A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

NeoBiota 97: 67–90 (2025)
DOI: 10.3897/neobiota.97.132365

Research Article

Have you seen this fish? Important contribution of stakeholder observations in documenting the distribution and spread of an alien fish species in Iceland

Theresa Henke[1,2], Hlynur Bárðarson[3], Magnús Thorlacius[3], Guðbjörg Asta Ólafsdóttir[1]

1 Research Centre of the Westfjords, University of Iceland, Aðalstræti 10-12, 415 Bolungarvík, Iceland
2 Estación Experimental de Zonas Áridas, Consejo Superior de Investigaciones Científícas (EEZA-CSIC), Almería, Spain
3 Marine and Freshwater Research Institute, Fornubúðir 5, 220 Hafnafjörður, Iceland
Corresponding author: Theresa Henke (theresa.henke.93@gmail.com)

Abstract

To address the increasing global issue of biological invasions adequate long-term monitoring data is crucial. Due to substantial resource requirements such continuous monitoring remains largely underdeveloped across many countries. In recent years, experiential knowledge of the public, or specific stakeholder groups, has become increasingly popular to gather species' occurrence data. In the context of aquatic alien species recreational fishermen often represent a valuable stakeholder group. Using the case study of alien European flounder (*Platichthys flesus*, Linneaus, 1758) in Iceland, we explore the benefits of incorporating stakeholder observation-based information with traditionally obtained data on the occurrence and distribution of an alien fish. We compiled records of European flounder reported by the recreational fishing community both when directly approached with an anonymous online survey as well as via social media conversations applying the approach of iEcology. We then contrasted this data with a compilation of European flounder records from databases at the Icelandic Marine and Freshwater Research Institute (MFRI). Our results show that including stakeholder-observation based distribution data in the monitoring of alien species offers significant advantage. While all data sources indicated similar patterns in the spread and distribution of European flounder in Iceland, they differed in the number of unique sites provided as well as their geographic distribution. Combining sources therefore allows to counteract inherent biases present across diverse sources. Our study furthermore indicates that interest in voluntarily reporting European flounder sightings decreased over time, but reemerged when stakeholders and/or the public were presented with an easily accessible opportunity to share information in the form of an online survey. We recommend implementing a monitoring approach for alien species that incorporates diverse sources of information and provides clear venues to report information for the public, and where possible involve stakeholders throughout the entire research process to holistically address biological invasions.

Key words: Biological invasions, European flounder, iEcology, local ecological knowledge, monitoring, recreational fishermen, stakeholder observations

Academic editor: Belinda Gallardo
Received: 17 July 2024
Accepted: 27 December 2024
Published: 31 January 2025

Citation: Henke T, Bárðarson H, Thorlacius M, Ólafsdóttir GA (2025) Have you seen this fish? Important contribution of stakeholder observations in documenting the distribution and spread of an alien fish species in Iceland. NeoBiota 97: 67–90. https://doi.org/10.3897/neobiota.97.132365

Introduction

Biological invasions are an increasing global phenomenon (Seebens et al. 2017; Seebens et al. 2020) that can cause severe negative impacts on the recipient environment (IPBES 2023; Schwindt et al. 2023) and result in substantial economic costs (Cuthbert et al. 2021). Managing the emerging alien species depends on the availability of timely data regarding their occurrence and spread (Groom et al. 2015; Cardoso et al. 2017; Latombe et al. 2017). Unfortunately, systematic management and monitoring of alien species is underdeveloped across many countries (Lehtiniemi et al. 2015; Latombe et al. 2017; Schwindt et al. 2023), often driven by the mismatch between the resources required for adequate monitoring and the funding available to the relevant management agencies and institutions (Piria et al. 2017; Robinson et al. 2020). As the detection rate of new aquatic alien species remains high (Bailey et al. 2020), diverse data sources are increasingly being used to refine distribution estimates (Hargrove et al. 2015; Jarić et al. 2020b; Robinson et al. 2020). These sources include public repositories, unpublished data and interviews with experts, such as those used by Ferreira-Rodríguez et al. (2020) to investigate the historical spread of the Asian clam *Corbicula* sp. in the Lower Danube region. Generally, it is increasingly recognized that collaborations between local stakeholders and researchers can greatly improve the collection of geospatial data (See et al. 2016). Information provided by the public or other stakeholders has often been utilized in invasion science for mapping and monitoring purposes, including studies on plants (Marchante et al. 2016; César de Sá et al. 2019; Gervazoni et al. 2023) and aquatic species (Ferreira-Rodríguez et al. 2020; Herrero et al. 2023).

Under the premise that people either possess valuable information based on their experiences and observations or are willing to learn new skills and contribute to the scientific process, the public can participate at various levels in survey projects (See et al. 2016). Local ecological knowledge (LEK) is defined as knowledge that has established within a specific group of people over time through their interactions with the local ecosystems and/or the utilization of local natural resources. It can be described as a knowledge-practice-belief concept (Olsson and Folke 2001; Löki et al. 2023). At a minimum this entails incorporating stakeholder observations as part of LEK in monitoring activities but ideally, stakeholders are involved throughout the entire research process, allowing them to holistically integrate their knowledge, experiences, and opinions to shape the process and outcome of projects beyond the simple provision of occurrence data. Information on stakeholder observations can be collected via a variety of sources and approaches, such as by directly interacting with target groups through interviews and online questionnaires (Löki et al. 2023) or accessing biodiversity platforms like iNaturalist (Howard et al. 2022). Finally, the emerging field of iEcology, defined as "the study of ecological patterns and processes using online data generated for other purposes and stored digitally" (Jarić et al. 2020a), offers promising, low-cost approaches to collect ecologically relevant data (Jarić et al. 2020a; Jarić et al. 2021). Following the approach of iEcology, data can be harnessed from various sources including social media platforms like Facebook (Pace et al. 2019).

European flounder (*Platichthys flesus* Linneaus, 1758) is a flatfish species that has been documented in Icelandic waters since 1999 (Jónsson et al. 2001) and is currently classified as potentially invasive (Gunnarsson et al. 2015). The species' native range is in Western Europe ranging from the Mediterranean Sea to the White Sea (Wilson and Veneranta 2019) where it is found in marine, estuarine and freshwater habitats (Skerritt 2010). The European flounder is catadromous (Summers 1979) but plasticity in life history and habitat utilization have been documented in several studies (Daverat et al. 2012; Le Pichon et al. 2014). Previous introductions of European flounder are known from the Great Lakes in North America, where it was introduced via ballast water but failed to establish (Cudmore-Vokey and Crossman 2000; Ricciardi and MacIsaac 2000). In the years following its first identification in Iceland, European flounder has rapidly spread throughout the country (Kristinsson 2011; Ragnarsdóttir and Metúsalemsson 2020) and while it is mostly encountered in nearshore habitats and estuaries (Henke et al. 2020), it also enters rivers and lakes (O'Farrell 2012; Hlinason 2013). Current information on the distribution of European flounder in Icelandic waters has accumulated through various sources, both formal (i.e. collected by scientific institutions) and informal (i.e. newspaper articles, interviews and similar) (Lúðvíksson 2013; Gunnarsson et al. 2015; NA 2017; Ragnarsdóttir and Metúsalemsson 2020), but there is no ongoing scientific monitoring program for this species. Investigations on the impacts of European flounder are limited but indicate potential competition with and direct predation on native fishes such as European plaice (*Pleuronectes platessa*) (Henke et al. 2020) and salmonids (O'Farrell 2012; Hlinason 2013). Furthermore, recreational anglers in Iceland perceive European flounder to negatively impact their angling activities (Henke et al. 2024). Globally, recreational fishermen have been successfully involved in various studies across different research fields (Löki et al. 2023) and the recreational fishing community in Iceland represents an important stakeholder group that frequently encounters the European flounder (Henke et al. 2024). In Iceland, recreational fishing is popular, with approximately 32.5% of the population participating (Toivonen et al. 2000), and with a revenue of approximately 4.9 billion krona (37 million USD) in angling permits purchased for Atlantic salmon and brown trout (Institute of Economic Studies 2018).

The Marine and Freshwater Research Institute (MFRI) in Iceland conducts many annual surveys targeting native species, for example to evaluate commercial marine ground fish species, and to monitor salmonid stocks in fishing rivers (Jakobsdóttir et al. 2023; Helgason and Bárðarson 2024). Additionally, previous research has shown a high willingness among recreational anglers in Iceland to participate in and contribute to research (Henke et al. 2024). Considering these two aspects, the case study of European flounder in Icelandic waters offers a valuable opportunity to explore the potential of incorporating stakeholder observations in the monitoring of an alien fish species in countries that, despite developed surveying system for many aquatic resources, has no established approach for the monitoring of aquatic alien species.

In the current study we contrast occurrence data of European flounder based on stakeholder observations to data from monitoring and research programs of the MFRI with the goal of evaluating if stakeholder observation-based data can supplement alien fish species monitoring in Iceland. First, we specifically targeted the recreational fishing community in Iceland as a source for occurrence data of European flounder, both with an online survey and with an iEcology approach by mining Facebook posts for location data. Moreover, we used multiple data sources available from the MFRI, marine ground fish surveys and salmonid monitoring, but also logbooks from recreational fishing rivers and voluntary reports of unusual or occurrences of rare fishes received by the MFRI (rare fish database). Specifically, we ask 1) Does European flounder distribution and spread estimates differ by different data sources, that is, regular surveys vs. stakeholder observation-based methods?; and 2) Is stakeholder observation-based data, including MFRI data provided by the public (logbooks and rare fish), a viable option for monitoring alien fish species in Iceland? We discuss the findings in the context of strengths and weaknesses of different data sources as a tool for monitoring and how the data availability indicates public and stakeholder willingness to contribute data.

Methods

For the purpose of this study, we have obtained occurrence data of European flounder in Iceland from six different sources (Fig. 1). In the following paragraphs we will introduce each source and provide additional information including how the data for each source was collected, indicate available parameters (i.e. time stamps and exact coordinates), as well as steps that have been taken to address differences in these available parameters. Furthermore, we outline the subsequent steps of analysis.

