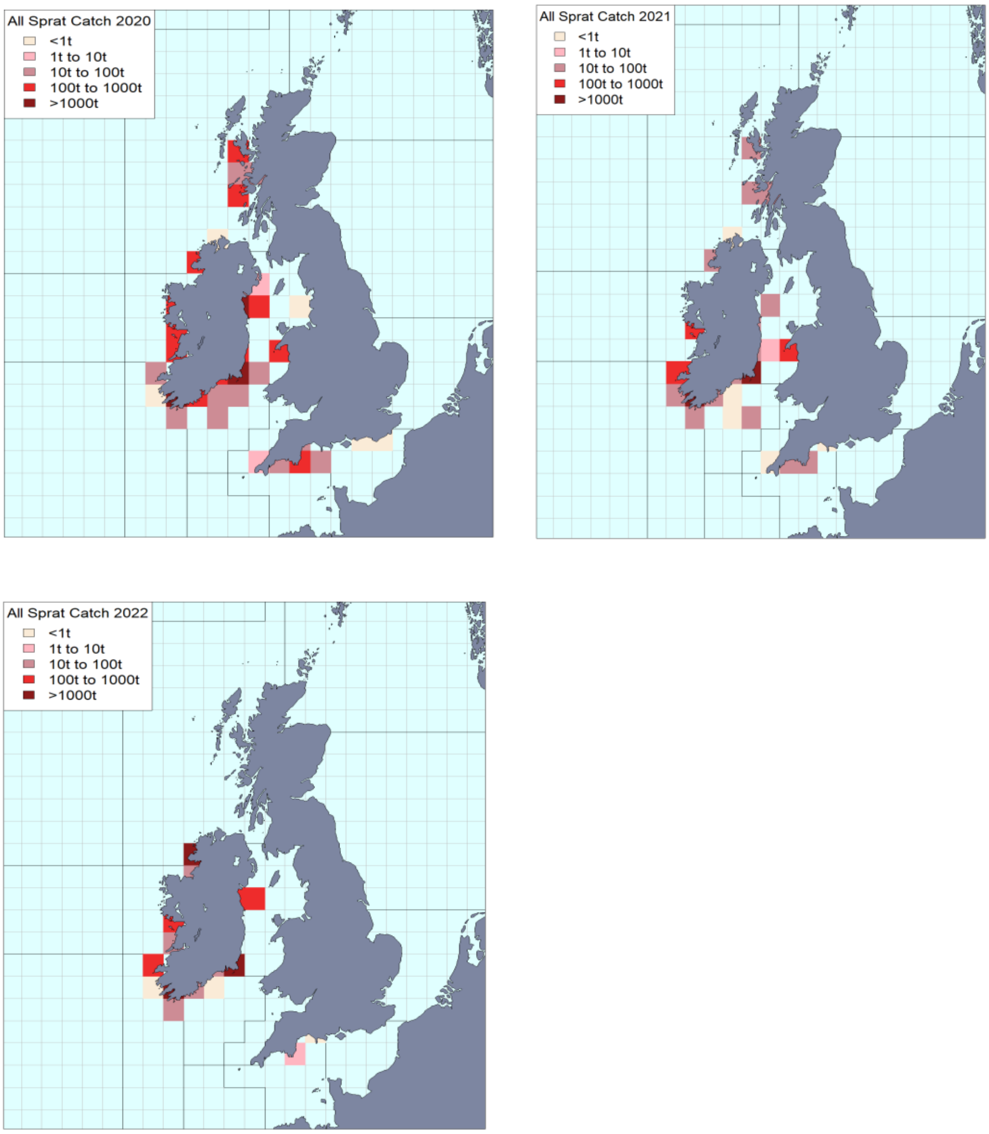

Figure 2.3.1 (continued). Sprat catch by statistical rectangle in ICES Subareas 6 and 7, 2000-2022 (Ireland, Scotland, England and Wales, the Netherlands and Denmark).

3 Importance of Healthy Sprat Populations in the Ecosystem

Sprat, as a forage fish, are a critical food source for a wide range of predators from whales, dolphins, and seabirds to other commercially exploited fish species. Forage fish are small, schooling species that are an essential link between two trophic levels. Sprat is one of the most important forage fish in inshore Irish waters.

Sprat is an important component of the diet of a suite of predators. Age 0 sprat and herring comprised a large proportion of the diet of fin and humpback whales in the Celtic Sea (Ryan et al. 2014). The importance of sprat in the diet of seabirds is not known but sprat are considered a key component of the diet of terns and auks, including puffins. There has been an increase in bluefin tuna in the Celtic Sea in recent years (Horton et al. 2021) caused by seasonal migrations into higher latitude waters of the North Atlantic to forage on a wide variety of caloric-rich pelagic prey such as sprat. All these species are highly protected under a suite of international legislation.

A fundamental question arising from the workshop that should be posed to ecosystem modellers is "should we fish forage fish in the Celtic Seas" and, if so, "how much can be safely harvested while leaving sufficient amount for the wider ecosystem?". To inform discussion on this subject, the workshop was presented with ongoing work to update an Ecopath with Ecosim (EwE) ecosystem model of the Irish Sea. The aim of this work was to identify key ecosystem linkages and drivers of sprat production. Section 3.1 details the main findings to date of this work, which is being conducted by MRAG under a contract for research services to the Marine Institute, Ireland.

3.1 Ecosystem Model Case Study: The Irish Sea[1]

Ecopath with Ecosim (EwE) is a widely used ecological/ecosystem modelling software suite, with over 500 models published globally (Christensen and Walters, 2004; Colléter et al., 2015). EwE has three main components: Ecopath – a static, mass-balanced snapshot of the system; Ecosim – a time dynamic simulation module; and Ecospace – a spatial and temporal dynamic module. EwE has been used to evaluate the ecosystem effects of fishing (Pauly et al., 2000), understand the links between species and the wider environment (Mackinson et al., 2009), analyse the influence and placement of protected areas (Coll et al., 2018), explore management policy options (Mackinson et al., 2018), model the effect of environmental change (Piroddi et al., 2021), and simulate the trade-offs of marine use and co-use (Serpetti et al., 2021).

EwE models exist for most Marine Strategy Framework Directive regions and subregions within Europe. EwE is increasingly being used to inform policy and management advice as countries progress their commitments to Ecosystem Based Fisheries Management (EBFM) and achieving Good Environmental Status (GES). Notable for the objectives of this project, recent advancements have seen EwE being used to inform an Ecosystem Approach for Fisheries Management (EAFM) by combining the tactical advice of single-species stock assessments with strategic EwE advice (Chagaris et al., 2020; Bentley et al., 2021; Howell et al., 2021; Figure 3.1.1Figure). While

[1] The entirety of section 3.1 is adapted from an MRAG progress report to the Marine Institute, Ireland. The research is ongoing.

the current approach has limitations, it represents a practical step toward EAFM, which can be adapted to a range of ecosystem objectives and applied within current management systems.

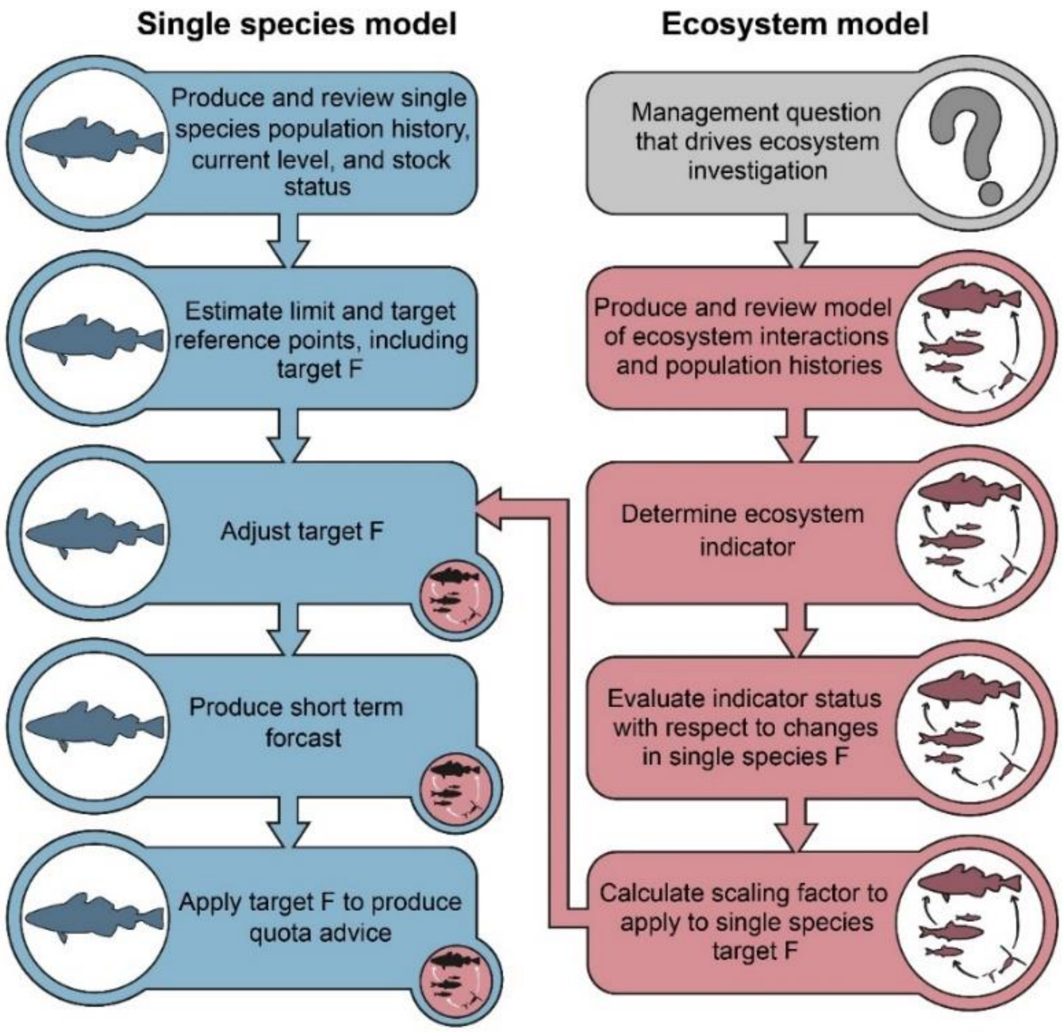

Figure 3.1.1. Flow chart outlining the steps in advice giving involved in the proposed method for enhancing single-species advice with ecosystem information (from Howell et al., 2021).

Within ICES, this approach has been adopted through the operation of an ecosystem-based fishing mortality reference point (Feco) within the precautionary 'pretty-good yield' ranges. The application of Feco is beginning to roll out, with Feco being provided as a catch option for Irish Sea Cod in the ICES advice for 2022 and multiple ICES Integrated Ecosystem Assessment (IEA) working groups beginning the process for other stocks. For pelagic/forage fish stocks (e.g., sprat) whose production is largely influenced by variation in the environment, Feco provides an operational route for adaptive management by recognizing key environmental variation in fisheries Management Strategy Evaluations (MSE).

Relevant to Irish waters, EwE models are available for the Irish Sea, Celtic Sea, and West Coast of Scotland. These models all inform the work of the ICES Working Group for Ecosystem Assessment of European Shelf Seas (ICES, 2022). No model has thus far been developed for the West of Ireland, leaving a notable gap in our capacity to use EwE to inform fisheries management for all Irish waters. This should be considered a priority for future development. The following text details the use of the Irish Sea EwE model, which has been formally reviewed by ICES WGSAM. Future work is planned to carry over the methods developed for the Irish Sea to EwE models of the Celtic Sea and West Coast of Scotland. The development of a model for the West of Ireland is a large undertaking, requiring time and funding. For future planning, the development of this model would require (i) the identification of all species present along with their biomasses, exploitation rates, and life-history parameters, (ii) fishing fleet structure information including catch, discard, and effort time-series, (iii) biomass and catch time-series for all species (aggregated into functional groups), and (iv) an empirical analysis of the key environmental drivers of ecosystem change. This covers the core information needed to make a temporal Ecosim model. Similar and additional spatial data would be needed to build an Ecospace model.

Irish Sea EwE ICES keyrun

The Irish Sea EwE model is one of three EwE models with an ICES keyrun approved by WGSAM (ICES 2019). The model includes 41 functional groups (Figure 3.1.2Figure), including the commercial species as adults and juveniles, as well as other groups ranging from detritus, discards, and primary producers to mammals and seabirds (Bentley et al., 2020). The different commercial fleets were included with their effort, as well as temperature, top–down (e.g., predation) and bottom-up (e.g., primary production) interactions, and the North Atlantic Oscillation (NAO) anomaly, all of which were identified as significant drivers of historic biomass and catch trends. A key element of the work was the continuous involvement of the stakeholders (both industry and environmental bodies) along with stock assessment scientists responsible for the key commercial stocks. The stakeholders were able to provide pivotal information for the diets of many key species in the model, particularly for 1973, the start year for the model, identifying 80 links of which 30 were previously unknown to the scientists from stomach content records (Bentley et al., 2019a). They also provided critical information on effort trends by gear, starting well before formal records that begin in 2003 (Bentley et al., 2019b).

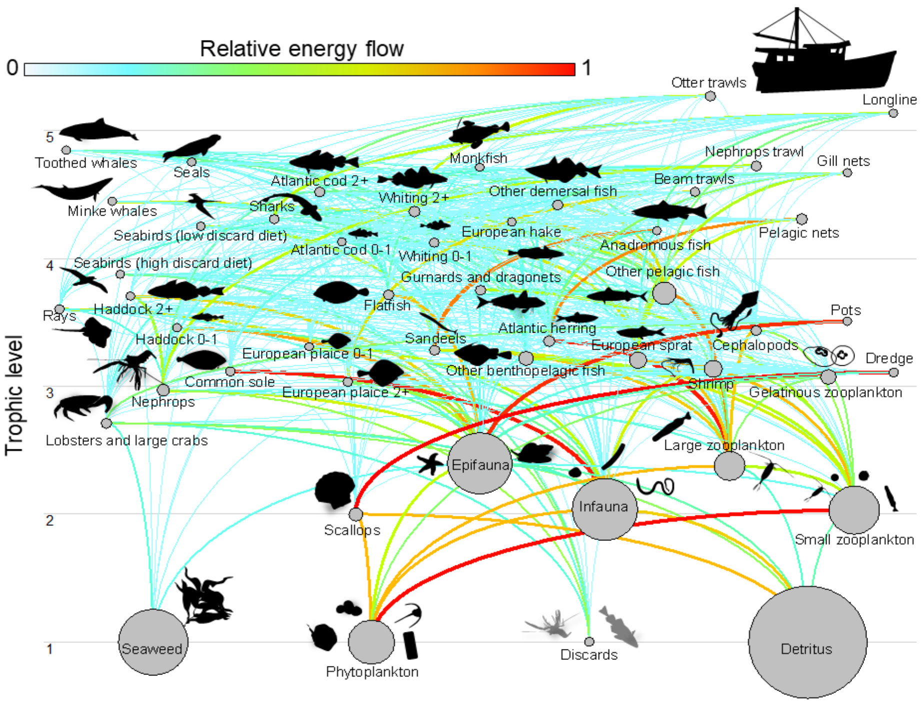

Figure 3.1.2. Energy flow and biomass diagram for the Irish Sea Ecopath foodweb model. Functional groups and fleets are represented by nodes; the relative size of functional group nodes denote their biomass whilst the size of fleet nodes denote the size of their catch. Lines represent the flow of energy and are scaled to reflect the relative energy flow. The y-axis denotes group trophic level. Future work will tease this diagram apart, highlighting the important trophic and fishery links for sprat in the model.

Sprat was included in the Irish Sea EwE model as a single species functional group. The decision was made not to split sprat into multiple age groups because (i) limited data were available and (ii) sprat was not one of the species of core relevance to the models intended use. The parameters used to populate sprat in the Ecopath model are shown in Table 3.1.1**Error! Reference source not found.**. During the balancing of the Ecopath model, sprat biomass was estimated by the model by assuming an Ectotrophic Efficiency (EE) of 0.95: this leads to the estimation of a biomass for which 95% of the sprat's mortality can be explained by predation and fishing.