Occurrence data collected from recreational anglers

First, we conducted an online survey targeting recreational anglers in Iceland to explore their experience with and perceptions of European flounder between October 2019 and June 2020. The anonymous survey, along with information about the aims of the scientific project, was predominantly shared through public Facebook pages of research institutions and a dedicated Icelandic recreational angling Facebook group (15.924 members as of November 2024). We chose Facebook as

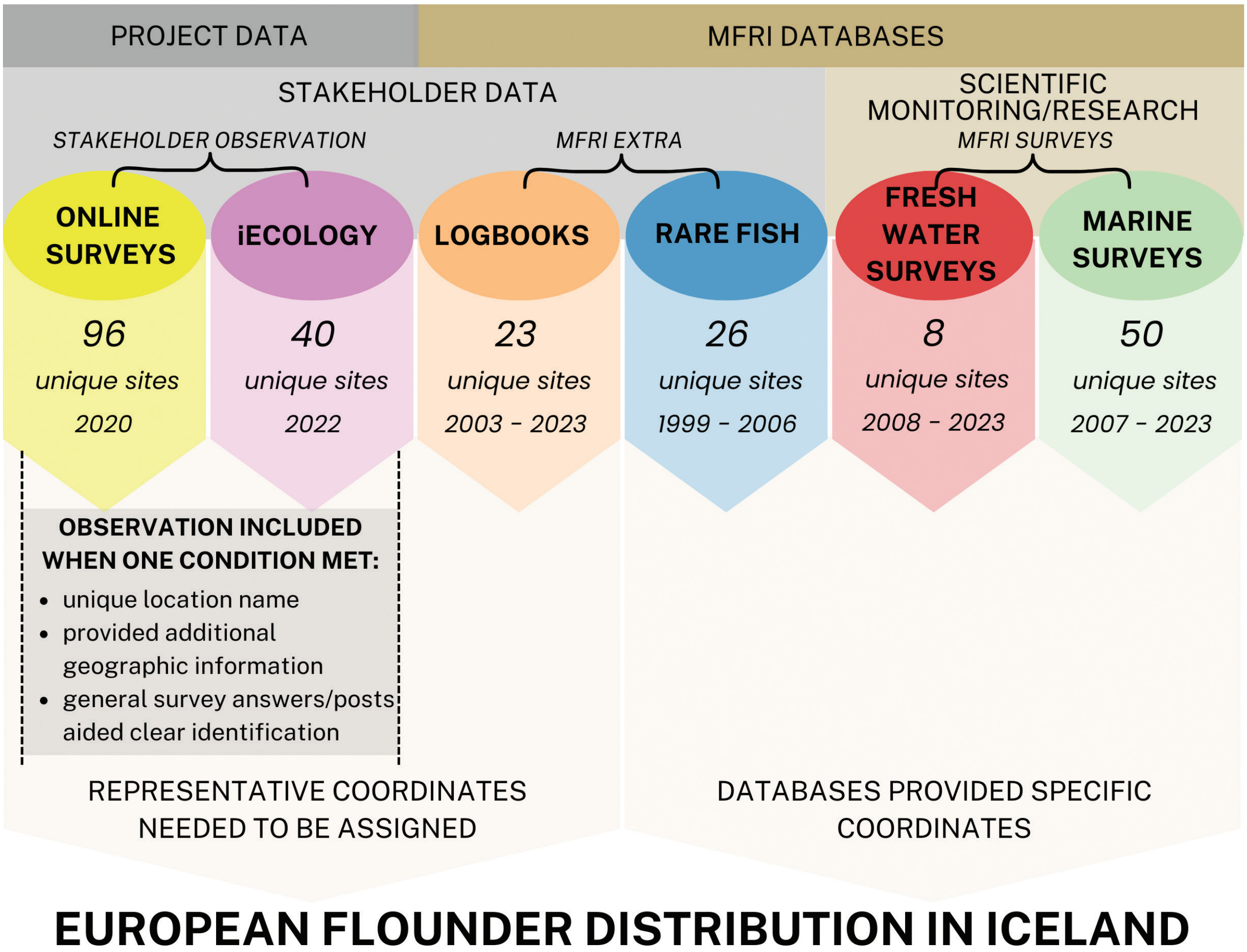

Figure 1. Overview of the six data sources incorporated in the current study.

a tool to reach a wide range of potential participants, as this is a highly popular social media platform in Iceland that around 65% of the population frequently use (Kemp 2024). In November 2019, an article published in a national Icelandic newspaper (Statistics Iceland 2024) that covered the research project (Jónsson 2019) further encouraged participation in the survey. In total, 209 people submitted responses to the survey.

In this survey we asked participants to provide locations where they encountered, either seen and/or caught, European flounder. The occurrence data from the survey was manually reviewed, removing those locations that we could not confidently assign to a specific waterbody. Due to the linguistic characteristics of the place names of Icelandic freshwater systems there are multiple rivers or lakes with the same name that can often only be differentiated when additional geographic indications are provided (e.g. the rivers “Varmá í Mósfellsbæ” and “Varmá í Hveragerði”). For each location provided by survey participants we checked whether at least one of the following conditions applied: 1) it is a recreational angling river/lake with a unique place name not requiring additional geographic information; 2) additional geographic information were provided allowing a clear identification; 3) additional information provided by the participant throughout the survey clearly identify the location such as through information on the region of Iceland they spent most of their time fishing. Locations were removed when none of these conditions were met.

Second, following the concept of iEcology (Jarić et al. 2021), we collected occurrence data from recreational fishermen in Iceland based on conversations within the Facebook group „Veiðidellan er frábær…“ [The fishing passion is great...], a group highly popular among the target group with 15.4 k members as of 02.05.2024. We evaluated different social media sources for their data availability on European flounder in Iceland as well as biodiversity platforms such as iNaturalist. While most platforms at the end of 2022 indicated a low number of data points relevant to this study (for example only three records had been submitted to iNaturalist prior to 2023) Facebook represented a popular tool among the Icelandic public (Kemp 2024) where European flounder has been frequently addressed. We manually identified Facebook posts and threads mentioning European flounder resulting in 50 recovered conversations occurring between 2013 and 2022 (see detailed information on the extraction and reach of the Facebook group in Henke et al. 2024). From those 50 conversations location reports of either catching or observing European flounder were extracted. Within this manuscript, this data is referred to as iEcology.

As neither the online survey nor the locations extracted from Facebook provided specific coordinates, we determined representative locations for each site. For rivers, representative locations were chosen near the lowest part of the river, for lakes near the mouth of the river through which European flounder most likely entered the lake, and for fjords within major estuaries. These locations were chosen under the assumption that they represent the minimum spread of the species. Where specific location names within habitats were provided, such as fishing beats within rivers, we pooled these locations together to create unique location records.

Occurrence data in the MFRI databases

Data on European flounder was extracted from all available data in the MFRI marine database resulting in European flounder occurrences from major annual surveys, such as, the spring groundfish survey (SMB), the autumn groundfish survey (SMH), and the gillnetting survey (SMN). The SMB and SMH are annual trawl surveys that sample widely around Icelandic waters in February-March and September-October respectively (Sólmundsson et al. 2022; Jakobsdóttir et al. 2023). The SMN is a spring gillnetting survey sampling inshore waters around Iceland (Bogason et al. 2024). There were also European flounder occurrences from less regular surveys, such as, a discontinued near-shore beam-trawl survey (2017–2022) (Thorlacius et al. 2024) and a demersal seine survey (1995–2013) (Pálsson and Sólmundsson 2017). In addition to these surveys, European flounder was also occasionally reported in marine research projects (Table 1). Survey- and research-based locations extracted from the MFRI marine database were pooled together under the group "marine surveys".

Similarly, the freshwater MFRI records comprised European flounder location data from two sources. First, we extracted all locations where European floun-

Table 1. The number of unique sites where European flounder has been reported using different data sources. Numbers in brackets indicate the total number of recorded sites. For the MFRI sources the years of the first and the most recent record are listed as well as the number of individual European flounder reported in the records. For the marine surveys data, we furthermore indicated how many of these unique sites were based on research activity or surveys.

Quadrant	SW	NW	NE	SE	Total
Online survey					
Unique sites	**36**	**39**	**10**	**11**	**96**
n records	(136)	(121)	(15)	(21)	(293)
iEcology					
Unique sites	**21**	**11**	**3**	**5**	**40**
n records	(31)	(30)	(5)	(7)	(73)
Logbooks					
Unique sites	**11**	**10**	**1**	**1**	**23**
n records	(17)	(24)	(1)	(1)	(43)
First record	2003	2012	2021	2018	2003
Most recent record	2023	2023	2021	2018	2023
n European flounder	29	434	1	1	465
Rare fish					
Unique sites	**15**	**1**	**0**	**10**	**26**
n records	(20)	(1)	(0)	(10)	(31)
First record	1999	2003	-	2000	1999
Most recent record	2006	2003	-	2006	2006
n European flounder	30	1	-	13	44
Freshwater surveys					
Unique sites	**5**	**3**	**1**	**0**	**9**
n records	(14)	(3)	(1)	(0)	(18)
First record	2008	2012	2023	-	2008
Most recent record	2023	2023	2023	-	2023
n European flounder	66	5	1	1	53
Marine surveys					
Unique sites	**34**	**13**	**1**	**2**	**50**
research	9	4	0	0	13
surveys	25	9	1	2	37
n records	(50)	(25)	(1)	(2)	(78)
First record	2007	2008	2018	2009	2007
Most recent record	2023	2023	2018	2021	2023
n European flounder	370	279	1	2	652

der had been caught in freshwater surveys conducted by the institute. The MFRI sampled widely across recreational fishing rivers in Iceland with the main goal of annual salmonid stock assessment, this sampling is conducted at the same time of the year, usually in late summer. Second, we extracted flounder catches documented in logbooks from recreational fishing rivers, a database maintained by the Freshwater Division of the MFRI. Under the Law on salmon and trout fishing (Act 61/2006), fishing associations in Iceland are required to submit catch information on salmonids in their rivers. While catch information was traditionally submitted in the form of physical logbooks, the option of electronic submissions has been available since 2011 and in 2023 the MFRI established an online form allowing anyone to register their catches.

In addition to European flounder occurrence in surveys and logbooks we used data from the "rare fish database" managed within the Demersal Division of the MFRI. The rare fish database is an ongoing project logging reports and catches reported by stakeholders, often fishermen but anyone can report catches. In 2006, European flounder became part of regular surveying in MFRI marine surveys and was no longer reported to the rare fish database (personal communication Klara Jakobsdóttir, MFRI).

Location data from MFRI surveys provided specific coordinates of catches. For freshwater surveys locations within the same river were pooled together to represent unique sites. As the marine habitat cannot be divided by similar geographic boundaries, locations were treated as unique by default and only pooled when the differences in neither longitude nor latitude between two locations were greater than 0.01 (approx. 1.11 km). Logbook locations did not include specific coordinates and were therefore treated like the locations obtained from the online survey and Facebook. A full list of all data used is presented in Suppl. material 1.

Validating sites reported in the online survey

Three sites from each quadrant of Iceland (SW, NW, NE and SE) that had been reported in the online survey were selected and subsequently sampled using a beach seine (10 m long, 6 mm mesh) to confirm the presence of European flounder. Local landowners and/or river managers were contacted for recommendations on sampling sites to increase the likelihood of accessing likely areas of European flounder occurrence as well as to ensure safety during the sampling process. Where the safety of the scientists could not be guaranteed due to known, strong currents, we selected an alternative site nearby based on local recommendations. The sampling at these 12 sites took place between July and September 2020. Sites where not at least one European flounder was caught were considered as not validated and therefore excluded from further analysis.

Data analysis

All data handling, statistics and figures were done using R (version 4.3.2, R Development Core Team 2023). First, we tested differences in the geographical representation of data sources by comparing both latitude and longitude between all data sources (marine surveys, freshwater surveys, logbooks, online survey and iEcology) using a pairwise Dunn test with Bonferroni correction implemented in the R package dunn.test (Dinno 2024).

To compare the annual detection of unique sites between data sources with time stamps available (rare fish, marine surveys, freshwater surveys and logbooks), we fitted a generalized additive model (GAM) to the number of unique sites per source using the *gam*() function of the *mgcv* package in R (Wood 2017). The statistical family was zero inflated Poisson (-0.593, 1.903) and the link function identity. We fitted the model with year as fixed and a smooth term.

Individual locations per year ~ Year + s (Year, by = Source)

We furthermore examined how well these four sources documented the temporal spread of European flounder in Iceland. As European flounder was first detected in the southwest and southeast of Iceland (Jónsson et al. 2001), we used latitude to approximate the species' northward spread. We fitted a GAM to the latitude of documented European flounder sites using *gam*() to investigate for differences in the detection of the species' spread between the four sources. The statistical family was Gaussian with an identity link function. The model was fitted with year as fixed effect and a smooth term.

Latitude ~ Year + s (Year, by = Source)

For both models the smooth term was Year with source as an interaction term to account for the differences between sources. Smoothing parameters were estimated using restricted maximum likelihood. For the purpose of model diagnostics, we inspected fitted residuals and tested for autocorrelation using the functions "simulate.residuals()" and "testTemporalAutocorrelation()" of the "DHARMa" package (Hartig 2022), respectively.

Results

The online survey (205 participants; see details in Henke et al. 2024) and the iEcology approach returned 97 and 40 individual locations, respectively, with the majority of sites located across western Iceland (Table 1, Suppl. material 1, Fig. 2). In monitoring surveys and research activities, the MFRI recorded 50 unique locations in marine habitats and nine in freshwater habitats, which were all predominantly located in southwest Iceland (Table 1, Fig. 2). European flounder was reported via logbooks for 23 individual sites mostly across western Iceland (Table 1, Fig. 2). There were 26 unique site records stemming from the 'rare fish' project and these were widely recorded along the south and southwest of the country but also in the northwest of Iceland (Fig. 2). These records date between 1999 and 2006 and represent the early spread of the European flounder before the species was no longer included in the rare fish database (2006/2007). The percentage of unique sites identified among the total records of European flounder differed widely between sources (Table 1). Among all records stemming from the online survey 32.8% were identified as a unique site. In comparison, the highest percentage was recorded for locations retrieved from the rare fish database, where 83.9% were unique sites.

The various data sources differed significantly in their geographical representation (Fig. 3). The marine surveys reported significantly more locations further west than the rare fish database, the iEcology approach and the online

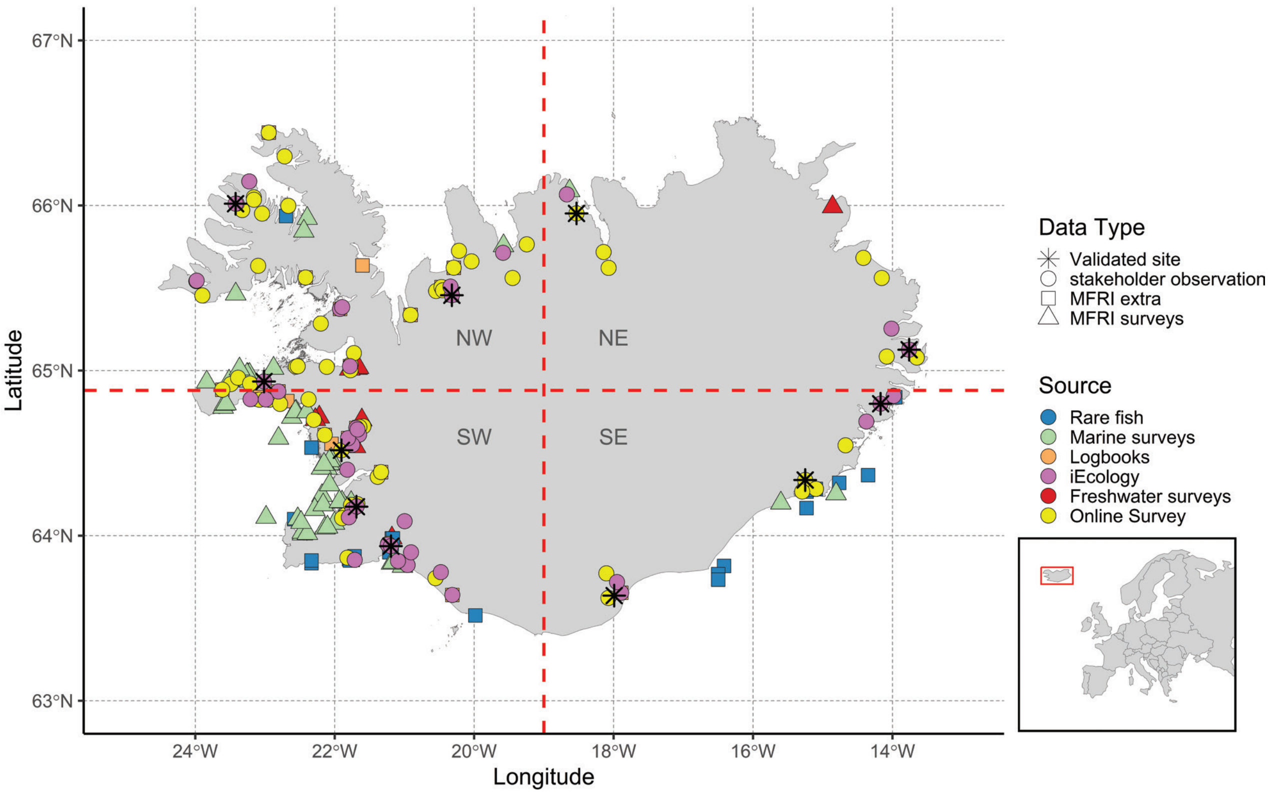

Figure 2. A map of Iceland showing all identified unique sites. For each site the color indicates from the six sources of European flounder locations while the shape highlights the three different data types that we divided the sources into, namely stakeholder observations (Online survey & iEcology), MFRI extra (Logbooks and Rare fish), and MFRI surveys (including both marine and freshwater surveys). Locations validated by sampling are indicated with a black asterisk.

survey (all pairwise Dunn-tests $p < 0.01$). No other pairwise comparisons were significant for longitude. For latitude the marine surveys had a significantly higher representation of southern sites than the online survey (pairwise Dunn test $p = 0.0209$). Moreover, the rare fish database had significantly higher representation of southern sites than any of the other sources apart from marine surveys (pairwise Dunn-test all $p < 0.01$). No other pairwise comparisons were significant for latitude.

Between the four sources that provided distribution data with attributed time information, the annual detection and overall cumulated number of unique sites widely differed (Fig. 4). The GAM smooths showed significant differences between all sources ($p < 0.05$ for all sources, Table 2). New sites recorded via logbooks increased the strongest in 2016 when nine new sites were added (Fig. 4). In the rare fish database, the highest number of new sites ($n = 8$) was recorded in 2002 (Fig. 4). While the number of new sites detected in marine surveys peaked in 2017 with 11 new sites, freshwater surveys recorded the highest number of new sites in 2012 and 2023 with three sites each (Fig. 4).