Updating the Irish Sea EwE ICES keyrun

The ICES EwE keyrun model of the Irish Sea ran from 1973 to 2016 (ICES 2019). For the purpose of this work, the model was updated to 2020 (nearest possible date based on available data) to better reflect current ecosystem conditions and fishing pressures. The model was updated by extending the driver and calibration time-series used by the model. Biomass and catch time-series for commercial stocks with stock assessments using outputs from the most recent ICES working group reports. Fishing effort trends for the fleets included in the model were updated using the most recent records from the Scientific, Technical and Economic Committee for Fisheries (STECF). Environmental time-series for sea surface temperature, the North Atlantic Oscillation, and the Atlantic Multidecadal Oscillation were also extended to 2020.

Based on the current available data it was not possible to separate sprat into multiple age groups in Ecopath.

Adding temperature as a driver of sprat production

A systematic literature review identified that temperature is a key driver of sprat production, recruitment, and survivability in the Northeast Atlantic Ocean (e.g., MacKenzie and Köster 2004, Daewel et al., 2008, Hunter et al., 2019, Fernandes et al., 2020).

Correlations between Sea Surface Temperature (SST) and sprat biomass in the Irish Sea were tested using Pearson's product-moment correlation analysis. Classical correlation tests tend to lead to a greater rate of Type 1 errors, where there is an increased chance of concluding that a correlation is statistically significant when in fact no correlation is present (Jenkins and Watts, 1968). Degrees of freedom were adjusted to compensate for autocorrelation using the methods modified by Pyper et al. (1998). Multiple augmented temperature trends were included in the analysis to account of the potential impacts of lags, multiyear effects, and links between temperatures and sprats key spawning time which is spring (March – June) with evidence to suggest peak spawning between May and June (Wahl and Alheit, 1988) (Table.1.1).

Table 3.1.1. Pearson's correlation analysis between sprat in ICES devision 7a (from AFBI annual herring acoustic survey; ICES 2021) and sea surface temperature in 7a (from the Hadley Centre Sea Ice and Sea Surface Temperature dataset; HadISST) from 1999-2020.

Temperature	Trend adjustment	Pearson's R	p value
Annual average	No adjustment	-0.412	0.051
	1 year lag	-0.183	0.403
	2 year lag	-0.235	0.280
	2 year moving average	-0.395	0.062
	3 year moving average	-0.564	*0.005*
Spring temperature (March - June)	No adjustment	0.161	0.461
	1 year lag	-0.399	0.059
	2 year lag	-0.148	0.500
	2 year moving average	-0.186	0.395
	3 year moving average	-0.262	0.227
Spring temperature (May - June)	No adjustment	0.138	0.529
	1 year lag	-0.416	*0.048*
	2 year lag	-0.328	0.127
	2 year moving average	-0.208	0.341
	3 year moving average	-0.378	0.075

The correlation analysis identified two trends which showed significant inverse correlation (p<0.05) with sprat biomass in area 7a. These include (i) a three-year moving average of annual sea surface temperature and (ii) spring (May-June) temperature with a one-year lag. The inverse relationship between temperature and sprat found in this analysis reflects other studies recently published for the North Sea (Hunter et al., 2019; Clausen et al., 2018) and Bristol Channel (Henderson and Henderson, 2017).

We do not have data to explain the mechanistic links between sea surface temperature and sprat biomass, however previous studies show temperature to (i) impact the development and survival of sprat eggs (Nissling, 2004), and (ii) impact larval and juvenile growth rates (Baumann et al., 2006).

Annual sea surface temperature with a three-year moving average had the strongest correlation with sprat biomass and was therefore added to the Irish Sea EwE model as an anomaly on the consumption rate of sprat as a proxy of altered metabolic performance. Future discussions should revolve around whether we want to keep this driver in the model or whether we would prefer to use the 1 year lagged May - June temperature time-series.

Model performance and retrospective analysis

The addition of an inverse temperature function on the consumption rate of Irish Sea sprat improved the performance of model simulations (Figure 3.1.3). EwE simulations track the recent trends in biomass and replicate the magnitude of the relative abundance from the herring acoustic survey. The model does not capture the high interannual variation, but this may be improved if we replace the moving average temperature driver with the lagged spring temperature time-series. The impact of input parameter uncertainty on model predictions was addressed using the Monte Carlo approach (Kennedy and O'Hagan, 2001). Basic input parameters (i.e. biomass, production/biomass, consumption/biomass, diet, and catch) were assigned data pedigree confidence intervals based on data origin. A total of 200 alternative mass-balanced models were produced using the EcoSampler plugin (Steenbeek et al., 2018). This plausible model set was used to produce 95% confidence intervals around model simulations.

Drivers of sprat production were removed independently from the model to identify their contribution to the model simulations (Figure 3.1.4Figure). Removing the temperature forcing function reduced the model's capacity to track observed data from 1998 to 2020. The earlier portion of the simulation remains relatively unchanged due to the prevailing predation pressure from whiting (discussed below). In the Irish Sea EwE model, zooplankton (large and small) simulations show good agreement with observed Continuous Plankton Recorder (CRP) data due to the inclusion of the North Atlantic Oscillation winter index (NAOw) as a driver of zooplankton dynamics (Bentley et al., 2020). We removed the NAOw driver from the model to remove the observed variation in zooplankton abundance. In doing so, simulations suggest that sprat biomass has at times been supressed by the limited availability of zooplankton prey (**Error! Reference source not found.**). The overall trend remained similar but the peaks in biomass were higher. Finally, fishing pressure was removed from sprat for the duration of the simulation. Outputs suggest that retrospective catches (based on current data) had little impact on the overall trend or biomass of sprat in the Irish Sea. The biomass of sprat in simulations without fishing were slightly higher when compared to simulations with fishing. This may be more clearly observed in Figure where the baseline trend from each driver combination scenario have been plotted together.

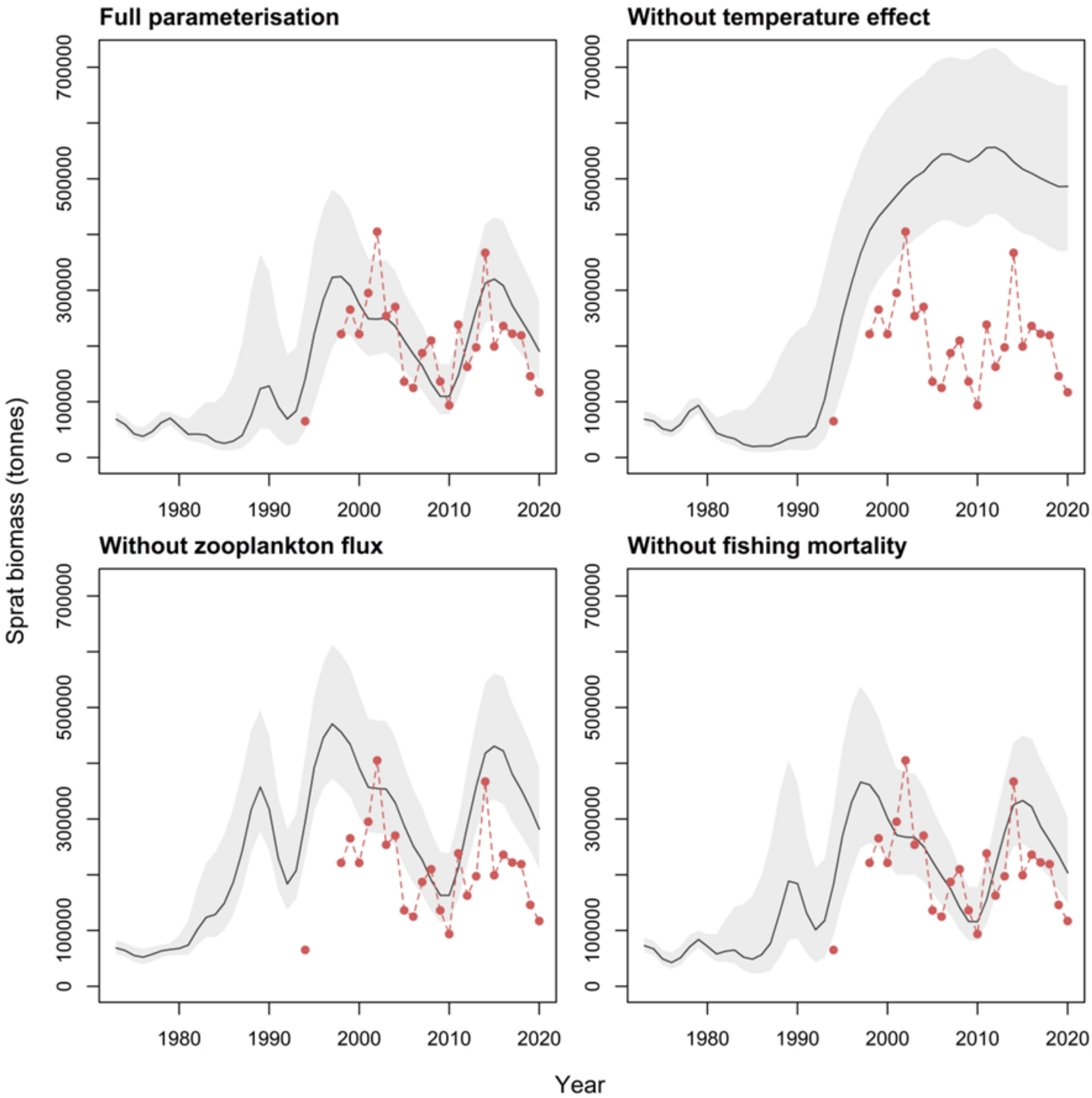

Figure 3.1.3. Retrospective simulations of sprat in the Irish Sea (ICES area 7a) with and without important drivers of production. Ecopath with Ecosim simulations (black line=base model; shaded polygon=95% confidence interval) are plotted against biomass data from the AFBI annual herring acoustic survey (red line and points).

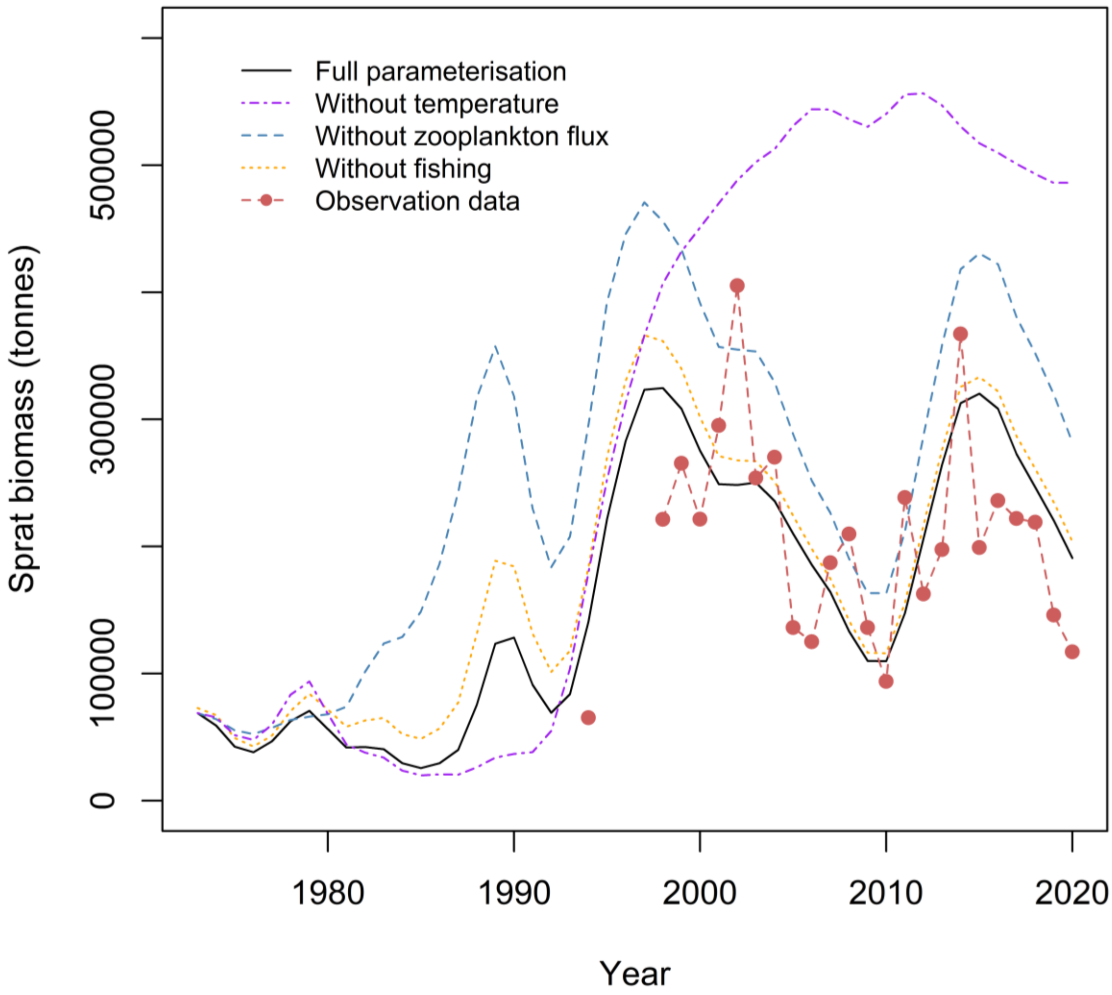

Figure 3.1.4. Comparison of retrospective simulations of sprat in the Irish Sea (ICES area 7a) with and without important drivers of production. Model simulations represent base model predictions.

Ecopath with Ecosim estimates of natural mortality

EwE dynamically simulates the production and consumption of all foodweb compartments and thus provides estimates of predation mortality for each. The total predation mortality for sprat for 1973 to 2020 is shown in Figure 3.1.5Figure. The total predation mortality simulated by the model declined steeply from 1985 to 2000 following the collapse of Irish Sea whiting. Sprat is the main prey of Irish Sea whiting, constituting between 15-46% of its average diet (Seyhan, 1994). The proportion of sprat in the diet of whiting changes between whiting age classes, with the preference for whiting peaking at age 1 (46% of diet). EwE simulations of sprat predation mortality have been broken down by predator in Figure 3.1.6Figure. Juvenile whiting (age 0-1) inflicts the highest predation mortality, followed by adult whiting (2+), other pelagic fish, and baleen whales.

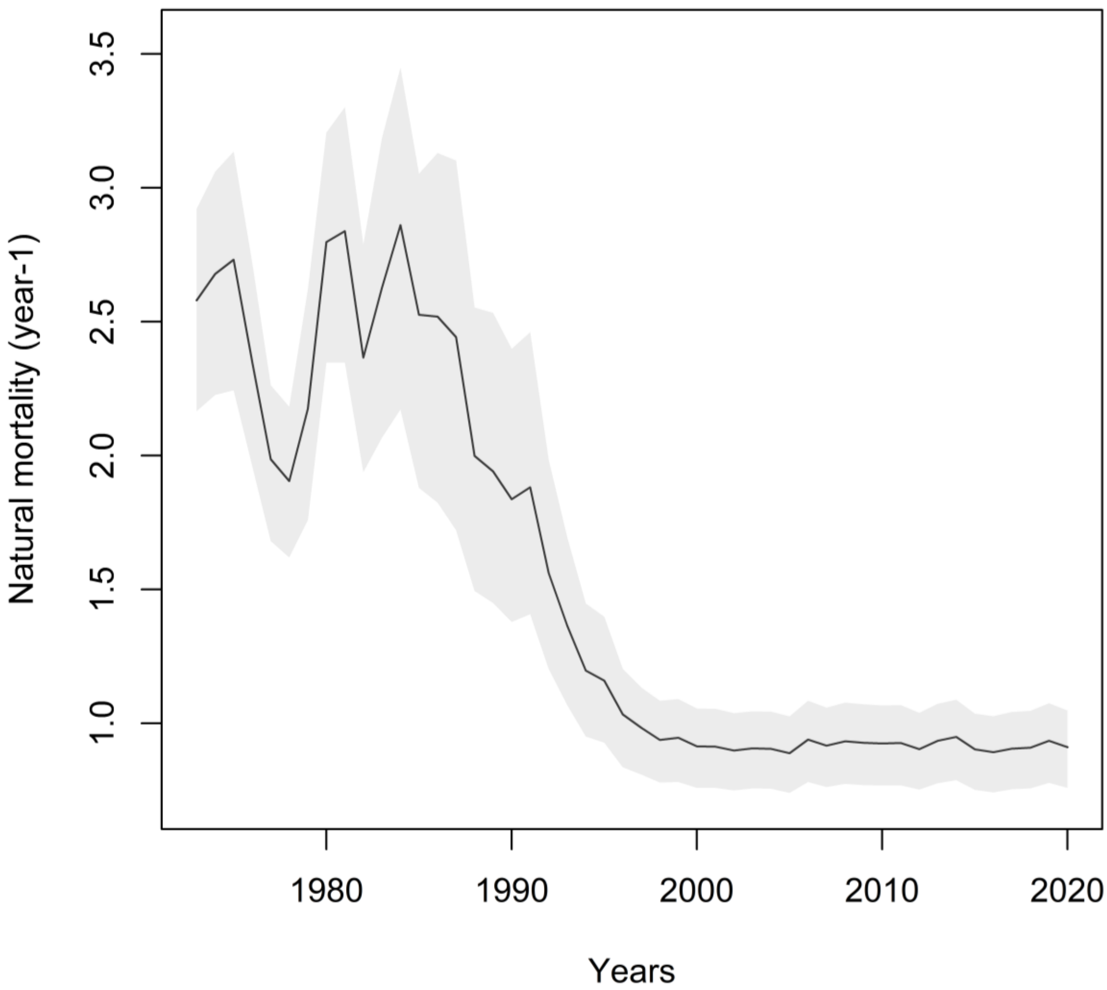

Figure 3.1.5. Sprat natural mortality caused by predation from 1973 to 2020. The solid line denotes the average mortality from a set of plausible model parameterizations while the shaded polygon denotes 95% confidence intervals.

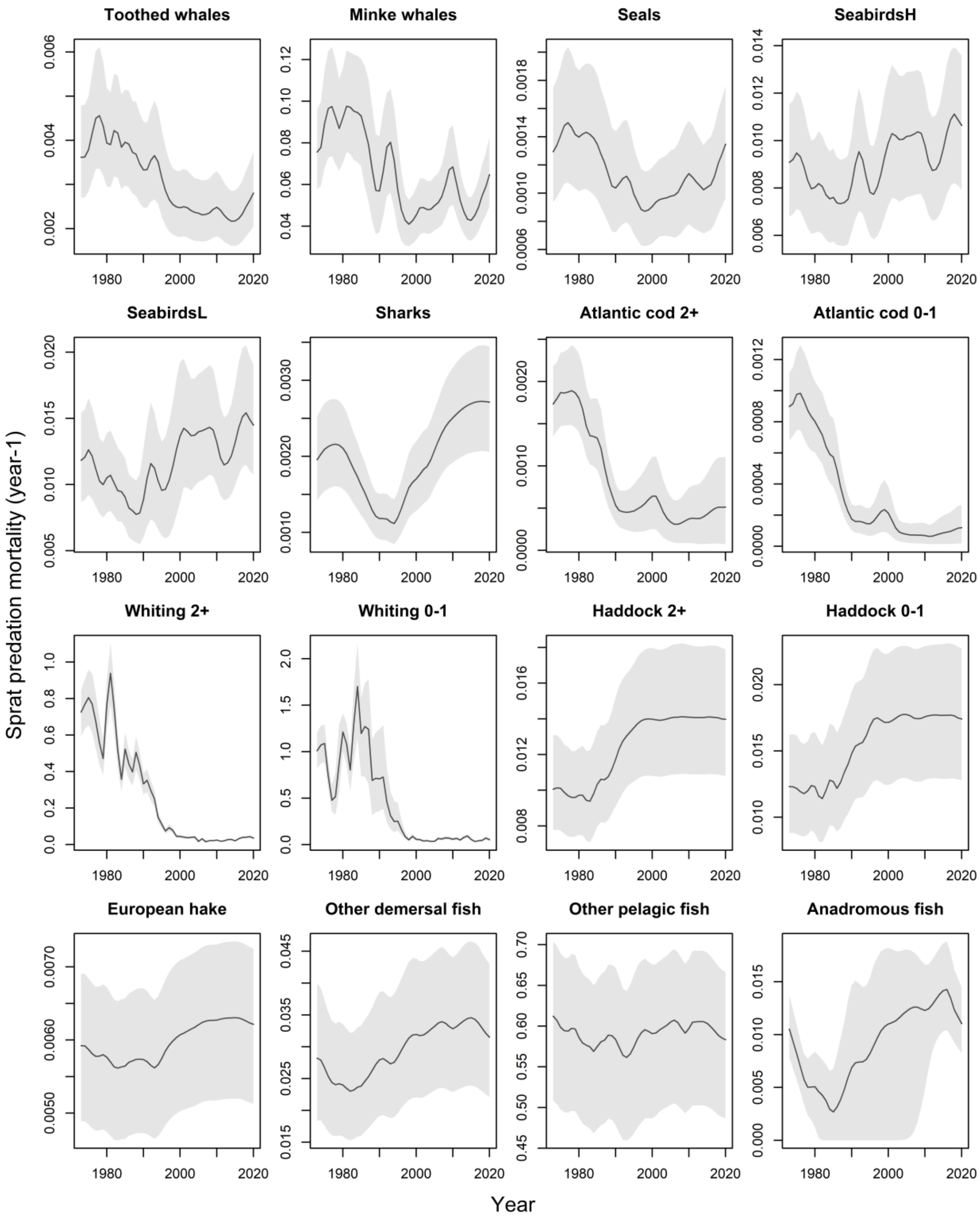

Figure 3.1.6. Sprat predation mortality estimates from the Irish Sea Ecopath with Ecosim model broken down by predator. The solid line denotes the average mortality from a set of plausible model parameterizations while the shaded polygon denotes 95% confidence intervals.

Impacts of sprat depletion on other components of the foodweb

When producing reference points for key prey species, such as sprat and other forage fish, it would be prudent to consider how any level of fisheries exploitation may impact the production of other components of the foodweb as well as more general ecosystem resilience. Such an understanding may inform reference points such as $B_{escapement}$ which, in its current estimation, provides a relatively shallow estimation of the needs of predators by failing to consider (i) the status of predators and (ii) the prey resource required to facilitate predator recovery.

EwE has been used to simulate the exploitation of Irish Sea sprat for levels of depletion ranging from 0 to 100% following previously published methods (Eddy et al., 2015). The impacts of sprat depletion were simulated by projecting the model forward while exposing sprat to incremental increases in fishing mortality. The fishing mortalities of all other exploited species were held constant at their 2020 levels. The level of depletion for sprat was calculated by comparing the biomass at each stage of exploitation to the biomass during a simulation where there was no exploitation (e.g., a depletion value of 100% means the biomass at that point is 0% of unfished biomass and vice versa).

While fishing mortality was used to drive the depletion of sprat in the model simulations, the outputs in Figure 3.1.7Figure have been presented in a way that they could also be viewed more generally as 'what might happen if sprat declines', i.e. due to fishing but also climate change and reduced prey availability.

At the current level of fishing mortality, sprat was estimated to be roughly 8% less than its potential unfished biomass. Limited positive or negative impacts were simulated for other foodweb components at this level of depletion. However, simulation suggest that an increase in sprat depletion could negatively impact the biomasses of key predators such as baleen whales, seals, seabirds, whiting, and haddock. Cod declined slightly but recovered as other prey became more available while sole and plaice showed a negligible response to the depletion of sprat. The biomass of herring and *Nephrops* increased with sprat depletion following declines in the biomass of their predators (e.g., baleen whales and cod).

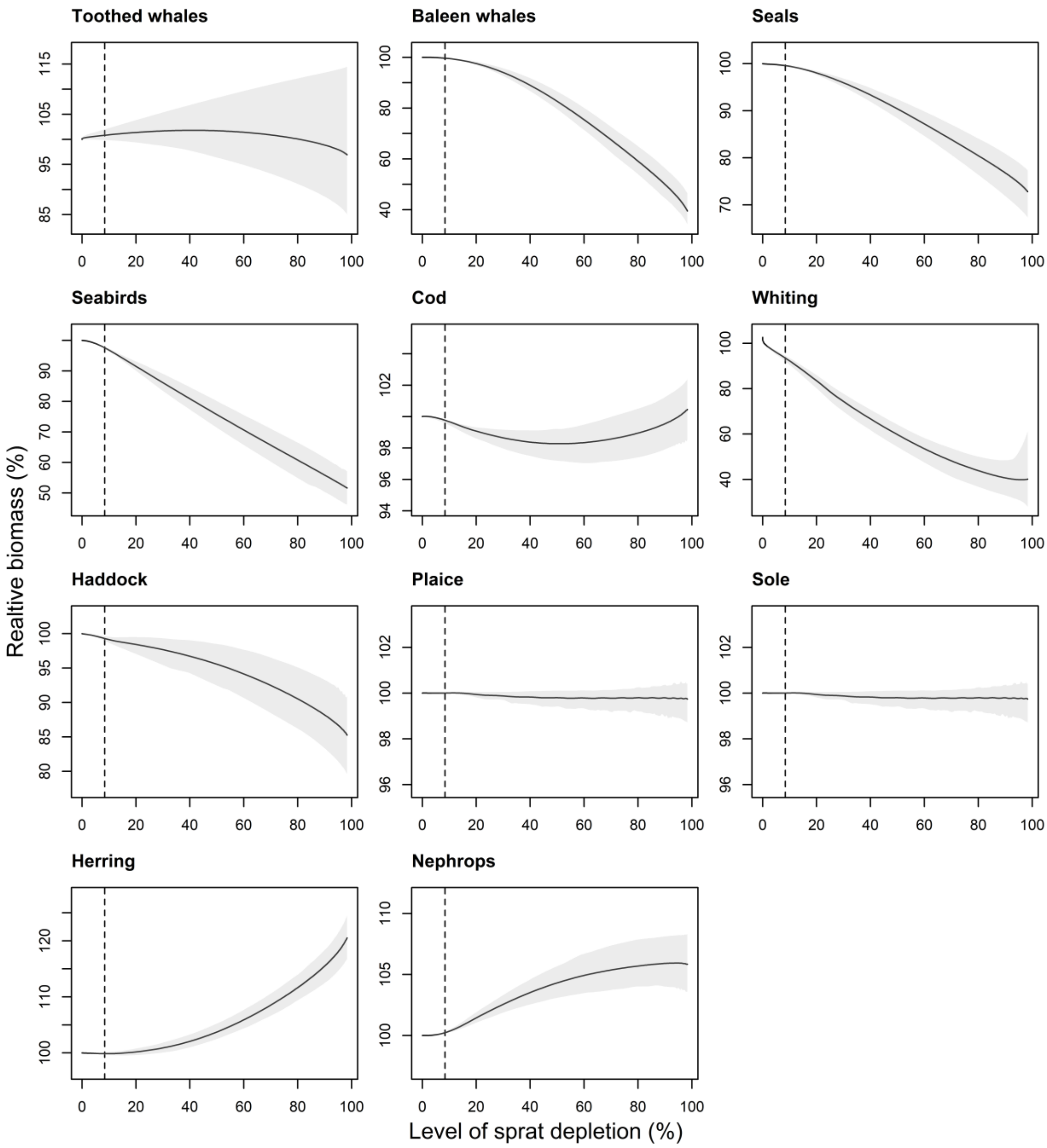

Figure 3.1.7. Impacts of sprat depletion on the relative biomass of mammals, seabirds, and commercial stocks in the Irish Sea (represented as the change in biomass compared to a scenario with no sprat exploitation). The solid line denotes the average mortality from a set of plausible model parameterizations while the shaded polygon denotes 95% confidence intervals. The vertical dashed line identifies the current level of sprat depletion based on fishing mortality in 2020.

4 Current Science Challenges and Weaknesses for Advice

4.1 Population/Stock Identification

The following section outlines the options available to investigate the potential structure and boundaries of sprat populations/stocks in the area.

4.1.1 Variability of Biological Traits

A previous study has investigated the stock structure of sprat around Ireland through an analysis of the shape of the otoliths (Moore, in prep[2]). While this type of analysis has been proven to be an effective method for identifying stock delimitation, the study concluded that no geographical stock separation is apparent from the samples. However, there was evidence of widely varying life-history patterns within sprat sampled from the waters around Ireland which suggests the possibility of regionally independent stock units. Moore *et al.* (2019) also found regional variation in the size-at-age of sprat, which similarly may be due to either stock separation or environmental drivers, or both.

Such variability of biological traits should be further investigated as an evidence base for identifying possible populations and stock boundaries. This work should focus on the requirements presented by the ICES Stock Identification Methods Working Group (SIMWG), particularly using recent and relevant examples such as Cod in 6a and 4a. Collation of these data should begin immediately in each national institute.

4.1.2 Genetic Techniques

ICES currently recognizes four sprat 'stocks'; sprat in Subdivisions 22-32 (Baltic Sea), sprat in Division 3.a and Subarea 4 (Skagerrak, Kattegat and North Sea), sprat in divisions 7.d and 7.e (English Channel) and sprat in Subarea 6 and Divisions 7.a-c and 7.f-k (West of Scotland, southern Celtic Seas). These stock divisions are largely based on the geographic separation of the sprat in these areas and on a small number of biological and genetic studies.

Among the earliest molecular studies on sprat were those of Nævdal (1968) and Jørstad and Nævdal (1981) who used haemoglobin and allozyme genetic variation to investigate the population structure of sprat in Norwegian waters. The methods were quite basic though and robust conclusions could not be made. Subsequent studies utilizing mitochondrial DNA and microsatellite markers, indicated population structure between the extremes of the species distribution, i.e. Northeast Atlantic, Mediterranean Sea and Baltic Sea, but little fine scale structure within these regions (Debes et al., 2008; Limborg et al., 2009). Glover et al. (2011) used the same set of microsatellite markers as Limborg et al. (2009) but expanded the distribution by including samples from Norwegian fjords. The fjord samples were significantly differentiated from the North

[2] Claire Moore, Maurice Clarke, Rick Officer, Deirdre Brophy, in prep. Sources of variability in sprat otolith shape and size. Do not cite without permission from the author.

Sea and Celtic Sea samples, which the authors suggested was evidence of limited connectivity between Norwegian fjord and sea-going populations. Limborg et al. (2012) presented a re-analysis of the combined Debes et al. (2008) and Limborg et al. (2009) samples, using the same microsatellite and mitochondrial markers as the original papers. The focus of this study was more academic in nature and the analyses were concerned with evolution of geographically isolated populations.

Two relatively recent studies have employed a more technologically advanced genetic method to attempt to understand the population structure of sprat. McKeown et al. (2020) and Quintela et al. (2020) employed Restriction site-Associated DNA sequencing (RAD-Seq), which is an approach that relies on subsampling the genome and then sequencing a small part of the genome to a high depth in order to identify and genotype a larger number of single nucleotide polymorphisms (SNPs), usually in a large number of samples. In this way RAD-Seq is seen as an approach that can be used to carry out population genetic studies on species with no, or limited, existing genetic data. McKeown et al. (2020) used a RAD-Seq approach to analyse a small number of samples (11 samples; 228 individuals) from the Celtic Sea, English Channel, North Sea, Skagerrak and Western Baltic areas. All samples comprised mixed age classes of adults at unspecified maturity stages apart from the Bristol Channel samples, which comprised juveniles. The analyses indicated that the Baltic Sea sample was significantly different from the other samples, but they failed to detect any other population structure across the regions of interest. Quintela et al. (2020) used a related RAD-Seq approach to analyse a larger sample set, which included many of the samples analysed in Limborg et al. (2009; 2012) and Glover et al. (2011) with a greater representation of sprat samples from the North Sea, Norwegian waters, transitional waters and in the Baltic Sea. However, only a single sample from the west of Ireland and a single sample from the Bay of Biscay were included in addition to two outgroup samples from the Mediterranean Sea. The maturity status of the samples was not presented, though the majority of samples were not collected in known spawning seasons.