Within each of the four MFRI sources, the first record was documented in the southwest of Iceland but the year of first record ranged from 1999 (rare fish) to 2008 (freshwater surveys) but the pattern (Fig. 5). The geographic distribution of records in the subsequent years differs between sources. Most notably here is that within four years (2000–2003) the rare fish data indicated European flounder distribution ranging from northwest to southeast Iceland (Fig. 5). However, statistical tests revealed no significant differences between sources in capturing

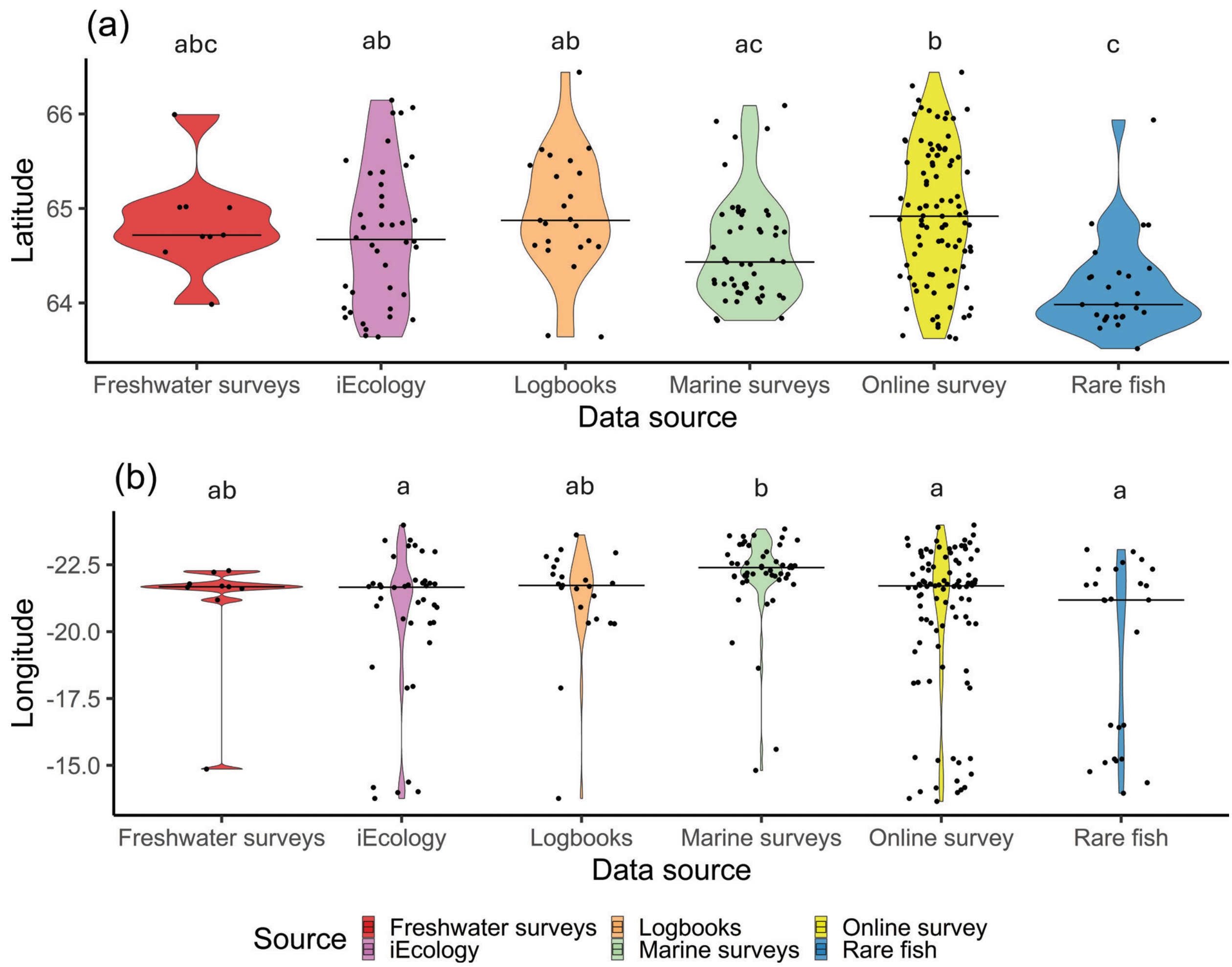

Figure 3. The geographical distribution of reported sites with flounder catches or sightings (note that the figure does not represent the number of fish caught). The figure highlights the geographical biases inherent in each survey method. The black points represent each site. Letters in the graph indicate the results of the pairwise Dunn test with Bonferroni correction where sources that share the same letter are not significantly different.

the northward spread of European flounder approximated by latitude (Suppl. materials 2, 3). It should be noted that the number of available data points for this analysis is low.

The ground truthing of online survey sites confirmed the presence of European flounder in 11 out of 12 sites around Iceland. Despite considerable sampling effort, the sampling at one site in the NE did not capture any European flounder and the record was consequently excluded from further analysis. Interestingly, one additional site in the NE was later confirmed by a MFRI freshwater survey in 2023. Therefore, the lack of validation by independent sampling of the NE sites does not necessarily confirm that European flounder is absent from these sites but is likely rarer in the NE than in other quadrants (Fig. 2).

Discussion

The current case study of European flounder in Iceland shows the benefits of stakeholder observation-based approaches, in addition to existing aquatic surveys, to document both the distribution and the spread of alien fish species.

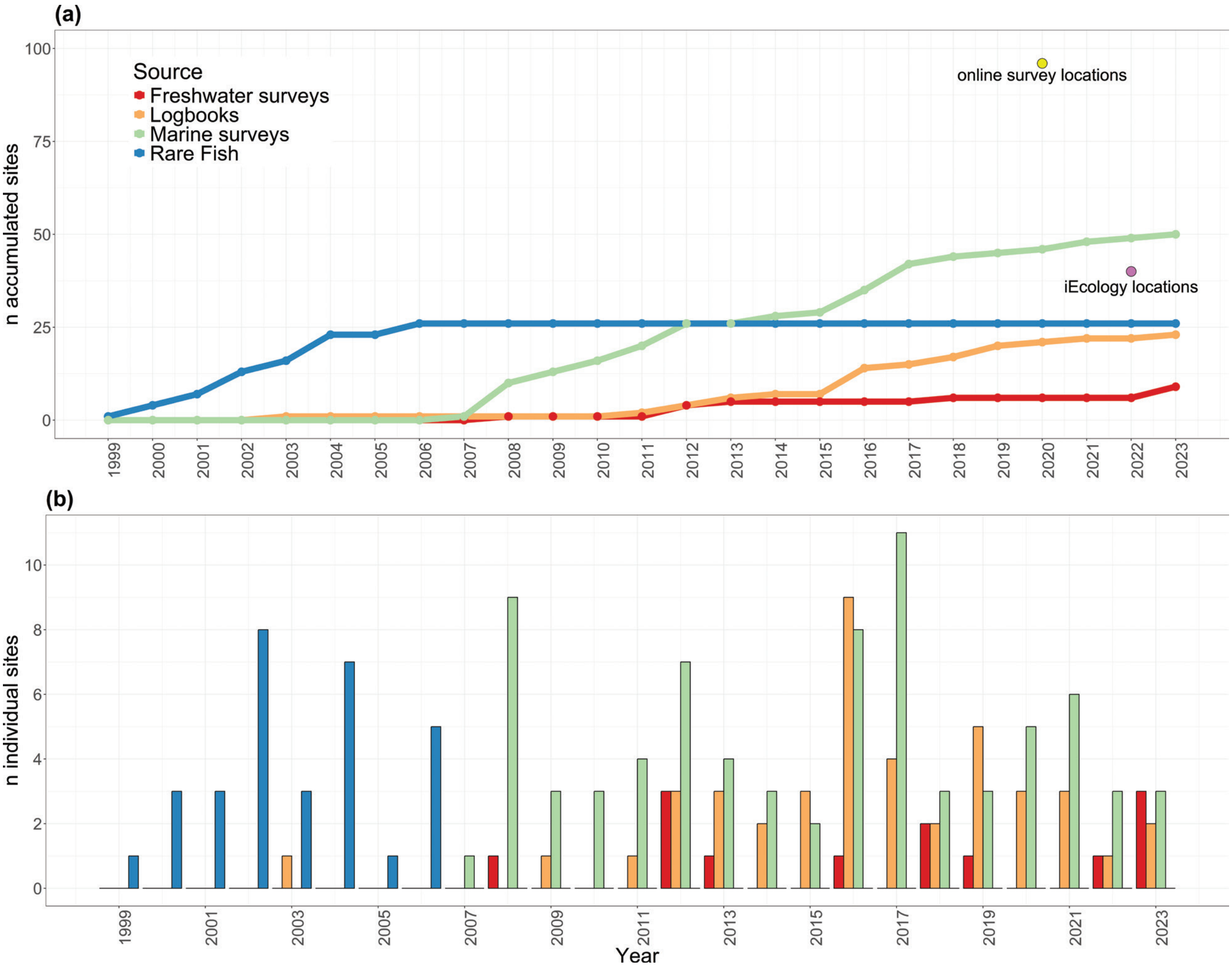

Figure 4. (a) Cumulated number of unique sites per source with time stamped data available. For comparison, the number of sites collected by online survey and iEcology are indicated (b) Barplots showing the number of unique sites recorded annually per source.

Table 2. Estimated parameters based on the generalized additive model (GAM) highlight the differences between data sources in recording unique sites of European flounder in Iceland.

Parametric coefficient	Estimate	Standard error	z value	Pr (>|z|)	
Intercept	0.000	0.00	NaN	NaN	
Year	-1.163 e^{-04}	7.749 e^{-05}	-1.501	0.133	
Smooth term	**Source**	**Edf**	**Ref. df**	X_2	**p value**
s(Year)	Freshwater surveys	1.000	1.001	6.593	0.0103
s(Year)	Logbooks	3.064	3.757	45.073	< 2 e^{-16}
s(Year)	Marine surveys	4.888	5.826	86.387	< 2 e^{-16}

Although the different data sources showed similar distributions and indicated a similar geographic pattern in the spread throughout Iceland, combining sources counteracted the inherent biases of using methods not specifically targeting European flounder. Furthermore, we show that stakeholders are willing to share their knowledge when directly approached with an opportunity such as the online survey, but also based on personal initiative and effort as seen by the occurrences in the rare fish database collected in the early stages of the European flounder spread in Iceland.

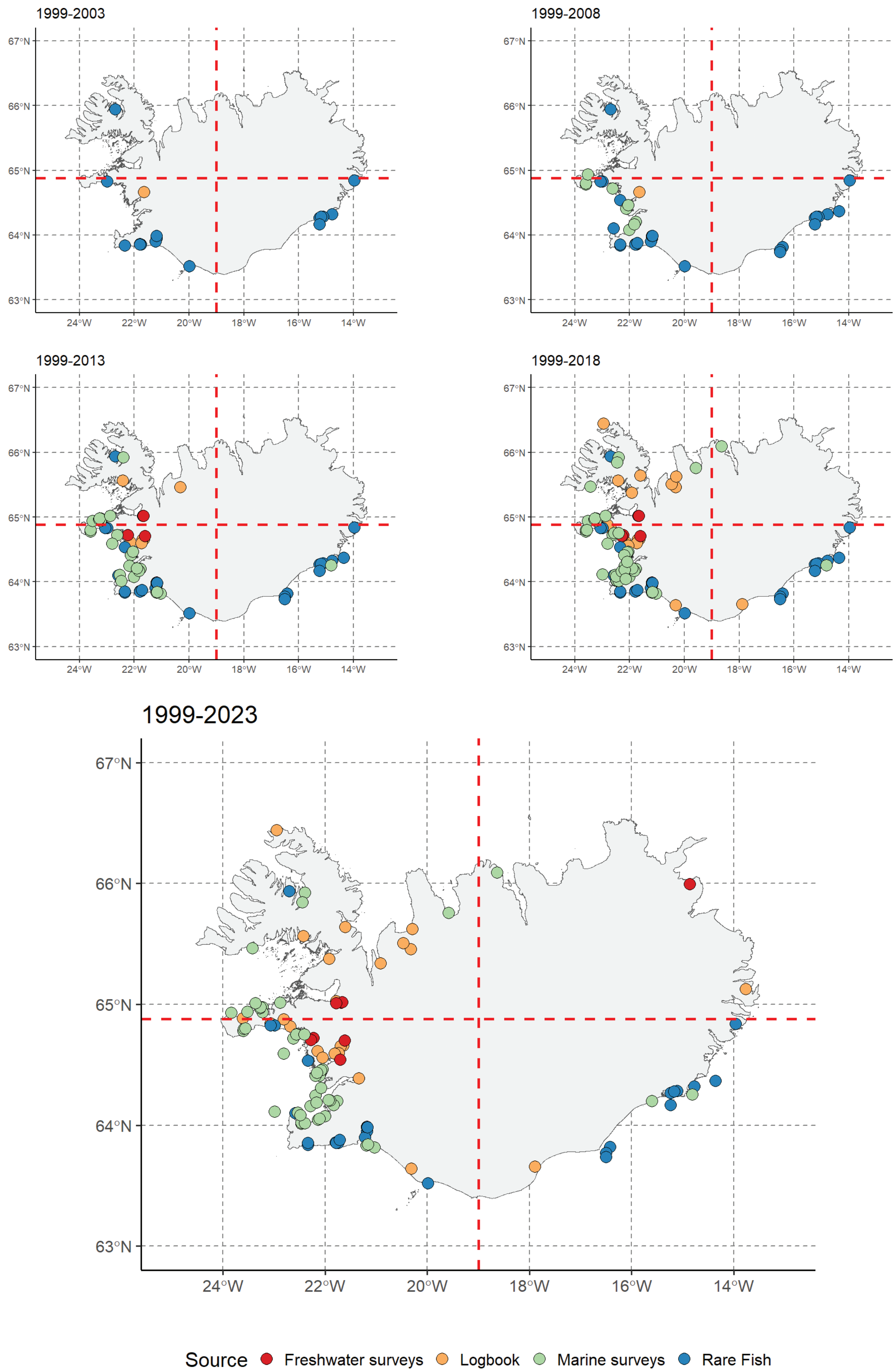

Figure 5. European flounder records mapped for each source that had time stamped data available. The five maps indicate the proceeding spread of European flounder throughout Iceland in five-year increments, with the final map showing all records documented in the MFRI sources until 2023.

Stakeholder observations to document the occurrence of European flounder

The results of the online survey targeting recreational fishermen generated 96 unique locations and therefore provided a higher number of occurrence locations than the previously available survey data based on the MFRI databases, which delivered 50 marine, and nine freshwater locations. Efforts to sample European flounder at 12 representative sites around Iceland named in the online survey showed a high validation rate of over 90% as the sampling at 11 out of 12 sites resulted in at least one individual. While the remaining site was consequently omitted from further analysis, the absence of European flounder in the river Hofsá in northeast Iceland is likely explained by the overall scarcity of European flounder in the northeast region of the country as its presence was confirmed in 2023 during monitoring of salmonid stocks in the same area. The knowledge of recreational fishing communities has previously proven valuable in addressing conservation issues in aquatic environments (Giovos et al. 2019; Löki et al. 2023).

Recreational fishers spend substantial time in the aquatic environments gathering experiential knowledge, beyond what is often available to scientists, and can therefore be more likely to encounter rare or new species (Silvano and Begossi 2012; Löki et al. 2023). The quantitative advantage of stakeholder observation-based data we documented in the current study on European flounder is in accordance with the results of these earlier case studies. While scientific surveying can maximize data quality by strategic sampling plans, stakeholder observation-based data are less predictable. In the current study, stakeholders reported unique sites at a lower ratio than scientific surveys, but the overall higher number of locations provided as well as the confirmation of persistent flounder occurrence provided by repeated reporting of some sites, is advantageous to monitoring activities. An additional advantage of stakeholder observation-based approaches is the increased awareness among stakeholders, which is crucial in addressing biological invasions especially at early stages (Dehnen-Schmutz et al. 2018). The advantages of stakeholder observation-based data were also supported by comparison of the different data sources available within the MFRI. Specifically, large parts of the previously available distribution data on European flounder were already based on stakeholder knowledge, in the form of logbook entries and voluntary submissions to the rare fish database. These submissions were predominantly by recreational anglers and commercial fishermen.

When directly targeting stakeholders or local knowledge holders is not feasible, for example, because of cost, need for prior training etc., iEcology can offer additional approaches to utilize already existing stakeholder observations stored in the form of web-based data such as social media conversations (Jarić et al. 2020a). In the current study the locations scraped from Facebook did not provide the same number of occurrences as the online survey, but it still exceeded the previously documented distribution data based on the freshwater records of the MFRI. Many challenges and limitations have been noted for iEcology approaches, such as, potential spatiotemporal biases and validation of data accuracy (Jarić et al. 2020a; Jarić et al. 2021). However, in the current study 80% of the locations extracted from social media were also named in the online survey, and the approaches produced a comparable distribution pattern, validating iEcology as a tool in the current case study. Overall, in combination with other sources of information and under considerations of potential limitations and biases, social media data can be of great value when addressing conservation issues (Toivonen et al. 2019) as well as recording new species (Cresson et al. 2021).

Despite the apparent advantages of stakeholder observation-based approaches for documenting European flounder occurrence it should be noted that they provided only presence data while data collected as part of scientific surveys most often provides both presence and absence as well as potential information on size, age, diet and environmental variables at the catch site, i.e. salinity, water depth, etc., as well as co-occurring species. These data are all needed to accurately estimate distribution and habitat suitability as well as the ecological impacts of alien species (Robinson et al. 2020). Conversely, involving stakeholder observation-based data in monitoring activities can enable scientists to obtain large amounts of data in a short amount of time, requiring less resources (Cardoso et al. 2017) and it may be particularly suitable to document early stages and spread of invasions.

Stakeholder observations to document the temporal spread of alien species

In addition to documenting occurrences and spread, public and stakeholder observations are often the first records of an alien species (Thomas et al. 2017; Epanchin-Niell et al. 2021; Kousteni et al. 2022; Pocock et al. 2024). The first official documentation of European flounder in Iceland was based on the submission of a specimen to the MFRI by a member of the public after it was caught at the mouth of the river Ölfusá in southwest Iceland (Jónsson et al. 2001). As shown in this study, stakeholder observation-based sources remain better in reporting European flounder at sites where this species is still rare. Where preventing the arrival of alien species, the most desirable scenario (Browne et al. 2009; Pyšek and Richardson 2010; Schwindt et al. 2023), fails, early detection of alien species becomes crucial (Pyšek and Richardson 2010; Schwindt et al. 2023) but often depends on the premise that the public recognizes and reports unusual observations. Dehnen-Schmutz et al. (2018) identified raising awareness as one of the main topics that should be prioritized in policies addressing biological invasions.

Following the first detection of an alien species, the experiential knowledge of stakeholders can contribute to the reconstruction of the species' temporal spread (Latombe et al. 2017). While there was overall no significant difference in the documentation of the European flounders' northward spread, the voluntary records submitted to the 'rare fish' project already indicated a distribution expansion ranging around half of the country in the early 2000s. While the records of European flounder catches in MFRI's marine surveys generally suggest a similarly fast expansion northward, note that the surveys only officially started recording European flounder after 2006. The recent catch of European flounder during routine freshwater surveying in 2023 provided the first confirmation of the species in the northeast corner of Iceland and the first contribution of formal freshwater surveys to the reconstruction of the temporal spread.

Maintaining stakeholder willingness to report observations

Stakeholder observations-based data highly depends on the willingness of the public and other stakeholders to share their knowledge. The comparably high number of documented locations of European flounder shown in this study indicate that there is quite some willingness among stakeholders, specifically, the recreational fishing community in Iceland to contribute their experiential knowledge for monitoring purposes. Globally, recreational fishermen have been increasingly involved in management and conservation (Granek et al. 2008) and the results of Copeland et al. (2017), suggest that among other incentives there are social factors providing motivation to get involved.

Our data indicates fluctuations in the number of observations submitted to the MFRI by fishermen, which has also been reported by Cresson et al. (2021), who suggest that the reporting of rare species is not only strongly linked to personal motivation and interest of the fisherman but is also likely to decline once the familiarity with this species increases. The reporting of European flounder catches to the MFRI were mostly initiated by stakeholders' personal motivation although in the years following the first documentation of European flounder news items and reports discussing its status as a new species were relatively common (Henke et al. 2024). The willingness to report could potentially be linked to the general awareness of the public and their interest in the topic of alien species, which for the European flounder in Iceland has been fluctuating over the years (Henke et al. 2024), as well as perceptions of European flounder as novel and "rare" and thereby of interest. In the years following the first official documentation of European flounder in Iceland (Jónsson et al. 2001) when it was still a novelty, occurrences were predominantly recorded as part of the 'rare fish' project, but these reports stopped after 2006. The public's attention towards conservation issues such as biological invasions is generally rather transient (Jarić et al. 2023). The current results suggest that public interest in an alien species is unlikely to be maintained at a level necessary to document spread after initial establishment. However, when stakeholders were approached with an opportunity to share their knowledge and opinions, along with information on the objectives and the anticipated value of their participation, they provided many more locations of European flounder occurrences.