Quintela et al. (2020) used a modified RAD-Seq approach to analyse a small number of samples (n=8 individual sprat) from a single Norwegian fjord to identify a small panel of 91 SNPs that were then used to genotype the full sample set using a genotyping by sequencing (GBS) approach. Surprisingly, the limited sample size and restrictive geographical range was used for the RAD-Seq analysis as this does not lend itself to identifying markers that are informative for differentiating populations from different areas. Regardless, four genetic groups were identified: (a) Norwegian fjords; (b) Northeast Atlantic including the North Sea, Kattegat–Skagerrak, Celtic Sea, and Bay of Biscay (c) Baltic Sea and (d) Mediterranean Sea. On the basis of the limited evidence presented in this study and an analysis of the North Sea and Kattegat-Skagerrak sprat stocks were merged (ICES, 2018).

In summary, there is very little comprehensive information currently available about the genetic population structure of sprat. All of the aforementioned studies have either had spatially and temporally limited sample sets, particularly to the west of Ireland and Britain, or have utilized non-exhaustive genetic methods. Further, few have focused on the collection of spawning baseline samples, which are the optimum sample type with which to conduct such analyses. There is a high probability that these studies have failed to identify biologically relevant boundaries indicative of population structure and may have incorrectly concluded panmixia between what are in reality different populations.

Comprehensive approach

The continued development of High-Throughout Sequencing (HTS) technologies and associated reduction in costs has fundamentally changed the way in which genetic sequence data are generated. It is now possible to generate large Whole Genome Sequencing (WGS) datasets for nonmodel species, which facilitate the identification of genetic loci with high discriminatory power for specific population differentiation questions (e.g. Han et al., 2020; Martinez Barrio et al., 2016). This is a more comprehensive approach than other commonly used methods (*e.g.* section 5.1), which rely on sequencing a subsection of the genome in the hope of finding informative genetic markers, e.g. RAD-Seq. The WGS approach for commercial fish species has been pioneered by Professor Leif Andersson's research group in Uppsala University, Sweden on Atlantic herring (*Clupea harengus*) through the ERC funded BATESON (Dissecting genotype-phenotype relationships using high-throughput genomics and carefully selected study populations) project (ERC Advanced Grant, LS2, ERC-2011-ADG_20110310), and the subsequent Norwegian funded GENSINC (GENetic adaptations underlying population Structure IN herring) project (Research Council of Norway project 254774). These projects have shown that the WGS approach is the only approach that can identify the true extent of genetic differentiation between different populations of marine fish. For example, the majority of the herring genome shows no differentiation across the entire distribution of the species. However, WGS has revealed hundreds of adaptive genes, linked to local environmental conditions, highlighting that herring populations are substantially structured and display a significant level of local adaptation (Han et al., 2020). Utilizing WGS to identify adaptive genes is key to accurate identification of populations and consequently delineation of stocks for the purposes of stock assessment. Subsequently, this can lead to development of sustainable management of marine resources. To this end the data gleaned from these projects has been used in an applied manner to resolve the stock identification issues concerning the herring stocks in Divisions 6.a, 7.b-c (Farrell et al., 2021; 2022). This has resulted in the realignment of the stock assessment areas to enable incorporation of population specific data into separate assessments for the 6.a.S, 7.b-c and 6.a.N herring stocks. This was achieved through the development of a genetic assignment model that enabled assignment of mixed survey samples back to their population of origin with a >90% level of accuracy (Farrell et al., 2021; 2022).

Proposed approach

The approaches outlined above are universal in their application and may be implemented in any species of interest. There are now no technological limitations in the ability to identify what populations constitute stocks, as they are currently defined. At the very least the alignment of populations with these stocks should be investigated to confirm that the bases of current assessments are valid. If not, then large-scale genetic stock identification is a tool that can be incorporated into regular data collection programmes and lead to a significant improvement in the input data for species-specific stock assessments. The schematic in Figure 4.1.2.1 illustrates the steps required to achieve this.

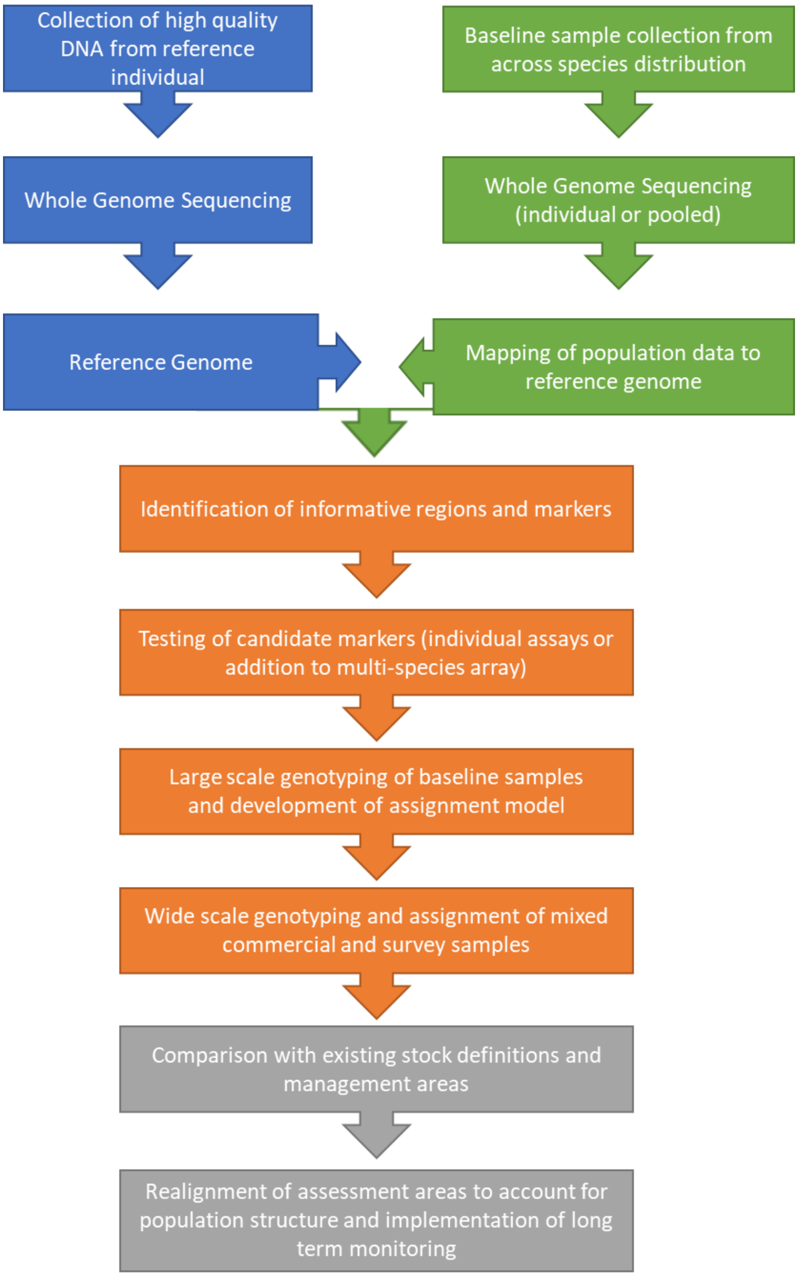

Figure 4.1.2.1 A simplified schematic of the steps involved in development of stock identification tools.

The WGS approach (Figure 4.1.2.1) for investigating population structure of sprat has already started, as presented at the WKRRCCSS (Andersson et al., invited presentation to WKRRCCSS). This study has already identified genetic differentiation in all cases where "oceanic sprat" were compared with sprat populations spawning in areas with reduced salinities. Such differentiation may be also relevant to the populations or sprat around Ireland and Britain, where sprat are often found in estuarine areas. These and other informative SNPs identified in this analysis have been included on the newly developed DNA TRACEBACK® Fisheries SNP genotyping array FSHSTK1D (IdentiGEN Limited, Dublin, Ireland), which is being used for largescale genotyping in a number of projects on herring and horse mackerel genetic stock identification. The analysis presented by Professor Andersson was based on Pool-Seq analysis of primarily the samples from Quintela et al. (2020); and as such did not include comprehensive representation of the potential populations present to the west of Ireland and Britain. Therefore, additional samples are required from the aforementioned regions, these should be added to the pre-existing dataset in order to conclusively determine whether or not there is population structure present in the sprat stocks in question. The optimum way to achieve this is outlined in a step-by-step process below.

1. Collect spawning baseline samples, at spawning time and as close to the spawning grounds as possible for each potential population that may be present in the area. The decision on what is a potential population should be informed by life-history analyses of samples from across the area, analysis of existing catch and survey datasets and with input of industry knowledge. Each sample should be a random mixture of males and females and comprise 48-96 individual fish. These should be collected following the protocol in Annex 4. Ideally, temporal replicates separated by at least 1 year for each potential population should be included.
2. Assuming spawning samples are collected then these can be sequenced using a Pool-Seq approach where the DNA from many samples (at least 30 individuals) is pooled together and sequenced as a single sample. This would enable the allele frequencies of each putative population to be compared and an assessment of the overall population structure to be made. If relevant structure is identified, then the informative markers underlying this structure may be selected and ultimately added to the DNA TRACEBACK® Fisheries SNP genotyping array for large-scale genotyping of further baseline and mixed samples.
3. If it is not possible to collect spawning baseline samples then it would be prudent to instead perform individual WGS on c.30 individuals from each of the available samples, which are identified as representing the putative populations. This will enable comparison of individual allele frequencies and in the event of any of the sample being of mixed population origin it will be possible to detect this and account for it in the analyses.
4. A sampling programme should be developed to enable further sampling of spawning baseline samples on an annual basis. In addition, this should incorporate sampling throughout the year across the entire distribution area to collect sprat samples through their life cycle from larva to juvenile to adult. These samples may be archived until the steps above have been completed and the genotyping array has been updated with newly identified markers.
5. In the event that no population structure is found despite following the rigorous steps above then it would be fair to conclude panmixia and adjust the assessment and management areas accordingly.

4.2 Surveys

With the exception of the PELTIC survey that is used in the constant harvest rate calculation for sprat in the channel, there are no surveys that can be used in their current form as indices of abundance, biomass or recruitment in a possible assessment for sprat in all of the Celtic Seas. Various surveys that could be adapted and/or combined to better inform an assessment (or indeed multiple assessments) of sprat in the area are described in the following sections.

4.2.1 Egg and Larval Surveys

Egg and larvae records of sprat from Cefas (UK) surveys

Table 4.2.1.1 plankton surveys undertaken by Cefas or whose data are on the Cefas database for the areas of interest: English Channel (ICES Division 7d,e) and Celtic Seas (ICES divisions 6a and 7).

Area	No. surveys*	Year range	Data storage
Bristol Channel	5	1987, 1989–1990, 2012	Cefas
Celtic Sea	10	1986, 1988–1990, 1992, 1995, 1998, 2001, 2004, 2010–2011	Cefas
English Channel	29	1961–1963, 1967, 1970–1971, 1984, 1987–1989, 1991–1992, 1994, 2002–2003, 2011–2012	Cefas
Irish Sea	32	1982, 1985, 1987, 1989, 1992–1996, 1999–2011	Cefas

*** Some surveys cover more than one area; therefore, the sum of this column does not reflect the actual total value.**

Egg and larvae records of sprat from Marine Institute (Ireland) surveys

No dedicated survey data are available; however maps of larval distribution were published in an Irish Fisheries Investigations paper (Figure 4.2.1.1).

An ichthyoplankton survey was carried out on board a 35m Irish commercial fishing vessel, MFV Girl Stephanie, between April 9th and May 5th, 2000. WGMEGS protocols were used, so station spacing was 0.5° longitude by 0.5° latitude. Samples were collected using a GULF III sampler, with a nose cone opening of 24.5cm, and a plankton net mesh size of 250 µm. The sampler was deployed at 4.5 knots to within 5m of the seabed, or a maximum depth of 200m. A logging CTD recorded the depth, temperature and salinity for each tow. 162 stations were sampled from the Celtic Sea to the North coast of Ireland.

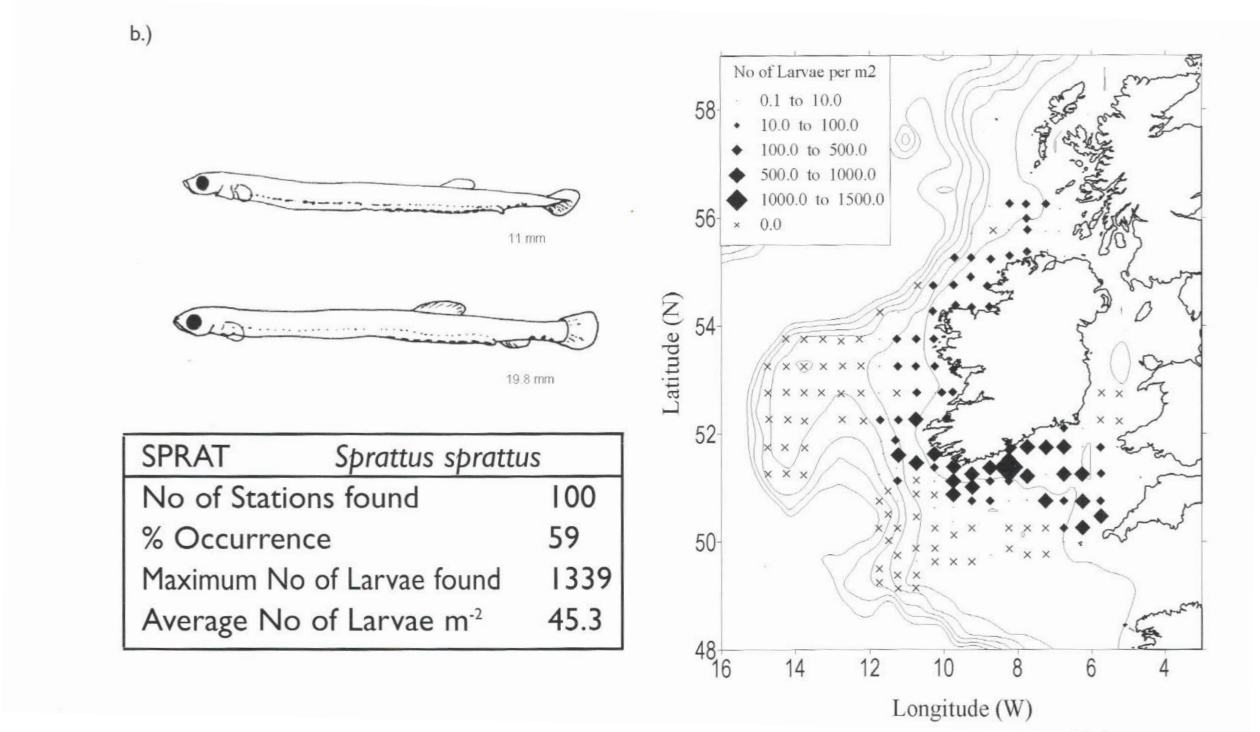

Figure 4.2.1.1. Larval images, occurrences and distribution map of sprat around Ireland during the Irish larval survey, April 9th - May 5th 2000.

Egg and larvae records of sprat from Ifremer (France)

IGA ecosystem survey (restricted access, 1987-20211). Monitoring of the Penly nuclear power station. All ecosystem compartments surveyed seasonally. Sprats eggs and larvae surveys occur in spring (Figure 4.2.1.2).