It has been recommended that at a minimum, countries should obtain updated occurrence records of alien species every five years and make these publicly available (Latombe et al. 2017). In this study, we have shown that stakeholder observation-based tools, when designed accordingly, can offer a great contributory source of data where resources for alien species monitoring are limited. Latombe et al. (2017) further suggests that national monitoring of alien species could be improved by building upon already existing structures. In line with previous studies (Jarić et al. 2020a; Löki et al. 2023), we show that there are many ways to collect stakeholder observation-based data, including logbooks, online questionnaires and iEcology. However, there are certain considerations on how to foster a continuous two-way knowledge exchange between stakeholders and scientists to be considered when designing such approaches (Courchamp et al. 2017). Here it can be beneficial to create platforms that are readily accessible and easy to use for the targeted stakeholder group. Recreational anglers in Iceland are required by law to submit catch reports of salmonids (Act 61/2006) and the electronic logbook of the MFRI offers an existing structure to submit catches of Atlantic salmon, brown trout and Arctic charr. A fourth option ("other") allows the records of other caught species, most applicable to catches of European flounder or pink salmon (*Oncorhynchus gorbuscha*), an invasive salmonid species that has shown strongly increasing abundances not only in Iceland but many other northern European countries (Lennox et al. 2023). Simply providing options specific to European flounder and pink salmon could raise awareness of this information being both officially recorded and important for management, thereby encouraging anglers to report catches. In turn, the resulting data could greatly improve the monitoring of the overall spread of alien fish species in Iceland and provide indications of abundance at very low cost. However, these considerations regarding accessible platforms for data collections should not end at the public and stakeholder level. It should be noted that while we are confident that the underlying data for this study represents the bulk of the available data on European flounder catches in Iceland, we are aware that other institutions and/or scientists may have collected additional catch data. A holistic database that keeps updated records across institutions would greatly benefit not only the monitoring of alien species in Iceland but also other conservation efforts.

Building upon stakeholder observation in the monitoring of alien species

We have shown that stakeholder observations can represent a valuable, complementary source in the monitoring of an alien species. However, considering the context dependency of biological invasions (Robinson et al. 2017; Catford et al. 2022) approaches involving stakeholders need to be carefully designed on a case-by-case basis to appropriately address each invasion individually. In the case of European flounder in Iceland, we selected Facebook over other social media or biodiversity platforms that are more commonly used in similar studies (Pace et al. 2019; Jarić et al. 2021) as Facebook was much more frequently used in this specific case. In addition to choosing the most appropriate data source(s), the reliability of observations regarding the correct species identification needs to be evaluated as this is a crucial aspect of gathering distribution data. In our case, we rated the reliability of stakeholder observations as high based on the fact that European flounder is easily distinguishable from other species in rivers and lakes as it represents the only flatfish species entering these habitats. This was further reinforced by successfully conducted site validation. We recommend that the approach implemented in this study, can be highly valuable and applicable in small nations where resources for formal, scientific monitoring of alien species is limited but collaborations between research institutions, management parties and stakeholder groups are easier to establish.

We acknowledge that, while stakeholder observations are part of Local ecological knowledge (LEK), to holistically incorporate the knowledge of stakeholder groups in the monitoring of alien species, their involvement must be established throughout the entire research process. As the phenomenon of biological invasions is inherently of interdisciplinary and complex nature, embedding LEK in the necessary research and management approaches is becoming increasingly recognized (Caceres-Escobar et al. 2019; McElwee et al. 2020). While the current study shows the benefits of including stakeholder observations in monitoring it does not fully integrate the available LEK. We recommend broadening the approaches to the monitoring of European flounder in Iceland as well as of other alien species, to include LEK where the context allows, for a more holistic understanding of the alien species and their impacts.

Conclusion

Our results show that even with active aquatic surveying, designed to monitor commercially and recreationally important species, there can be a significant advantage to including stakeholder observation-based data sources to monitor alien species. In the case of the European flounder in Iceland, diverse sources based on stakeholder observations, ranging from logbook entries to online questionnaires and social media data, notably improved the information available from surveys carried out by the national marine and freshwater institute. Based on these results and the observation that interest in reporting European flounder as a novel species decreased over time, we therefore recommend monitoring approaches that build upon existing structures providing a clear venue for reporting European flounder occurrences and increased efforts to increase awareness about the issue of biological invasions as well as the value of their contribution. We further recommend expanding on the approach of stakeholder observations and integrating the full scope of LEK embedded in the involved stakeholder group.

Acknowledgements

We thank all the people who have contributed to this project by taking part in the anonymous online surveys, sharing the surveys among the recreational angling communities in Iceland and whose feedback and engagement especially on social media have contributed to shaping the idea of this project. We furthermore thank the three anonymous reviewers for their valuable feedback on this manuscript.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

Theresa Henke was funded by Rannsóknasjóður (the Icelandic Research Fund, Grant number 239953-051).

Author contributions

Conceptualization: TH, GÁÓ. Data curation: MT, TH, HB. Formal analysis: GÁÓ, TH. Funding acquisition: TH, GÁÓ. Methodology: GÁÓ, TH. Project administration: TH. Supervision: GÁÓ. Visualization: TH, GÁÓ. Writing – original draft: TH. Writing – review and editing: HB, MT, GÁÓ.

Author ORCIDs

Theresa Henke https://orcid.org/0000-0002-0729-7818
Hlynur Bárðarson https://orcid.org/0000-0001-7336-3919
Magnús Thorlacius https://orcid.org/0000-0002-5050-2880
Guðbjörg Ásta Ólafsdóttir https://orcid.org/0000-0002-2814-9160

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

References

Bailey SA, Brown L, Campbell ML, Canning-Clode J, Carlton JT, Castro N, Chinho P, Chan FT, Creed JC, Curd A, Darling J, Fofonoff P, Galil BS, Hewitt CL, Inglis GJ, Keith I, Mandrak NE, Marchini A, McKenzie CH, Occhipinti-Ambrogi A, Ojaveer H, Pires-Teixeira LM, Robinson TB, Ruiz GM, Seaward K, Schwindt E, Son MO, Therriault TW, Zhan A (2020) Trends in the detection of aquatic non-indigenous species across global marine, estuarine and freshwater ecosystems: A 50-year perspective. Diversity & Distributions 26(12): 1780–1797. https://doi.org/10.1111/ddi.13167

Bogason V, Björnsson H, Sólmundsson J (2024) Handbók um Stofnmælingu hrygningaþorsks með þorskanetum (SMN) 2024. Marine and Freshwater Research Institute, 29 pp. https://www.hafogvatn.is/static/research/files/kv2024_05.pdf

Browne M, Pagad S, De Poorter M (2009) The crucial role of information exchange and research for effective responses to biological invasions. Weed Research 49(1): 6–18. https://doi.org/10.1111/j.1365-3180.2008.00676.x

Caceres-Escobar H, Kark S, Atkinson SC, Possingham HP, Davis KJ, Gimenez O (2019) Integrating local knowledge to prioritise invasive species management. People and Nature 1(2): 220–233. https://doi.org/10.1002/pan3.27

Cardoso AC, Tsiamis K, Gervasini E, Schade S, Taucer F, Adriaens T, Copas K, Flevaris S, Galiay P, Jennings E, Josefsson M, López B, Magan J, Marchante E, Montani E, Roy H, von Schomberg R, See L, Quintas M (2017) Citizen Science and Open Data: A model for Invasive Alien Species in Europe. Research Ideas and Outcomes 3: e14811. https://doi.org/10.3897/rio.3.e14811

Catford JA, Wilson JRU, Pysek P, Hulme PE, Duncan RP (2022) Addressing context dependence in ecology. Trends in Ecology & Evolution 37(2): 158–170. https://doi.org/10.1016/j.tree.2021.09.007

César de Sá N, Marchante H, Marchante E, Cabral JA, Honrado JP, Vicente JR (2019) Can citizen science data guide the surveillance of invasive plants? A model-based test with Acacia trees in Portugal. Biological Invasions 21(6): 2127–2141. https://doi.org/10.1007/s10530-019-01962-6

Copeland C, Baker E, Koehn JD, Morris SG, Cowx IG (2017) Motivations of recreational fishers involved in fish habitat management. Fisheries Management and Ecology 24(1): 82–92. https://doi.org/10.1111/fme.12204

Courchamp F, Fournier A, Bellard C, Bertelsmeier C, Bonnaud E, Jeschke JM, Russell JC (2017) Invasion Biology: Specific Problems and Possible Solutions. Trends in Ecology & Evolution 32(1): 13–22. https://doi.org/10.1016/j.tree.2016.11.001

Cresson P, Iglésias SP, Jakobsdóttir KB, Lynghammar A (2021) Updating the records of *Diretmichthys parini* in the North East Atlantic: limited effect of temperature and potential role of social media. Cybium 45: 189–192. https://doi.org/10.26028/cybium/2021-453-002

Cudmore-Vokey B, Crossman EJ (2000) Checklists of the Fish Fauna of the Laurentian Great Lakes and Their Connecting Channels. Can MS Rpt Fish Aquat Sci, 39 pp. https://www.globalgreatlakes.org/static/gglws/GGLFiles/PDFs/FishSpecies_LGL_CUD-MORE-VOKEY&CROSSMAN.pdf

Cuthbert RN, Pattison Z, Taylor NG, Verbrugge L, Diagne C, Ahmed DA, Leroy B, Angulo E, Briski E, Capinha C, Catford JA, Dalu T, Essl F, Gozlan RE, Haubrock PJ, Kourantidou M, Kramer AM, Renault D, Wasserman RJ, Courchamp F (2021) Global economic costs of aquatic invasive alien species. The Science of the Total Environment 775: 145238. https://doi.org/10.1016/j.scitotenv.2021.145238

Daverat F, Morais P, Dias E, Babaluk J, Martin J, Eon M, Fablet R, Pécheyran C, Antunes C (2012) Plasticity of European flounder life history patterns discloses alternatives to catadromy. Marine Ecology Progress Series 465: 267–280. https://doi.org/10.3354/meps09910

Dehnen-Schmutz K, Boivin T, Essl F, Groom QJ, Harrison L, Touza JM, Bayliss H, Duncan R (2018) Alien futures: What is on the horizon for biological invasions? Diversity & Distributions 24(8): 1149–1157. https://doi.org/10.1111/ddi.12755