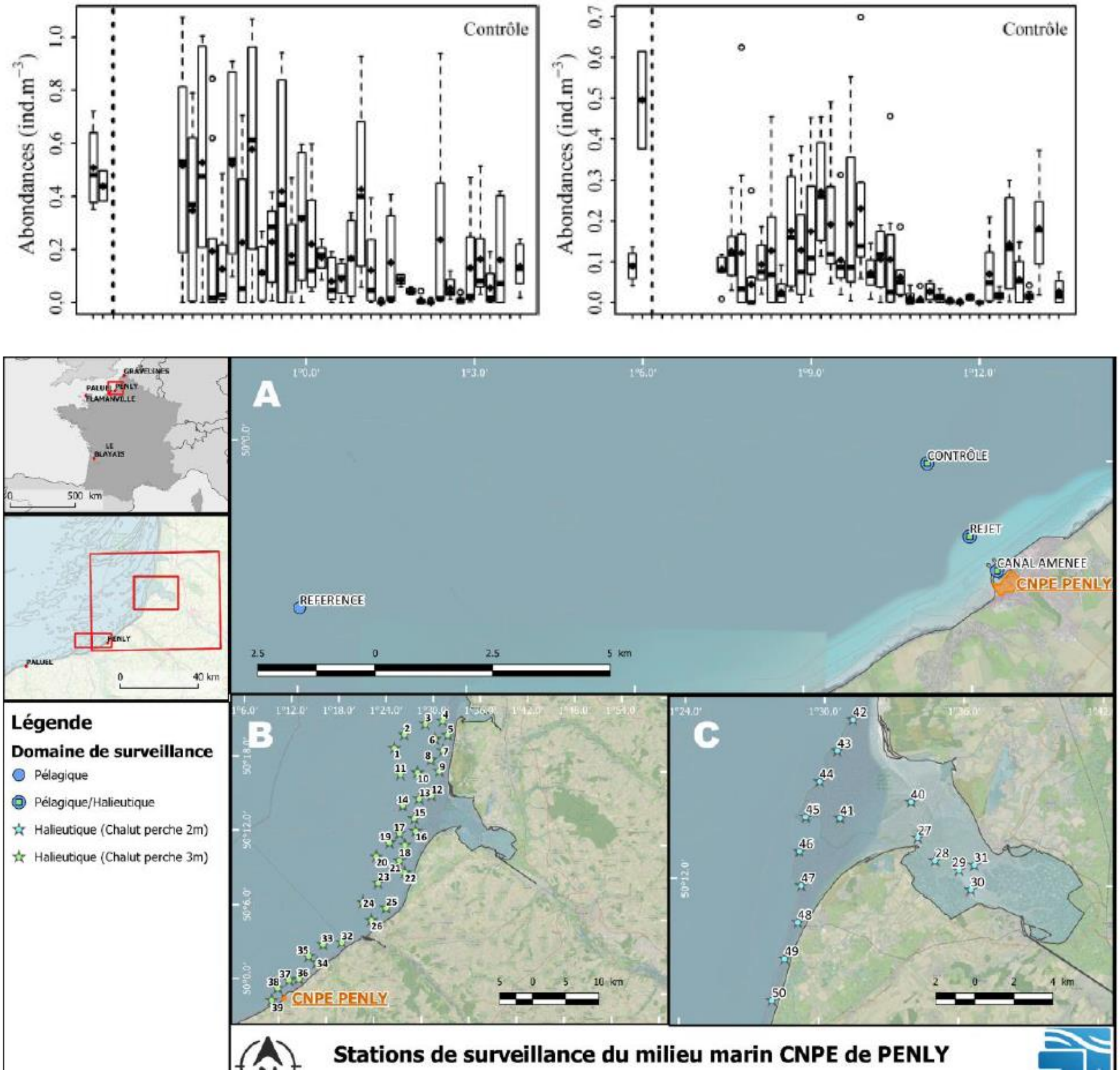

Figure 4.2.1.2. An example of sprat egg (top left) and larval (top right) abundance from the French IGA survey (bottom).

4.2.2 International Bottom Trawl Surveys

A number of groundfish surveys are carried out in the Celtic Seas ecoregion. Whilst these surveys do not target sprat, some sprat can be caught incidentally and may provide a coarse index of sprat presence. The catchability is very low and it would not be meaningful to compare bottom-trawl-derived biomass indices year-on-year for small pelagics (this is in contrast to acoustic surveys). Despite this, when records are considered across many months, multiple years and multiple surveys, presences can be confirmed. Figure 4.2.2.1 shows a presence map using these groundfish data, however it is important to interpret this in the context that the summed number is reflective of the amount of sampling effort.

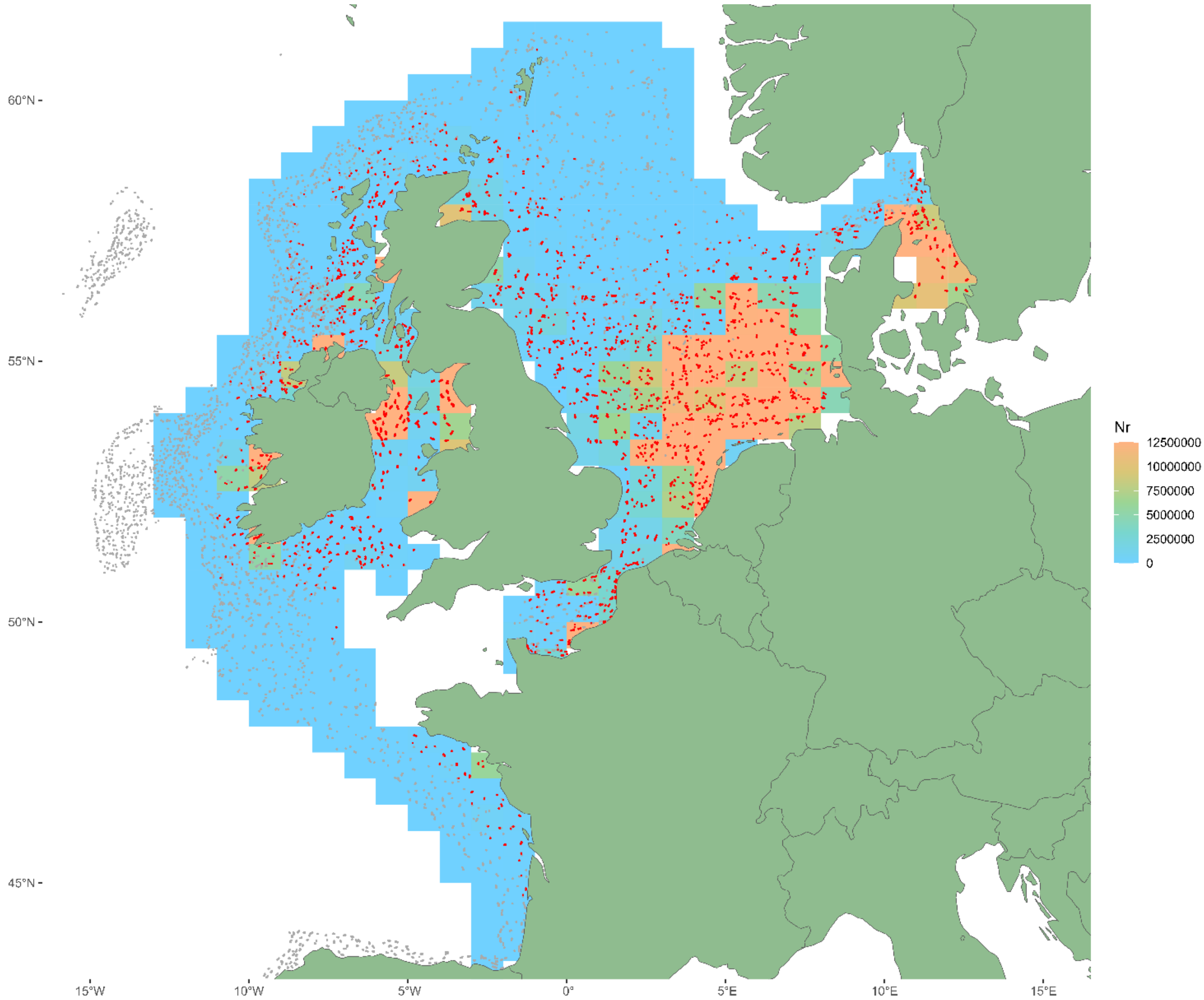

Figure 4.2.2.1. Mean swept-area abundance of sprat by ICES rectangle. Generated using the R 'SwAF' library (in development). DATRAS records downloaded 21 Apr 2023 for period 2013-2022. Red dots indicate hauls which caught sprat, grey dots indicate hauls with no sprat recorded. Combined DATRAS survey data for the surveys of acronym: FR-CGFS, IE-IAMS, NIGFS, SCOROC, SP-PORC, SP-NORTH, NS-IBTS, EVHOE, SP-ARSA, IE-IGFS, SCOWCGFS. See DATRAS website for details on survey acronyms.

4.2.3 Acoustic surveys

All the acoustic surveys in Table 4.2.3.1 report to WGIPS in January (apart from the new WoSSAS targeting sprat in Scottish sea lochs) with survey reports going back in time found here: https://www.ices.dk/community/groups/pages/wgips.aspx . Some of the large surveys are also multidisciplinary and therefore are true ecosystem surveys (CSHAS, WESPAS, PELTIC), including daylight mammal and seabird observations and hydrographic/zooplankton monitoring at point stations. The target species referenced in Table 4.3.3.1 reflect what is reported to WGIPS. These do not represent the complete list species found on these individual surveys. For instance, sprat is found on WESPAS, HERAS, NW Herring and 6aSPAWN surveys, but these are not generally worked up as an estimate for these surveys. The WoSSAS, NW Herring and 6aSPAWN survey indices do not get inputted directly into stock assessments, but are used as background qualitative information at ICES WGs. Figures 4.2.3.1-8 show example coverage of each survey in a typical year.

Table 4.2.3.1. Acoustic surveys in ICES divisions 6 and 7 targeting sprat or with potential to target sprat

Survey	Institute	ICES area	Timing	Duration/ vessel	Design/ operation	Target species
CSHAS	Marine Institute, Galway	7g, 7j 7aS	October	3 weeks RV Celtic Explorer	Stratified parallel transects with random start point. Increased transects and replicates in some areas 24 hour operation	Herring, sprat
PELTIC	CEFAS Lowestoft	7e, 7f, 7g, 7aS	Sept-Oct-Nov	35 days RV CEFAS Endeavour	Stratified parallel transects with random start point - daylight only	Sprat, anchovy, sardine
WESPAS	Marine Institute, Galway	7g, 7h, 7j, 7e, 7f, 7b, 7c, 6a	Jun-Jul	6 weeks RV Celtic Explorer	Stratified parallel and zig/zag transects with random start point 20 hour operation 0400-0000	Herring, boarfish, horse mackerel
HERAS	Marine Scotland Science, Aberdeen	6aN	Jul	3 weeks RV Scotia	Stratified parallel transects with random start point 20 hour operation 0300-2300	Herring
ISAS	Agri Food and Biosciences Institute, Belfast	7aN	Aug/Sept	2 weeks RV Corystes	Parallel and zig/zag transects with random start point	Herring, sprat
ISSS	Agri Food and Biosciences Institute, Belfast	7aN	October	2 days Industry vessel	Parallel and zig/zag transects with random start point	Herring, sprat
WoSSAS	Marine Scotland Science, Aberdeen	6aN	October	10 days RV Alba na Mara	Parallel and zig/zag transects in bays/strata with random start point 12 h operation, 0700-1900	Sprat
NW Herring	Marine Institute, Galway and Irish industry	6aS	Nov-Mar	8 - 10 days on various small inshore vessels	Parallel and zig/zag transects in bays/strata with random start point 10 h operation, daylight only	Herring
6aSPAWN	Marine Scotland Science, Aberdeen and SPFA	6aN	Sept	8 – 10 days on various large pelagic vessels	Stratified parallel transects with random start point 12 h operation, 0700-1900	Herring

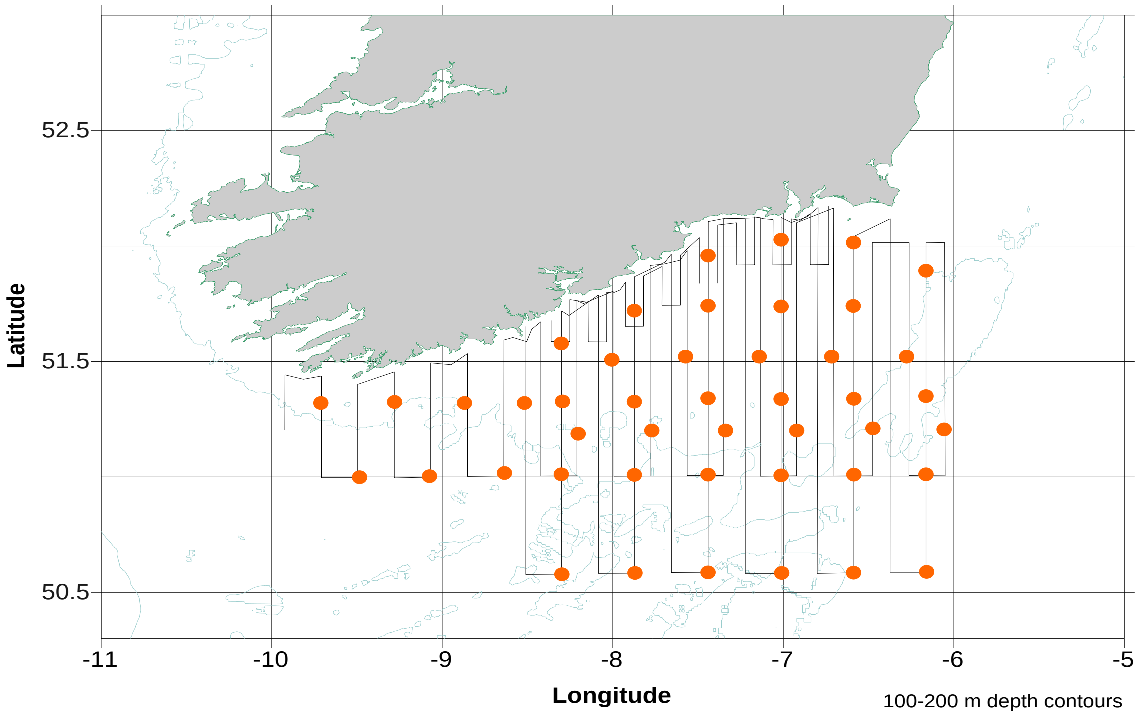

Figure 4.2.3.1. CSHAS survey plan for 2022. Survey is 3 weeks long and targets herring and sprat. The survey design uses a laddered broad scale survey with focused adaptive high resolution site surveys. Hydrographic stations are also shown as orange waypoints.

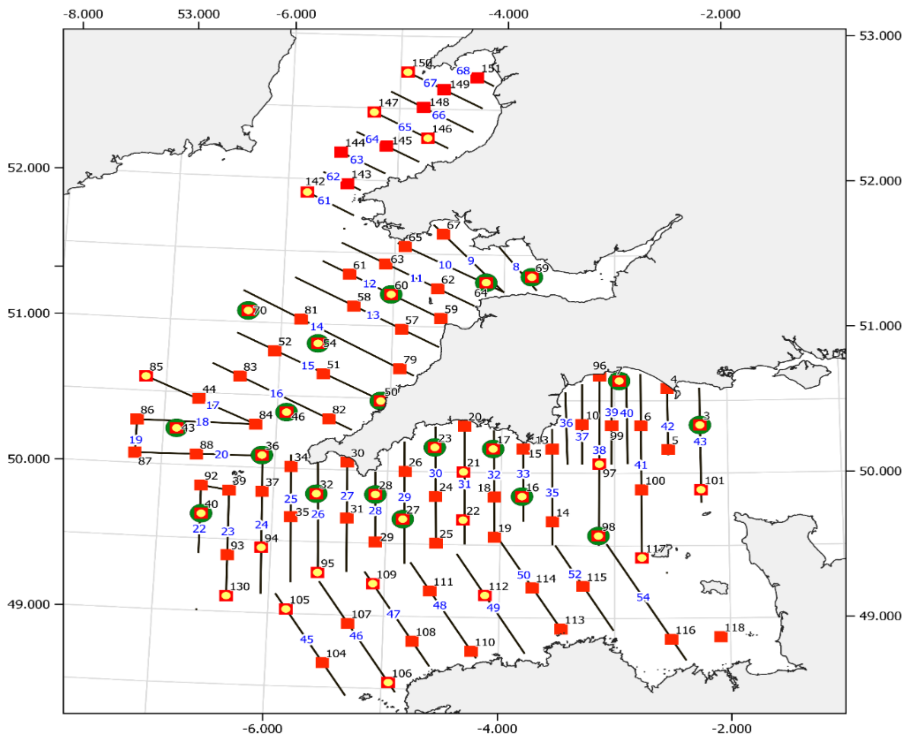

Figure 4.2.3.2. PELTIC survey plan for 2022 with acoustic transect (black lines), plankton stations (red squares) and hydrographic stations (yellow circles). The survey is multidisciplinary, but the sprat and sardine estimates are used directly in assessments.

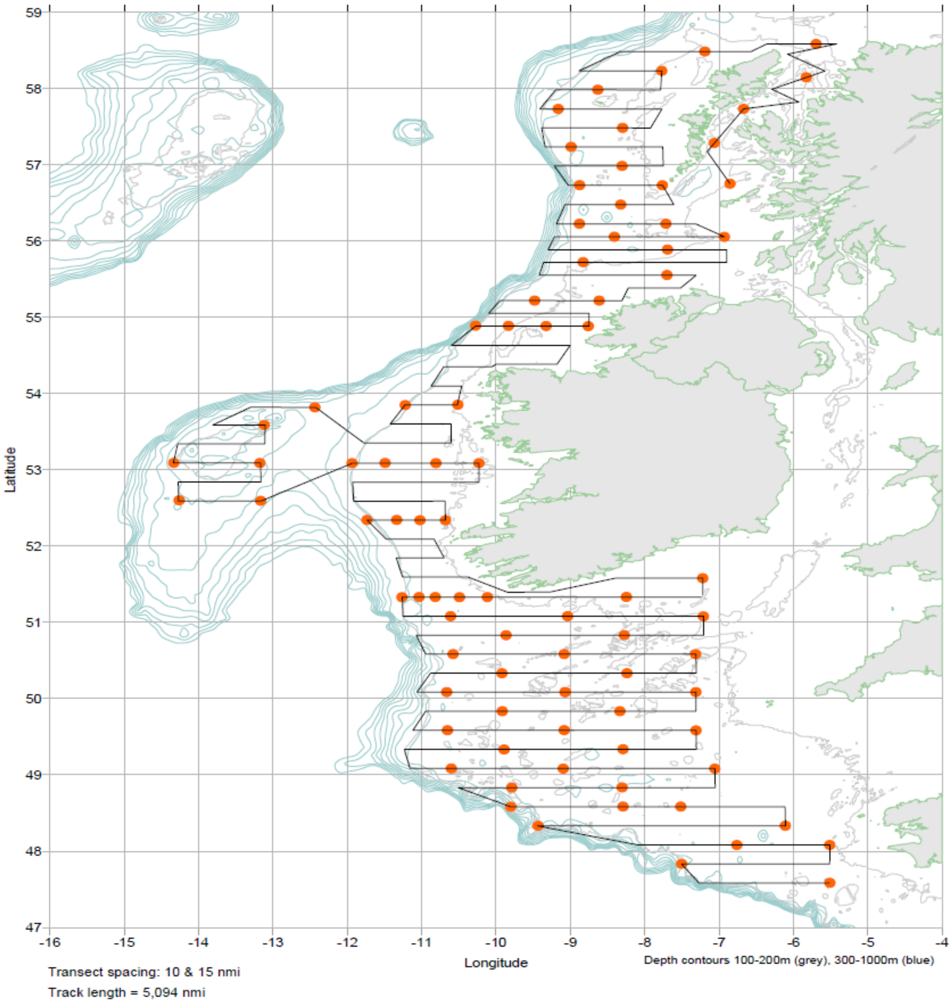

Figure 4.2.3.3. WESPAS survey design 2022. Survey is annual, 6 weeks long in June and July with the main target species being Malin Shelf herring, Boarfish and horse mackerel. Celtic Sea herring and spat are also found on this survey. Hydrographic stations are also shown as orange waypoints.

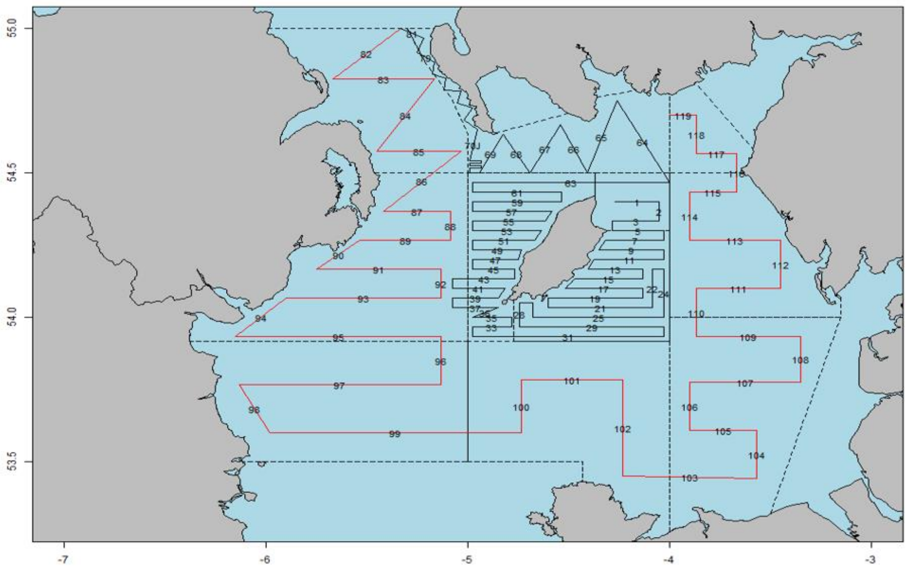

Figure 4.2.3.4. ISAS survey design 2022. The annual survey targets herring and sprat in 7aN in late August/early September.

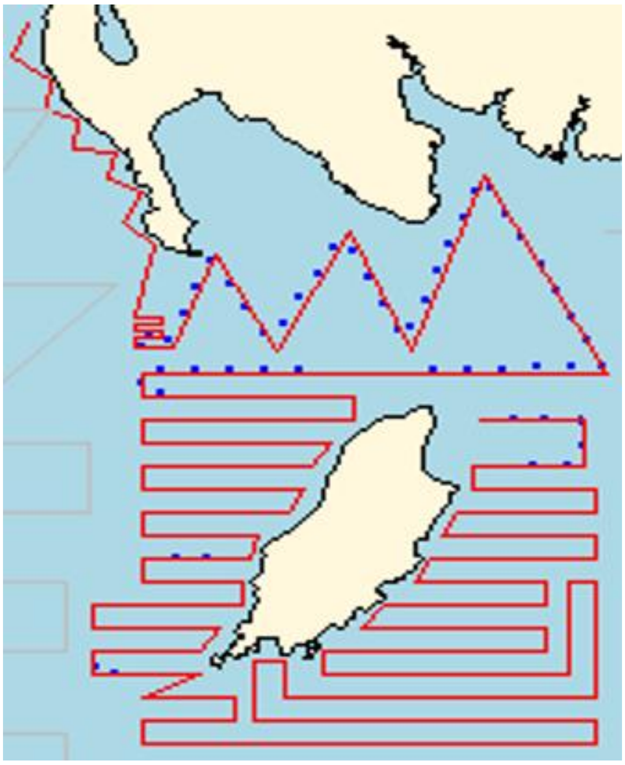

Figure 4.2.3.5. ISSS survey design 2022. The annual survey is conducted on an industry vessel mainly around the Isle of Man on known spawning grounds for Irish Sea herring in October.

Figure 4.2.3.6. WoSSAS survey design 2022. The survey is conducted in inshore bays and sea lochs with a focus on sprat. The first survey was in 2022 and the aim is to conduct surveys in ca. 9 bays/strata on the west coast of Scotland in areas where sprat are known to be distributed during this time.

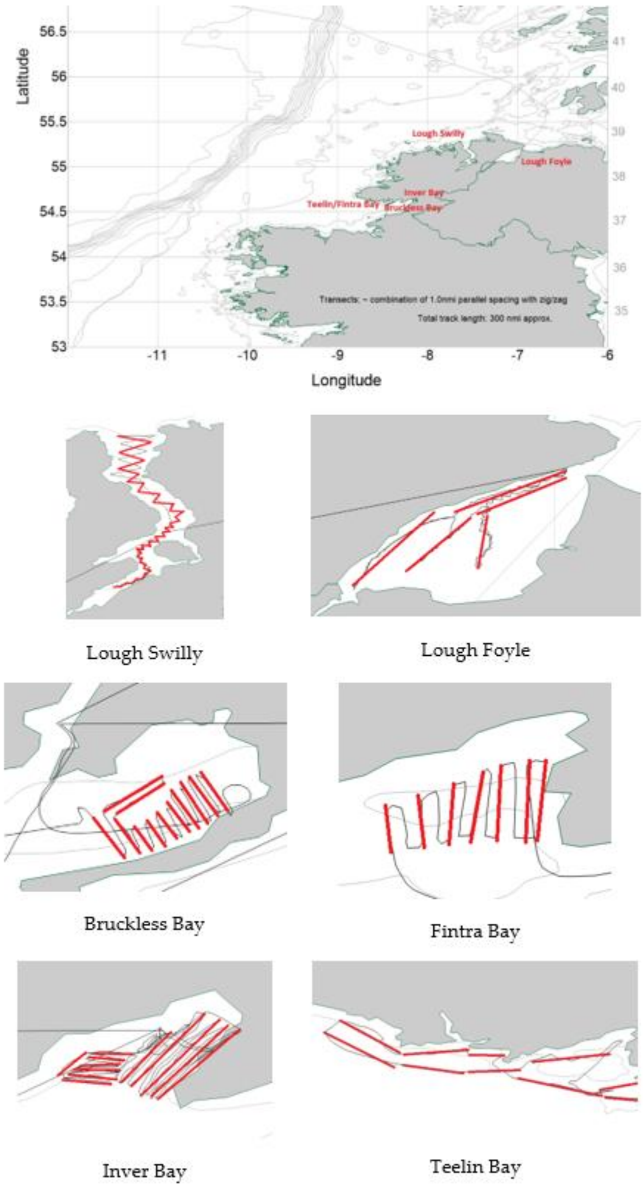

Figure 4.2.3.7. NW Herring survey design in 2022. The survey is conducted in inshore bays with a focus on aggregations of spawning and prespawning herring. The survey aims to conduct surveys in 5 - 6 bays/strata where herring are known to be distributed during this time.

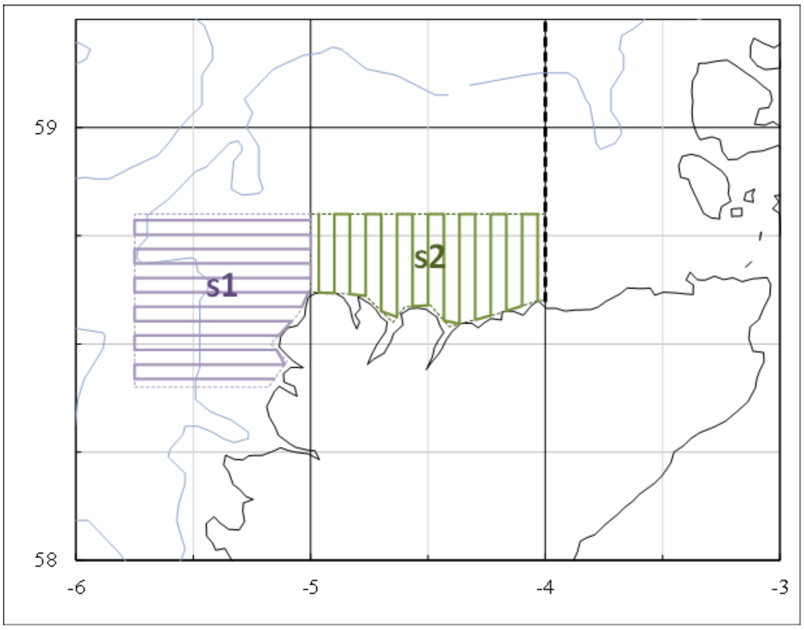

Figure 4.2.3.8. 6aSPAWN survey design in 2022. The survey area is split into 2 strata with a focus on spawning 6aN herring. The survey is conducted on industry vessels.

4.2.4 Biological Data Sampled from the Commercial Catch and Scientific Surveys

Table 4.3.4.1. Biological Data recorded from sprat samples from the commercial catch and scientific surveys, by country.

Country	Biological Parameters recorded on survey	Biological Parameters recorded during port sampling	Notes (e.g. years available, plans to start ageing *etc.*)
Ireland	Lengths, weights	Lengths, weights	Sprat aged in 2011, 2013 and 2014 (Moore *et al* 2019). Mainly 0,1 and 2 year olds. No plans to start ageing.
Scotland	Obtain samples of sprat 3 per half cm for biological analysis, including age, length, weight, sex, maturity and *ichthyophonus* infection.	Obtain samples of sprat 3 per half cm for biological analysis, including age, length, weight, sex and maturity.	MSS have age, length data going back to 2012 and started a targeted sprat survey in 6a in October 2022.
France	Length, weight		Abundance and length frequencies from CGFS-Q4 (7d: 1988-2022; 7e: 2015-2016, 2018-2019, 2021-2022) and IBTS Q1 in the eastern part of 7d (2008-2022)
England and Wales	Length, weight, age, maturity, sex for up to 5 specimens per 0.5 cm length class per trawl from 2012	Length, weight	Additional self-sampling of length and weights in 7.de.

4.3 Sprat Operating Model and Management Strategy Evaluation

The workshop was presented with ongoing work to develop an operating model and management strategy evaluation (MSE) for sprat in the Celtic Sea. The following text in Sections 4.3.1 and 4.3.2 outline this work and is adapted from a progress report by MRAG to the Marine Institute under a contract for research services.

4.3.1 Operating Model

The approach used by this project to combine strategic information from an ecosystem model with the tactical advice of a single species operating model takes inspiration from the work of ICES WKIrish (the first integrated benchmark assessment for the Irish Sea). The WKIrish framework brought multiple stakeholder groups together, including fishers, scientists, regulators, environmental non-governmental organizations, and other interested parties to enhance fisheries advice and co-develop an operational route for EAFM. The work plan for the WKIrish Framework was a multiyear process focused on improving the single-species stock assessments and advice for the Irish Sea, incorporating a mixed fisheries model, and developing an approach for the integration of stakeholder knowledge and ecosystem science in order to work toward an integrated assessment. Of particular interest to the work developed here, WKIrish 5 and WKIrish 6 (ICES, 2018b, 2020) established a new approach for the combined use of single species models and ecosystem models to create an ecosystem-based fishing reference point: F_{eco} (Bentley et al., 2021). F_{eco} is a precautionary F within the predefined F_{MSY} range based on the strategic understanding available from ecosystem models. F_{eco} provides a quantitative mechanism for incorporating ecosystem information from empirical and model-derived indicators into the ICES single-species stock assessment process. The F_{eco} concept helps deliver EAFM and is a stepping-stone toward EBFM, identifying a pragmatic, transparent route by which ecosystem information can be immediately incorporated into the current single-species stock assessment process without the need to revise any existing ICES protocols.