Dinno A (2024) dunn.test: Dunn's Test of Multiple Comparisons Using Rank Sums. R package version 1.3.6. https://doi.org/10.2307/1266041

Epanchin-Niell R, Thompson AL, Treakle T (2021) Public contributions to early detection of new invasive pests. Conservation Science and Practice 3(6): e422. https://doi.org/10.1111/csp2.422

Ferreira-Rodríguez N, Pavel AB, Cogălniceanu D (2020) Integrating expert opinion and traditional ecological knowledge in invasive alien species management: Corbicula in Eastern Europe as a model. Biological Invasions 23(4): 1087–1099. https://doi.org/10.1007/s10530-020-02420-4

NA (2017) Flundran komin í Norðfjarðará til að vera. https://www.na.is/index.php/2017/1080-flundran-komin-inordhfjardhara-til-adh-vera [accessed 20.06.2024.2024]

Gervazoni P, Minuti G, Fuentes-Rodriguez D, Coetzee J, Sosa A, Sabater L, Franceschini C (2023) Citizen Science Improves the Known and Potential Distribution of a Strong Wetland Invader: Implications for Niche Modeling and Invasion Management. Environmental Management 71(6): 1176–1187. https://doi.org/10.1007/s00267-023-01802-3

Giovos I, Stoilas VO, Al-Mabruk SAA, Doumpas N, Marakis P, Maximiadi M, Moutopoulos D, Kleitou P, Keramidas I, Tiralongo F, de Maddalena A (2019) Integrating local ecological knowledge, citizen science and long-term historical data for endangered species conservation: Additional records of angel sharks (Chondrichthyes: Squatinidae) in the Mediterranean Sea. Aquatic Conservation 29(6): 881–890. https://doi.org/10.1002/aqc.3089

Granek EF, Madin EM, Brown MA, Figueira W, Cameron DS, Hogan Z, Kristianson G, de Villiers P, Williams JE, Post J, Zahn S, Arlinghaus R (2008) Engaging recreational fishers in management and conservation: Global case studies. Conservation Biology 22(5): 1125–1134. https://doi.org/10.1111/j.1523-1739.2008.00977.x

Groom Q, Desmet P, Vanderhoeven S, Adriaens T (2015) The importance of open data for invasive alien species research, policy and management. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 6(2): 119–125. https://doi.org/10.3391/mbi.2015.6.2.02

Gunnarsson K, Þórarinsdóttir GG, Gíslason ÓS (2015) Framandi sjávarlífverur við Ísland. Náttúrufræðingurinn 85: 4–14.

Hargrove JS, Weyl OL, Allen MS, Deacon NR (2015) Using Tournament Angler Data to Rapidly Assess the Invasion Status of Alien Sport Fishes (Micropterus spp.) in Southern Africa. PLoS ONE 10(6): e0130056. https://doi.org/10.1371/journal.pone.0130056

Hartig F (2022) DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.4.6. https://CRAN.R-project.org/package=DHARMa

Helgason SÓ, Bárðarson H (2024) Vöktun á laxfiskastofnum Norðfjarðarár í kjölfar efnistöku – Áfangaskýrsla 2023 / Monitoring of salmonid populations in River Norðfjarðará following quarrying – Status report 2023. Marine and Freshwater Research Institute, 29 pp. https://www.hafogvatn.is/static/research/files/hv2024_19.pdf

Henke T, Patterson W, Ólafsdóttir G (2020) First record of niche overlap of native European plaice (Pleuronectes platessa) and non-indigenous European flounder (Platichthys flesus) on nursery grounds in Iceland. Aquatic Invasions 15(4): 671–682. https://doi.org/10.3391/ai.2020.15.4.08

Henke T, Novoa A, Bárðarson H, Ólafsdóttir GÁ (2024) Let's talk aliens – Stakeholder perceptions of an alien species differ in time and space. NeoBiota 93: 117–141. https://doi.org/10.3897/neobiota.93.117200

Herrero JJ, Simes DC, Abecasis R, Relvas P, Garel E, Ventura Martins P, Santos R (2023) Monitoring invasive macroalgae in southern Portugal: Drivers and citizen science contribution. Frontiers in Environmental Science 11: 1324600. https://doi.org/10.3389/fenvs.2023.1324600

Hlinason ÁV (2013) Lífshættir flundru (*Platichthys flesus*) á ósasvæði Hvítár í Borgarfirði. Landbúnaðarháskóli Íslands, 90 pp. https://skemman.is/bitstream/1946/16760/1/2013_MS_Asgeir_Hlinason.pdf

Howard L, van Rees CB, Dahlquist Z, Luikart G, Hand BK (2022) A review of invasive species reporting apps for citizen science and opportunities for innovation. NeoBiota 71: 165–188. https://doi.org/10.3897/neobiota.71.79597

Institute of Economic Studies (2018) Virði lax- og silungsveiða. 81 pp. https://ioes.hi.is/files/2021-05/Virdi-lax-og-silungsveida.pdf

IPBES (2023) Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Roy E, Pauchard A, Stoett P, Renard Troung T, Bacher S, Galil B, Hulme P, Ikeda T, Sankaran K, McGeoch M, Meyerson L, Nuñez M, Ordonez A, Rahlao S, Schwindt E, Seebens H, Sheppard A, Vandvik V (Eds) IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.7430692

Jakobsdóttir KB, Hjörleifsson E, Pétursson H, Björnsson H, Sólmundsson J, Kiristinsson K, Bogason V (2023) Stofnmæling botnfiska að haustlagi 2023: framkvæmnd og helstu niðurstöður / Icelandic autumn groundfish survey 2023: implementation and main results. Marine and Freshwater Research Institute, 34 pp. https://www.hafogvatn.is/static/research/files/hv2023_46.pdf

Jarić I, Correia RA, Brook BW, Buettel JC, Courchamp F, Di Minin E, Firth JA, Gaston KJ, Jepson P, Kalinkat G, Ladle R, Soriano-Redondo A, Souza AT, Roll U (2020a) iEcology: Harnessing Large Online Resources to Generate Ecological Insights. Trends in Ecology & Evolution 35(7): 630–639. https://doi.org/10.1016/j.tree.2020.03.003

Jarić I, Roll U, Arlinghaus R, Belmaker J, Chen Y, China V, Douda K, Essl F, Jahnig SC, Jeschke JM, Kalinkat G, Kalous L, Ladle R, Lennox RJ, Rosa R, Sbragaglia V, Sherren K, Smejkal M, Soriano-Redondo A, Souza AT, Wolter C, Correia RA (2020b) Expanding conservation culturomics and iEcology from terrestrial to aquatic realms. PLoS Biology 18(10): e3000935. https://doi.org/10.1371/journal.pbio.3000935

Jarić I, Bellard C, Correia RA, Courchamp F, Douda K, Essl F, Jeschke JM, Kalinkat G, Kalous L, Lennox RJ, Novoa A, Proulx R, Pysek P, Soriano-Redondo A, Souza AT, Vardi R, Verissimo D, Roll U (2021) Invasion Culturomics and iEcology. Conservation Biology 35(2): 447–451. https://doi.org/10.1111/cobi.13707

Jarić I, Correia RA, Bonaiuto M, Brook BW, Courchamp F, Firth JA, Gaston KJ, Heger T, Jeschke JM, Ladle RJ, Meinard Y, Roberts DL, Sherren K, Soga M, Soriano-Redondo A, Veríssimo D, Roll U (2023) Transience of public attention in conservation science. Frontiers in Ecology and the Environment 21(7): 333–340. https://doi.org/10.1002/fee.2598

Jónsson A (2019) Vill fræðast um ferðir og lífshætti flundru [Wants to learn about the flounder's distribution and lifestyle]. Morgunblaðið. https://www.mbl.is/200milur/frettir/2019/11/21/vill_fraedast_um_ferdir_og_lifshaetti_flundru/

Jónsson G, Pálsson J, Jóhannsson M (2001) Ný fisktegund, flundra, *Platichthys flesus* (Linnaeus, 1758), veiðist á Íslandsmiðum. Náttúrufræðingurinn 70: 83–89.

Kemp S (2024) Digital 2024: Iceland. https://datareportal.com/reports/digital-2024-iceland [accessed on 12.03.2024]

Kousteni V, Tsiamis K, Gervasini E, Zenetos A, Karachle PK, Cardoso AC (2022) Citizen scientists contributing to alien species detection: The case of fishes and mollusks in European marine waters. Ecosphere 13(1): e03875. https://doi.org/10.1002/ecs2.3875

Kristinsson K (2011) Rannsókn á stofnum sjóbleikju og flundru í vötnum og ám við Húnaflóa haustið 2011. VMST/13032. Veiðimálastofnun, 22 pp.