The Feco approach was reviewed at ICES Workshop on ICES reference points (WKREF2), which recommended that ICES guidelines include the possibility to use an F_{eco} approach to adjust the F based on ecosystem model information. The following criteria were outlined for the adoption of Feco in a particular benchmark:

- The revised F should not exceed $F_{P.05}$
- The ecosystem model to be used should have been reviewed as a Key Run by WGSAM
- The implementation should be evaluated and reviewed at a benchmark process.

Sprat is a target species in the Celtic Sea; however, current harvest advice is based on landings, and there is insufficient information to estimate stock status, trends, or target and limit reference points. Various approaches, based on catch-only or length data, have been developed to assess stocks in such data-limited situations (e.g., Pons et al., 2018). For example, catch-only models can be used to make general statements about global and regional stock status (Worm et al., 2006), identify stocks of most concern as part of a risk assessment, or provide advice on a stock-specific basis (Bouch et al., 2020). Simulation has shown, however, that catch-only models are highly sensitive to the choice of priors about such known unknowns (Wetzel and Punt, 2015), and cannot be used as part of feedback control management procedures (Kell et al., In press).

A key step for data-limited stocks is to identify what information, data and knowledge, are required to provide robust advice, i.e. that can still meet management objectives despite uncertainty. Therefore, the International Council for the Exploration of the Sea (ICES) that provides catch advice for fish stocks in the Northeast Atlantic (ICES, 2021a) classifies fish stocks into six categories depending on available data and applicable methods (ICES, 2012). Stocks in category 1 are usually assessed with age-structured stock assessments, and the catch advice is based on a short-term forecast. In most cases, this advice is based on the ICES MSY rule (ICES, 2021a), which is a harvest control rule aiming at the fishing mortality corresponding to the maximum sustainable yield (MSY), FMSY, but with F reduced when the spawning-stock biomass (SSB) is estimated to be below a trigger value Btrigger. Guidelines specify how these management reference points should be derived (ICES, 2021), and this usually involves a stochastic long-term simulation assuming stationarity.

The ICES data-limited stock assessment framework (ICES, 2012) is a collection of methods for stocks in categories 2 - 6, i.e. for those without absolute estimates of biomass and fishing mortality. Category 2 was originally meant for stocks with quantitative assessments, which were considered to provide only relative estimates due to large uncertainty. For stocks in categories 3 - 6, there is typically no stock assessment due to data limitations or because assessment models do not meet acceptance criteria. For category 3 stocks, a survey or catch per unit effort index exists and can indicate stock trends. The standard method for this category is a status quo catch rule, which adjusts the recently advised catch by the trend in a stock index, typically a “2 over 3'' rule, where the trend is defined as the average of the two most recent index values divided by the average of the three preceding values. The remaining stocks are classified as category 4 (stocks with a time-series of reliable catch, including discard estimates, which can be used in catch-only models), 5 (stocks with only landings or short catch time-series insufficient for catch-only models), and 6 (stocks with negligible landings or bycatch). Celtic Sea sprat is potentially a Category 3 stock as an acoustic survey, length data and catch are available.

Recently, there have been developments to revise the ICES data-limited framework, guidelines were proposed in (WKLIFEX) and published in (ICES, 2020b) to overhaul the system for category 3 stocks. The first step of the revised framework is to check whether a surplus production model (e.g., SPiCT; Pedersen, 2017) can be fit. If such a model fit meets acceptance criteria, the stock can be upgraded to category 2 and a fractal rule is applied. The fractile rule involves taking the SPiCT model fit and running a stochastic short-term forecast targeting FMSY, resulting in a distribution of catch values in the forecast year. Instead of using the median of this distribution, a percentile below 50\%, e.g., the 35th percentile, is then used for the catch advice. This approach accounts for model uncertainty, and larger uncertainty leads to lower catch advice.

In the absence of quantitative stock assessments, empirical (model-free) MPs were developed through testing with generic simulations and tuning to achieve precautionary criteria for a wide range of life histories and uncertainties. One of the new empirical MPs is the ``rfb rule'' (Fischer, 2020) which derives advice by adjusting the previous catch advice by the trend from a biomass index, the catch length data as a proxy for fishing pressure, and a biomass safeguard protecting against low stock size. Another suggested MP is a harvest rate rule which sets catch advice by targeting a relative harvest rate divided by a biomass index (Fischer, 2022). The rfb rule was already applied to two stocks in 2021 (ICES, 2021ab) and in the first half of 2022, the rfb and harvest rate rules were applied to five stocks each (ICES, 2022a), with a further rollout being anticipated. However, recently Fischer et al. (accepted 2022) have shown that Category 3 rules can perform as well as Category 1 rules.

However, the rfb rule does not work well for short-lived species, *i.e.* those like sprat with variable recruitment, high natural mortality and fast individual growth rate. Therefore, the Workshop on Data-limited Stocks of Short-lived Species (WKDLSSLS3) was established to develop methods for stock assessment and catch advice for short-lived stocks in categories 3 – 4, focusing on the provision of advice rules that are within the ICES MSY framework. On the basis of the outcomes of WKLIFE VII–X (2017–2020), WKSPRAT 2018, WKSPRATMSE 2018, and WKDLSSLS I–II (2019–2020), in 2022 tested different assessment methods for data-limited short-lived species (e.g., seasonal SPiCT, depletion models, stage-based biomass models) and explored the appropriateness of the other management procedures for short-lived species based on direct use of abundance indices (category 3) by means of Long-Term Management Strategy Evaluations (LT-MSE). Testing simple dynamic rules which can approach maximum sustainable harvest rates.

A review of the current ICES technical guidance on advice rules for short-lived species in Category 3 concluded that trend-based management procedures (the ICES 2 over 3 rule, the rfb-rule or any other combination of x over y rules with or without additional elements such as uncertainty caps or biomass safeguards) led to poor management performance (high risks, low yields) for such species and should be avoided. In addition, the only way to comply with precautionary principles for such rules and species is to apply very precautionary multipliers (very low catch advice). Consequently, the recommendation would be to very cautious with trend-based rules for faster-growing species and consider abandoning them. Instead, alternative management procedures (e.g., harvest rate-based rules or escapement strategies) should be explored for faster-growing species.

The fast dynamics of sprat (e.g., boom and bust; de Moor et al., 2011) warrant alternative modelling approaches e.g., where seasonal dynamics are explicitly considered. Therefore, a seasonal operating model has been developed, this will allow alternative management procedures, such as escapement strategies, to be consider. For example, where an index of abundance from an acoustic survey (I) is used to set a target harvest rate (Figure 4.3.1.1). Trigger reference point ($I_{trigger}$) can then be linked to the lowest observed index value often set to w = 1.4 in the absence of better knowledge (ICES, 2017, 2021c). This can be linked to the needs of predators by setting a $B_{escapement}$ with ecosystem information.

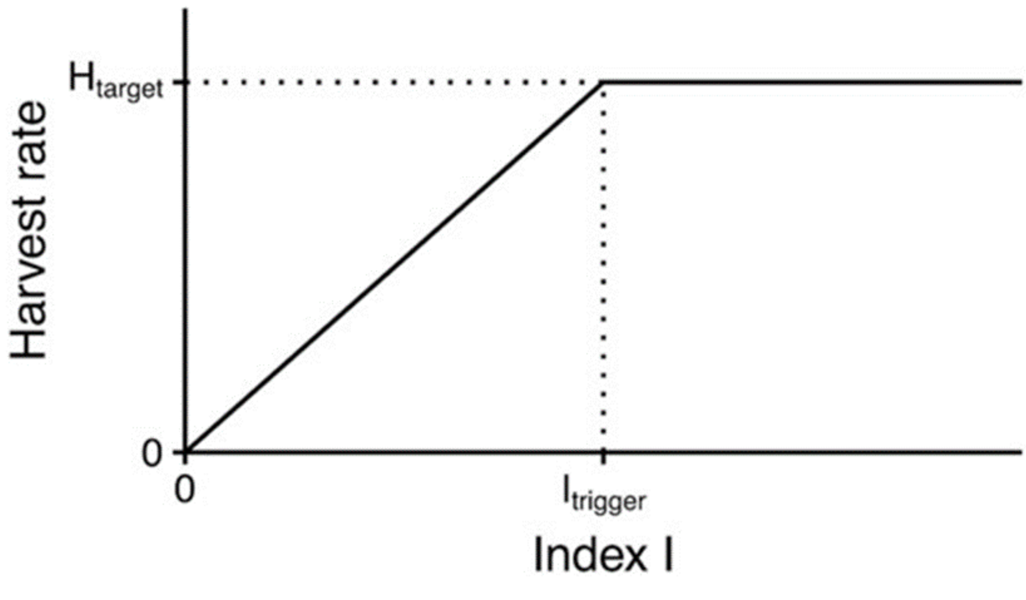

Figure 4.3.1.1 Hypothetical relationship between an index of abundance (I) against a target harvest rate.

4.3.2 Management Strategy Evaluation

Combining strategic information to enhance tactical stock assessment advice

Managing small pelagic fisheries is difficult because they have short lifespans, and highly variable recruitment with rapid changes in biomass levels due to regimes or pulses. Additional problems are that management objectives often include stability of catches and escapement for predators as part of an Ecosystem Approach to Fisheries Management (EAFM)

The adoption of the voluntary Code of Conduct on Responsible Fishing and the United Nations Fish Stocks Agreement (PA, Garcia, 1996) requires that reference points and management plans are developed for all stocks. Reference points are used in management plans as targets to maximize surplus production and as limits to minimize the risk of depleting a resource to a level where productivity is compromised. Reference points must integrate dynamic processes such as growth, fecundity, recruitment, mortality, and connectivity into indices for exploitation level and spawning reproductive potential. An example of a target reference point is the fishing mortality (F) that will produce the maximum sustainable yield (FMSY), commonly defined as the fishing mortality with a given fishing pattern and current environmental conditions that gives the long term maximum yield. To ensure sustainability requires preventing a stock from becoming overfished, so that there is a low probability of compromising productivity. Therefore, many fishery management bodies also define a limit reference point, e.g., B_{lim}, at a biomass at which recruitment or productivity is impaired (Restrepo and Powers, 1999).

Management Strategy Evaluation (MSE) is a valuable tool for developing management plans and has been used for a variety of Small Pelagic Fisheries (e.g., Siple et al., 2021). The starting point when conducting MSE is to agree the management objectives. Objectives should explicitly include consideration of the role that Small Pelagic Fisheries play within the ecosystem. It is important to distinguish between the conceptual objective (e.g., maintain a sustainable fishery) which are related to high-level policy goals, and the tactical objective (e.g., ensure SSB remains above B_{lim}). For Celtic Sea sprat this may require consideration of alternative advice rules used by ICES, as harvest control rules should be designed to accommodate the unique characteristics of Small Pelagic Fisheries.

There are six primary ways in which EAFM can be explicitly considered in MSE. The actual choice depending on the level of knowledge, data and models available. These are:

1. Use an ecosystem model as the Operating Model

This is most demanding with respect to data and computational requirements, as it requires Models of Intermediate Complexity for Ecosystem assessments (MiCE) conditioned on data for all components. In principle, the approach is useful for tactical management advice, and realistic given computing time limitations compared to other ecosystem models (Siple et al. 2021, Blamey et al. 2022). However, by definition such models are limited to only key components of the ecosystem, and no MiCE model exists for Celtic Sea sprat. Although MiCE models are avilable for the Irish and North Seas.

2. One-way coupling of the Operating Model with another model/relationship to provide EAFM performance statistics.

Output for the target species from the Operating Model is input to another model. For example, in the case of a single Operating Model based on sprat, the projected future biomass (which will vary for each HCR) is input into a model such as EwE. This requires knowledge of the relationships between prey biomass and that of the predators.

3. Density-dependent natural mortality (M)

M typically includes all forms of non-fishery-related deaths, and predation and can be separated into background (M1) and predation (M2) mortality. If mortality is relatively greater when the forage fish biomass is low then density-dependent M could be used as a proxy for non-negligible changes in predation pressure. This is one-way as it only models the predator impact on Small Pelagic Fisheries (Saraux et al., 2021)

4. Performance statistics based on ecosystem thresholds

For example, proportion of years for which Small Pelagic Fisheries biomass is predicted to fall below a threshold level for a given MP (Robinson et al., 2015), e.g., if ICES defines the threshold as 20%B0.

5. Informing control parameters of the HCR

Using external relationships to preselect reference points used in an HCR. For example, the F_{ECO} concept recommends keeping the target F within the pretty-good-yield range, and then scales fishing mortality down when the ecosystem conditions for the stock are poor and up when conditions are good.

However, an HCR's performance in relation to an EAFM threshold can be highly dependent on the Operating Models used and their relative weighting, and ideally control parameters are ideally selected by "tuning" an HCR to ensure performance statistics meet objectives and/or trade-off between objectives

6. Adjusting performance metrics related to conceptual objectives

Performance statistics based on Targets and limits RPs, allow these to change.

4.4 Data Limited Stock Assessment

Data limited stock assessment has advanced considerably in recent years for small pelagic and short-lived species, this is a credit to the work of the data-limited stocks of short-lived species group WKDLSSLS. The group was convened in 2019 following the testing of MSYCat34 catch rules 3.2.1 (ICES 2017). The MSYCat34 catch rules were tested as part of WKLIFE VII and found to perform poorly for stocks with a k >0.32 (ICES 2018). The subgroup examined the response of ICES HCR rules on short lived stocks using management strategy evaluation at 3 subsequent working groups, WKDLSSLS 1,2 and 3. The workshop produced some important considerations for the management of short-lived stocks, which are incorporated into the advice rules themselves but should be kept in mind when seeking to implement them. Namely the lag between survey, advice and implementation greatly impacts the effectiveness of a rule. This can be demonstrated by the advice history of 7de sprat, which previously operated under the 2 over 3 rule (with uncertainty cap). That being the survey biomass index of the past two years over the past three years which effectively meant advice was being issued based on fish that where no longer present in the population. The implication of this is that the rule was unable to respond to the high year-to-year variation that can occur in biomass for short lived stocks. Second the group found that historical exploitation of the stock influenced the success or failure of a HCR. For ICES implementation, this presents a problem for data-limited stocks, which may have a catch time-series, but cannot relate this to a stock biomass. When such a situation occurs, it is advisable to err on the side of caution and to assume and test parameters for the stock in question that are precautionary and cover a range of exploration history's. An example of this precautionary approach to data-limited stocks can be seen in the sprat 7de inter benchmark, which tested a range of exploitation history's, survey catchabilities and assumed life-history parameters on the low end of the range for the species (ICES 2021b). The results of the WKDLSSLS 1 and 2 were codified under WKLIFE X (ICES 2021c) and formally accepted as guidance for category 3 short lived data-limited stocks. This provided the first official framework for the implementation of the new rules translated to ICES HCRs for category 3 data-limited stocks.

- SPiCT (Surplus production model)
- MSE derived CHR (management strategy derived constant harvest rate)
- 1 over 2 with and 80% uncertainty cap (Index over Index with cap)

The details of these can be found in WKLIFE X (ICES 2021c), it is key to remember that the three HRC's are still data-limited and are all based on catch and an index. An emergent weakness of this has been producer driven fisheries that will not have a representative catch history or fisheries that purposefully limit their catch of a stock prior to that stock becoming an ICES advised stock. Similarly, a great deal of emphasis is put on the representativeness of the biomass survey index.

4.5 Future Innovation

The conversation on possible future innovations and research was wide ranging and ambitious. Goals that were deemed essential and could be generally considered as SMART (specific, measurable, assignable, realistic and time-related) were included in the research road-map. Other possibilities that were raised are outlined below. This is not to say that such research could not or will not constitute an important part in the improvement of sprat advice in ICES Subareas 6 and 7 but rather that they reflect emerging methods or technologies, or that they are not realistically achievable given the resources, or simply that there was no subject expert in the room.

Envirnomental DNA (eDNA) from survey samples could possibly be used to supplement the understanding of sprat distribution, and the timing thereof.

Lipid and fatty acid analyses could be used to identify populations of sprat feeding in different areas at a fine scale.

Predator (i.e. seabirds and marine mammal)vs.sprat density modelling. Some studies available but only for a small subset of the region.

4.6 Resourcing and Science

4.6.1 Funding Mechanisms

Initially, these studies will need to utilize a combination of competitive scientific funding e.g. EU funding initiatives and national resources.

4.6.2 Expertise

The participants of WKRRCCSS felt that while there was a high level of expertise in sprat fisheries science, particularly with regards surveys, there was identified an obvious need for a more "joined up approach" between different countries. As such the workshop utilized the expertise present to standardize sampling SOP's to be utilized aboard survey vessels and this was seen as a very positive step.

A number of workshop participants reported that while there was a good level of expertise in genetic work within the ICES community that there was limited expertise in certain research areas. In particular, it was noted that with regards population wide genome sequencing of sprat it should be priority to identify the finer differences in population structure to allow good effective area management to be applied.

5 Research Roadmap

Table 5.1 outlines the agreed set of research needs and actions for Channel and Celtic Seas sprat, roughly ordered by their priority and including an indicative timeline. Those of the highest priority and shortest deadline will occur simultaneously. Dependencies on other items on the roadmap are identified. This is a living table and will be updated as and when necessary.

Table 5.1. Research roadmap for Channel and Celtic Seas Sprat.

Item	What	Who	When/Timeline	Notes
1	Literature Review, data Collation	-	-	-
1.1	Literature Review, data Collation	Each national institute	Before HAWG 2023	
	Field: Literature Review of sprat in Predator Diets			Irish Sea Ecopath model, more work on other models
1.2	Mapping of biomass/catch – Data call for historical catch by statistical rectangle	WKRRCCSS Chairs to send data request.	Before HAWG 2023	Completed. Recommendation to include catch by statistical rectangle in all future HAWG datacalls for Channel and Celtic Seas sprat.
1.3	Egg and larval data compilation and mapping	MI, CEFAS, MSS	2023	Done internally. Bring to WGALES and WGSINS (i.e. surveys of ichthyoplankton)
2	Sampling			
2.1	Sampling SOP – genetics, field sampling – decide maturity scale – test genetic sampling on next survey - tails	CEFAS to draft, all contribute.	ASAP, survey boats leaving soon	Follow Scottish procedure for biological sampling. Started and in progress
2.2	Sample catalogue (e.g. on WKRRCCSS sharepoint)	CEFAS	Immediately	
2.3	Sample collection	CEFAS leading, all to contribute	Begin immediately; make periodic genetic sampling standard.	Representative samples from surveys/port sampling required from putative populations. Spawning samples particularly important.

Item	What	Who	When/Timeline	Notes
2.4	Sampling options– surveys, port sampling, chartering, beach seining, dip netting of bait balls	All	As required	Work in conjunction with industry, co-sampling etc.
3	Surveys			
3.1	Compile all survey indices, identifying gaps, possible adaptions to surveys to better cover sprat in the area	Collated in the current report. Internal discussions at national level first, then bring to WGIPS.	2024 for talks of possible synoptic coverage.	Need to get all survey coordinators involved.
3.2	Modelling of movement of eggs and larvae - Could show potential stock boundaries	As yet unassigned.	No timeline as yet.	To be investigated
4	Wider Ecosystem Question			
4.1	Sprat as a key forage fish species in the Celtic Seas and Channel Ecosystems	Ongoing MI research project (MRAG) addresses much of Celtic Seas	2023/4	Also bring to appropriate ICES WGs on ecosystem modelling
4.2	Continue to develop Ecopath with Ecosim (EwE) model for sprat in the Irish Sea.	MI research contract	In progress. Due November 2023	
4.3	EwE model for other areas (West of Scotland, Celtic Sea, Channel etc)	No specific person or institute identified at this time	1-2 years	Existing models may need updating/adapting. Gap: There is no West of Ireland Ecopath model
4.4	Manage: Economic value of sprat outside fishing capture (direct + indirect value may be greater than the value to the catch sector)	No specific person or institute identified at this time	1-2 years	
5	Population/Stock Identification			
5.1	Biological studies – reproduction, differences in age or group in various populations – important evidence of separation of stocks	National projects. Some Irish information available in unpublished PhD study.	As soon as practical.	Link to genetics below. SIMWG – cod 6a and 4a use as an example of what they need as evidence (See background documents on SP) Data: Length v Maturity

Item	What	Who	When/Timeline	Notes
5.2	Genetics – WGS – poolseq or individual WGS – poolseq cheaper with mixed pool. If not confident that we are sampling a pure baseline then better going with individual	CEFAS (Genotyping by Uppsala University)	Begin immediately. Rough timeline of two years before usable results. Best to aim to align with update of SNPChip (2024).	High quality -80°C flash frozen sprat sample required – MI sampled on October herring survey. Being supplied to UU.
6	Improving Advice for Management			
6.1	MSE for sprat in Celtic Sea – continue to develop operating model, test scenarios, HCRs *etc*., agree on objectives, - bring to WKLIFE	MI research contract (MRAG)	1-2 years	List methods that are on the table, can then compare and improve if possible. Results to be review by ICES WKLIFE
6.2	Change to in-year advice. Stock boundary changes for assessment purposes is within the remit of ICES. Stock boundary changes for the introduction of TACs in the Celtic Seas or part thereof lies outside the remit of ICES.	WKRRCCSS members, stock coordinator, HAWG	As soon as possible. The change can be made in one assessment year but the evidence required to precipitate the change may take up to 5 years.	Follow example of Channel sprat benchmark.
6.3	Articulate ambitions from a range of stakeholders incl. sea angling, marine tourism, hospitality	All	Ongoing and indefinite	
6.4	Potential area based management based on CHR or similar, see Norwegian fjord example			Following stock ID work.

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Annex 2: Resolutions

WKRRCCSS - Workshop on a Research Roadmap for Channel and Celtic Seas Sprat

This resolution was approved on the Resolutions Forum 2 June 2021 – new dates announced 16 May 2022 on the Resolutions Forum

2021/2/FRSG27 A Workshop on a Research Roadmap for Channel and Celtic Seas sprat (WKRRCCSS) will be established (Co-Chairs: Cormac Nolan*, Ireland and Campbell Pert*, UK (Scotland)) and will meet in Galway, Ireland, and online (hybrid meeting) 12–14 September 2022 to:

a) Identify methods and data available for the identification of sprat stock boundaries in the Channel and Celtic Seas.
b) Identify and prioritize potential and existing datasets (including environmental parameters), and assessment methods of utility for these sprat stocks.
c) Identify the advice needs of fisheries managers and stakeholders for sprat in the Channel and Celtic Seas.
d) Produce a roadmap for the delivery of the future research needed to underpin the scientific advice on management of the sprat fisheries in the Channel and Celtic Seas.

WKRRCCSS will report by 28 September 2022 for the attention of ACOM, FRSG and HAWG.

Supporting Information

Currently ICES recognizes two sprat (Sprattus sprattus) 'stocks' outside the North Sea (Sub-area 4) and Division 3a, namely sprat in Divisions 7d,e (Channel sprat) and sprat in the Celtic Seas. The Channel sprat is subject to a Category 3 assessment with advice based on a Constant Harvest Rate but the Celtic Seas sprat (residing in Divisions 7a, b, f-k and 6a) is not assessed, with ICES providing precautionary advice every second year. The stock structure of sprat found all around the British Isles is uncertain and where, if at all, there are stock boundaries is unknown. Catch data are collated for all areas where sprat are caught either in targeted fisheries or as a bycatch. In addition there are a number of surveys (acoustic and bottom trawl) where catches of sprat occur and in some cases the abundance is enumerated.

Sprat is the subject of a targeted fishery in Divisions 7d,e, currently mainly in Lyme Bay along the south coast of England in Division 7e. Recently there has been interest in developing targeted fisheries for sprat in the Celtic Sea (7aS, f-j), southern part of 7a and also in inshore waters of 6a. In recent years there have been increased landings of sprat from the Celtic Sea with the uptake thought to be due to the recent scarcity of Celtic Sea herring.

Currently there is insufficient understanding, information and data on the sprat populations in the Celtic Sea region to be able to provide robust advice on the current 'stocks' or on potential changes in productivity in the short to medium time frames. Sprat are a key forage fish in these ecosystems forming an important part of the food chain for key predatory species, including mackerel (Scomber scombrus), whiting (Merlangius merlangus), Atlantic cod (Gadus morhua), horse mackerel (Trachurus trachurus), marine mammals and birds to name a few. Therefore, there is a need for advice which takes their role in ecosystem functioning into account.

PRIORITY:	The identification of stock boundaries and the logical definition of management units is vitally important for the sustainable exploitation of fish stocks. In addition, the acquisition of appropriate data on the sprat which occurs in the Celtic Seas is necessary for providing scientific advice in selected areas where fisheries are occurring. A workshop is needed to collate the available information on sprat in the Celtic Seas and to identify gaps in our knowledge and provide a roadmap of the research necessary to be able to provide robust advice to management.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	The aims of this workshop are to collate the information available on sprat populations in the Celtic Seas with a view to determining the stock structure (stock boundaries), data on biological characteristics and abundance, the ecological role of sprat in this ecosystem, where data are missing and a roadmap for research needed to underpin the advice and management of the spart in the area.
RESOURCE REQUIREMENTS:	No specific resource requirements beyond the need for members to prepare for and participate in the preparatory ‘meetings’ and participate in the final meeting.
PARTICIPANTS:	In view of its relevance to the EU Data Collection Framework (DCF) and the UK, the Workshop is expected to attract interest from ICES Member States.
SECRETARIAT FACILITIES:	None.
FINANCIAL:	Some additional funding will be required for attendance of personnel at the final worksop. Attendance at other meetings and the use of Skype will be used for the preparatory work to minimize any finacial requests. Potential external expertise by invitation.
LINKAGES TO ADVISORY COMMITTEES:	ACOM
LINKAGES TO OTHER COMMITTEES OR GROUPS:	HAWG, ACOM
LINKAGES TO OTHER ORGANISATIONS:	

Annex 3: Agenda

Monday 12th September 10:00 am – 4:30 pm.

10:00 On-line set up and meeting etiquette

Welcome to the ICES WKRRCCSS (Campbell/Cormac)

Introductions from all participants

ICES overview

ToRs and aims of this meeting

11:00 **ToR a** - *Identify methods and data available for the identification of sprat stock boundaries in the Channel and Celtic Seas.*

Presentations from Leif Andersson (Uppsala University), Joshua Lawrence/Paul Fernandes (Heriot Watt University) and Steven O'Connell (MSS)

12:30 – 13:30 Lunch

13:30 – 15:00 **ToR b** - Identify potential and existing datasets (including environmental parameters) for the assessment and management advice for western sprat stocks.

Presentations from Ellie MacLeod (MSS), Laurie Kell and Jacob Bentley (MRAG) and Johnathan Ball and Jeroen Van Der Kooij (Cefas)

15:00 – 15:30 Break

15:30 – 16:15 Discussion and Closing Summary

Tuesday 13th September 10:00 am – 4:30 pm.

10:00 – 12:00 **ToR c -** *Identify the aspirations and concerns of fisheries managers and stakeholders in the development of sprat fisheries in the Channel and Celtic Seas.*

Presentations from Simon Berrow (IWDG), Gus Caslake (Seafish) and Alan McRobb (IFC)

12:00 – 13:00 Lunch

13:00 – 16:00 **ToR d** - Produce a roadmap for the delivery of future research needs for the scientific advice that underpins management of the sprat fisheries in the Channel and Celtic Seas.

Three Groups for Discussion, dial in to any or all that interest you:

1. 13:15- 14:00 Field surveys/Data Collection (otoliths, genetics collection)

2. 14:15- 15:00 Data Analysis and Modelling

3. 15:15 – 16:00 Management Aspirations

16:00 – 16:15 Closing Summary

Wednesday 14th September 10:00 am – 3:00 pm.

10:00 – 12:00

Report back to larger group summary from each group on discussions.

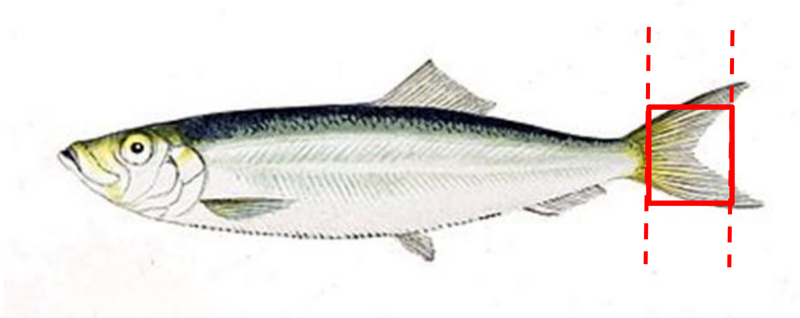
Drafting of Research Roadmap, incorporating break-out group outcomes, including goals, timelines, priorities, aspirations *etc*.

12:00 – 13:00 Lunch

13:00 – 14:30 Summary Overview of workshop and closing discussions.

14:30 **Meeting closed**

Annex 4: Sprat Genetic Sampling SOP



Equipment

- Barcoded tubes (2ml preferred)
  - CryoGen® Tubes 1D CLEARLine® (biosigma.com) product code CL2AR-BIPS2D/B or Ziath - CryzoTraq™ Tubes and Racks
- Tube rack (CLEARLine®Polycarbonate Cryoboxes 2D product codeBSM581002D/B)
- Note: if using standard non-barcoded micro-tubes ensure that they have a rubber gasket in the lid and that the labelling system used is solvent and freezing proof.
- Scanner and scanner software
- Disposable scalpels
- Pipette (plus tips)
- UV sterilisation cabinet
- Tube storage box

Note: If using standard non-barcoded microtubes ensure that they have a rubber gasket in the lid and that the labelling system used is solvent and freeze proof.

Consumables and reagents

- Molecular grade Ethanol (EtOH)
- 10% bleach solution or biological decontaminant (e.g., Microsol)

Note: ensure that denatured ethanol, i.e. with methanol added, is not used as this interferes with DNA extraction.

Barcode scanning of tubes

1. Scan tube barcodes and create spreadsheet
2. Spreadsheet should contain following metadata columns
   a. Tube barcode number
   b. Institute sample code (so it can be linked to the database)
   c. Vessel
   d. Source i.e. survey name/code or commercial
   e. Date
   f. ICES Division
   g. Latitude and Longitude
   h. Length
   i. Weight
   j. Sex

- **k.** Maturity (scale used)
- **l.** Age if available or an indication if otoliths are collected and stored or not

Note: If no scanner available create spreadsheet manually on excel spreadsheet. tubes also have a user readable linear barcode.

Prefilling tubes with tissue preservative

1. Filling step should be completed in a clean laboratory, away from sources of potential biological contamination. It is recommended to complete these steps in a PCR cabinet with a UV light.
2. Sterilise the working area including the UV cabinet by wiping down with bleach solution/microsol.
3. Sterilise all plastic consumables (racks, tubes, pipette tips) in the UV cabinet by subjecting to UV light for 15 mins.
4. Using pipette, prefill tubes with 1.5ml EtOH (do not overfill, remember tissue still needs to go in)

Genetic sample collection

1. Clean down the workspace and equipment with bleach solution/microsol
2. Set up the workspace with required equipment (measuring board, tube storage box, forceps, scalpel, gloves.
3. Keep tube storage box in a suitable position where it will not be contaminated and will remain clean and dry
4. For onboard sampling, use non-slip mats to stabilize tube storage box.
5. Make a cut across the caudal peduncle and another across the tail fin rays (see image above) using scalpel and use forceps to place sample into tube containing ethanol
6. Record metadata in spreadsheet next to the associated tube barcode number
7. Decontaminate equipment using bleach solution/microsol before moving on to the next sample.
8. When finished place genetic storage box containing samples into fridge (4oC) or freezer (-20oC) until further processing.