Latombe G, Pyšek P, Jeschke JM, Blackburn TM, Bacher S, Capinha C, Costello MJ, Fernández M, Gregory RD, Hobern D, Hui C, Jetz W, Kumschick S, McGrannachan C, Pergl J, Roy HE, Scalera R, Squires ZE, Wilson JRU, Winter M, Genovesi P, McGeoch MA (2017) A vision for global monitoring of biological invasions. Biological Conservation 213: 295–308. https://doi.org/10.1016/j.biocon.2016.06.013

Le Pichon C, Trancart T, Lambert P, Daverat F, Rochard E (2014) Summer habitat use and movements of late juvenile European flounder (Platichthys flesus) in tidal freshwaters: Results from an acoustic telemetry study. Journal of Experimental Marine Biology and Ecology 461: 441–448. https://doi.org/10.1016/j.jembe.2014.09.015

Lehtiniemi M, Ojaveer H, David M, Galil B, Gollasch S, McKenzie C, Minchin D, Occhipinti-Ambrogi A, Olenin S, Pederson J (2015) Dose of truth—Monitoring marine non-indigenous species to serve legislative requirements. Marine Policy 54: 26–35. https://doi.org/10.1016/j.marpol.2014.12.015

Lennox RJ, Berntsen HH, Garseth ÅH, Hinch SG, Hindar K, Ugedal O, Utne KR, Vollset KW, Whoriskey FG, Thorstad EB (2023) Prospects for the future of pink salmon in three oceans: From the native Pacific to the novel Arctic and Atlantic. Fish and Fisheries 24(5): 759–776. https://doi.org/10.1111/faf.12760

Löki V, Nagy J, Neményi Z, Hagyó A, Nagy A, Vitál Z, Mozsár A, Lukács BA (2023) Exploring ecological knowledge in recreational fishing for conservation purposes: A literature review. Global Ecology and Conservation 48: e02697. https://doi.org/10.1016/j.gecco.2023.e02697

Lúðvíksson K (2013) Mikið af flundru í Hraunsfirði. Morgunblaðið. https://www.mbl.is/frettir/veidi/2013/06/13/mikid_af_flundru_i_hraunsfirdi/

Marchante H, Morais MC, Gamela A, Marchante E (2016) Using a WebMapping Platform to Engage Volunteers to Collect Data on Invasive Plants Distribution. Transactions in GIS 21(2): 238–252. https://doi.org/10.1111/tgis.12198

McElwee P, Fernández-Llamazares Á, Aumeeruddy-Thomas Y, Babai D, Bates P, Galvin K, Guèze M, Liu J, Molnár Z, Ngo HT, Reyes-García V, Roy Chowdhury R, Samakov A, Shrestha UB, Díaz S, Brondízio ES, Wheeler H (2020) Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: Reviewing the experience of the IPBES Global Assessment. Journal of Applied Ecology 57(9): 1666–1676. https://doi.org/10.1111/1365-2664.13705

O'Farrell (2012) Range expansion of European Flounder *Platichthys flesus* to Icelandic waters. A threat to native salmonids? University of Akureyri, 81 pp. https://skemman.is/bitstream/1946/12312/1/For_Skemmen.pdf

Olsson P, Folke C (2001) Local Ecological Knowledge and Institutional Dynamics for Ecosystem Management: A Study of Lake Racken Watershed, Sweden. Ecosystems (New York, N.Y.) 4(2): 85–104. https://doi.org/10.1007/s100210000061

Pace DS, Giacomini G, Campana I, Paraboschi M, Pellegrino G, Silvestri M, Alessi J, Angeletti D, Cafaro V, Pavan G, Ardizzone G, Arcangeli A (2019) An integrated approach for cetacean knowledge and conservation in the central Mediterranean Sea using research and social media data sources. Aquatic Conservation 29(8): 1302–1323. https://doi.org/10.1002/aqc.3117

Pálsson J, Sólmundsson J (2017) Könnun á flatfiski í Faxaflóa sumrin 1995-2013. Marine and Freshwater Research Institute, 72 pp. https://www.hafogvatn.is/static/research/files/hv2017-008.pdf

Piria M, Copp G, Dick J, Duplić A, Groom Q, Jelić D, Lucy F, Roy H, Sarat E, Simonović P, Tomljanović T, Tricarico E, Weinlander M, Adámek Z (2017) Tackling invasive alien species in Europe II: Threats and opportunities until 2020. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 8(3): 273–286. https://doi.org/10.3391/mbi.2017.8.3.02

Pocock MJO, Adriaens T, Bertolino S, Eschen R, Essl F, Hulme PE, Jeschke JM, Roy HE, Teixeira H, de Groot M (2024) Citizen science is a vital partnership for invasive alien species management and research. iScience 27(1): 108623. https://doi.org/10.1016/j.isci.2023.108623

Pyšek P, Richardson DM (2010) Invasive Species, Environmental Change and Management, and Health. Annual Review of Environment and Resources 35(1): 25–55. https://doi.org/10.1146/annurev-environ-033009-095548

R Development Core Team (2023) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Ragnarsdóttir SB, Metúsalemsson S (2020) Framandi tegundir í straumvötnum, stöðvötnum og strandsjó. Náttúrufræðistofnun Íslands, 49 pp. https://utgafa.ni.is/skyrslur/2020/NI-20011.pdf

Ricciardi A, MacIsaac H (2000) Recent mass invasion of the North American Great Lakes by Ponto-Caspian species. Trends in Ecology & Evolution 15(2): 62–65. https://doi.org/10.1016/S0169-5347(99)01745-0

Robinson T, Havenga B, van der Merwe M, Jackson S (2017) Mind the gap – context dependency in invasive species impacts: A case study of the ascidian Ciona robusta. NeoBiota 32: 127–141. https://doi.org/10.3897/neobiota.32.9373

Robinson OJ, Ruiz-Gutierrez V, Reynolds MD, Golet GH, Strimas-Mackey M, Fink D, Maiorano L (2020) Integrating citizen science data with expert surveys increases accuracy and spatial extent of species distribution models. Diversity & Distributions 26(8): 976–986. https://doi.org/10.1111/ddi.13068

Schwindt E, August TA, Vanderhoeven S, McGeoch MA, Bacher S, Galil BS, Genovesi P, Hulme PE, Ikeda T, Lenzner B, Nuñez MA, Ordonez A, Pauchard A, Rahlao SJ, Renard Truong T, Roy HE, Sankaran KV, Seebens H, Sheppard AW, Stoett P, Vandvik V, Wilson JRU, Meyerson LA (2023) Overwhelming evidence galvanizes a global consensus on the need for action against Invasive Alien Species. Biological Invasions 26(3): 621–626. https://doi.org/10.1007/s10530-023-03209-x

See L, Mooney P, Foody G, Bastin L, Comber A, Estima J, Fritz S, Kerle N, Jiang B, Laakso M, Liu H-Y, Milčinski G, Nikšič M, Painho M, Pődör A, Olteanu-Raimond A-M, Rutzinger M (2016) Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. ISPRS International Journal of Geo-Information 5(5): 55. https://doi.org/10.3390/ijgi5050055

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pysek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jager H, Kartesz J, Kenis M, Kreft H, Kuhn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8(1): 14435. https://doi.org/10.1038/ncomms14435

Seebens H, Bacher S, Blackburn TM, Capinha C, Dawson W, Dullinger S, Genovesi P, Hulme PE, van Kleunen M, Kuhn I, Jeschke JM, Lenzner B, Liebhold AM, Pattison Z, Pergl J, Pysek P, Winter M, Essl F (2020) Projecting the continental accumulation of alien species through to 2050. Global Change Biology. https://doi.org/10.1111/gcb.15333

Silvano R, Begossi A (2012) Fishermen's local ecological knowledge on Southeastern Brazilian coastal fishes: Contributions to research, conservation, and management. Neotropical Ichthyology 1o(1): 133–147. https://doi.org/10.1590/S1679-62252012000100013

Skerritt DJ (2010) A review of the European flounder *Platichthys flesus* – biology, life history and trends in population. Eastern Sea Fisheries Joint Committee, 37 pp.

Sólmundsson J, Karlsson H, Pétursson H, Björnsson H, Jónsdóttir IG, Jakobsdóttir KB, Bogason V (2022) Stofnmæling botnfiska á Íslandsmiðum 2022 – framkvæmd og helstu niðurstöður / Icelandic groundfish survey 2022 – implementation and main results. Marine and Freshwater Research Institute, 34 pp. https://www.hafogvatn.is/static/research/files/hv2022-14.pdf

Statistics Iceland (2024) Circulation of daily newspapers by titles 1906–2010. https://px.hagstofa.is/pxen/pxweb/en/Samfelag/Samfelag__midlun__1_Fjolmidlar__blod/MEN02103.px/table/tableViewLayout2/ [accessed 13.03.2024]

Summers RW (1979) Life cycle and population ecology of the flounder *Platichthys flesus* (L.) in the Ythan estuary, Scotland. Journal of Natural History 13(6): 703–723. https://doi.org/10.1080/00222937900770531

Thomas ML, Gunawardene N, Horton K, Williams A, O'Connor S, McKirdy S, van der Merwe J (2017) Many eyes on the ground: Citizen science is an effective early detection tool for biosecurity. Biological Invasions 19(9): 2751–2765. https://doi.org/10.1007/s10530-017-1481-6

Thorlacius M, Bogason V, Jónasson JP, Jónsdóttir BS, Baranowska E, Sigurðsson GM (2024) Grunnslóðaleiðangur 2016–2022. Marine and Freshwater Research Institute, 42 pp. https://www.hafogvatn.is/static/research/files/hv2024_04_l01022024.pdf

Toivonen A, Appelbad H, Bengtsson B, Gertz-Hansen P, Guðbergsson G, Kristoffersen D, Kyrkjebø H, Naverud S, Roth E, Tuunainen P, Weissglas G (2000) Economic value of recreational fisheries in the Nordic countries. Nordic Council of Ministers, 70 pp. https://doi.org/10.1046/j.1365-2400.2003.00376.x

Toivonen T, Heikinheimo V, Fink C, Hausmann A, Hiippala T, Järv O, Tenkanen H, Di Minin E (2019) Social media data for conservation science: A methodological overview. Biological Conservation 233: 298–315. https://doi.org/10.1016/j.biocon.2019.01.023

Wilson K, Veneranta L (2019) Data-limited diadromous species – review of European status. ICES Cooperative Research Report, 273 pp. https://doi.org/10.17895/ices.pub.5253

Wood SN (2017) Generalized additive models: An introduction with R. Chapman and hall/CRC.

Supplementary material 1

Overview table of the underlying European flounder distribution data

Authors: Theresa Henke, Hlynur Bárðarson, Magnús Thorlacius, Guðbjörg Ásta Ólafsdóttir

Data type: docx

Link: https://doi.org/10.3897/neobiota.97.132365.suppl1

Supplementary material 2

Estimated parameters based on the generalized additive model (GAM) highlight the differences between data sources in recording the northward spread of European flounder within Iceland

Authors: Theresa Henke, Hlynur Bárðarson, Magnús Thorlacius, Guðbjörg Ásta Ólafsdóttir

Data type: docx

Link: https://doi.org/10.3897/neobiota.97.132365.suppl2

Supplementary material 3

GAM smooths with confidence intervals for the recorded northward spread of European flounder in each of the four sources

Authors: Theresa Henke, Hlynur Bárðarson, Magnús Thorlacius, Guðbjörg Ásta Ólafsdóttir

Data type: docx

Link: https://doi.org/10.3897/neobiota.97.132365.suppl3