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1 **Harvesting geo-spatial data on coastal fish assemblages through coordinated citizen science.**

2

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7

8

9 **Abstract**

10 In response to repeated complaints from recreational and commercial coastal fishermen about
11 declining fishing opportunities in inner Danish waters, focus was directed to inshore fish stocks.
12 However, without data targeting inshore areas, it was not possible to investigate potential changes
13 in fish distribution or abundances, or their causes. As a first step, a voluntary catch registration
14 system was initiated in 2002, in collaboration with locally organized recreational fishermen. Using
15 citizen science as a methodology, scientists and the fishermen developed a protocol for data
16 collection, which the fishermen then implemented. The aim was to establish regular monitoring of
17 fish catches from gill net and fyke net fisheries in coastal waters around Denmark in order to
18 provide data that could inform management. After three years, during which time recreational
19 fishermen could use their own gear and fish where they normally fished, the data was evaluated. As
20 a result, the fishing method was switched in 2005 to fixed gears and fixed positions, to enable
21 comparison between areas, years and season. The project has been very successful in recruiting
22 highly motivated fishermen, who register their entire catch regularly. The time-series of data spans
23 more than a decade and covers over 16,000 instances of fishing. The data from this project are now
24 being used to create coastal fish indicators for managers to assess environmental status at a regional

25 scale. Here we present an analysis of a subset of the data on one species, the European flounder
26 (*Platichthys flesus*), to illustrate how the spatial and seasonal coverage can be utilized further for
27 investigation of coastal ecosystems and to inform management.

28

29 **Keywords:** recreational fishing, fish monitoring, coastal fish

30

31 **1 Introduction**

32 Monitoring and management of coastal ecosystems along exposed coasts, bays, fjords, estuaries
33 and lagoons are regularly the focus of environmental policy in Europe (European Parliament and
34 Council of the European Union, 2000; Ferreira et al., 2007), the United States (Karr, 1981) and
35 Australia (Commonwealth of Australia, 2006), among others. This focus reflects the relative
36 intensity and diversity of human activities impacting upon these enclosed and nearshore ecosystems
37 (Airoldi and Beck, 2007). The anthropogenic pressures that act on nearshore marine habitats have
38 cumulative impacts (Halpern et al., 2007; Lotze, 2006; O'Meara et al., 2017). The variety and scale
39 of these impacts influence the distribution of coastal fish (Dutz et al., 2016), the productivity of
40 juvenile habitats (Vasconcelos et al., 2007) and many other important life history stages (Seitz et
41 al., 2014). Coastal fish, subject to these impacts, provide many ecosystem services which both
42 support ecosystem function and benefit humans (Hattam et al., 2015). However, without data on
43 coastal fish assemblages, it may be difficult to generate changes in management of coastal systems
44 and gradual losses in ecosystem services may go unheeded.

45 *1.1 Cultural services*

46 In terms of cultural services, coastal fish are exploited by both small-scale commercial and
47 recreational fisheries for the provision of food and recreational value. Small-scale coastal fisheries

48 are poorly understood, often due to a lack of available data (Natale et al., 2015). Whilst small-scale
49 commercial fisheries and recreational fishers share a common resource, data on recreational fish
50 catches are even more sparse. In Denmark, both groups of fishers have noted declines in coastal
51 catches of several fish species (Støttrup et al., 2014; V. Gram, pers. comm.). Reports of such
52 declines from recreational fishermen's organizations were the original impetus for this collaborative
53 study.

54 *1.2 Information services*

55 Coastal fish assemblages react to a broad range of anthropogenic pressures (Barausse et al.,
56 2011; Hallett et al., 2012; Henriques et al., 2013) and can thus provide important information as
57 biological indicators of the coastal ecosystem status. As indicators, the state of coastal fish
58 assemblages provide a service. The value of this service is reflected in the European Union's Water
59 Framework Directive (WFD) (Borja, 2005). Here it is stated that fish should be included in the suite
60 of biological indicators applied to an integrated environmental assessment of pressures within
61 coastal ecosystems (Borja et al., 2008; Ferreira et al., 2007; Korpinen et al., 2012). Fish as
62 indicators for system health have also been developed for estuarine systems in the USA (Deegan et
63 al., 2016).

64 Around the Baltic Sea, countries such as Sweden (Olsson et al., 2012) and Estonia (HELCOM,
65 2017) have established fisheries-independent coastal fish monitoring regimes, which can both
66 provide local stock information and inform coastal fish indicators. In other Baltic states, monitoring
67 practices have been sporadic due to the high cost of implementation and fluctuations in financial
68 support. Alternatively, monitoring is dependent on small-scale commercial fisheries data, e.g.
69 Finland (HELCOM, 2015). In Denmark, no coastal fish monitoring has been established by relevant
70 authorities. As required by the EU Data Collection Framework introduced in 2001 and recently
71 amended in 2016 (EU, 2016), estimates of recreational catches for several species should be

72 provided annually. Species requirements vary across regions (Hyder et al., 2018). In Denmark,
73 estimates of recreational catches are provided for (Atlantic cod (*Gadus morhua*), European eel
74 (*Anguilla anguilla*) and sea trout (*Salmo trutta*)), but these rely on off-site interview surveys
75 (Olesen and Storr-Paulsen, 2015)

76

77 1.3 Citizen science

78 Citizen sciences engages the public and enhances their participation in marine resource
79 management (Vann-Sander et al., 2016). Engaging citizens or a focus group of citizens allows the
80 provision of data on higher spatial and temporal scales than under present day monitoring programs
81 in for example the Baltic Sea region ([http://www.helcom.fi/Lists/Publications/Guidelines](http://www.helcom.fi/Lists/Publications/Guidelines%20for%20Coastal%20fish%20Monitoring%20of%20HELCOM.pdf)
82 [%20for%20Coastal%20fish%20Monitoring%20of%20HELCOM.pdf](http://www.helcom.fi/Lists/Publications/Guidelines%20for%20Coastal%20fish%20Monitoring%20of%20HELCOM.pdf); accessed 03.05.2018).
83 Citizen science is becoming more commonplace with increased recognition of its value among
84 academia and in national and international organizations (McKinley et al., 2017). For example,
85 focus groups consisting of divers were engaged to provide new knowledge about rare coral reef
86 species (Chin, 2014) or in another instance student focus groups documented invasive species
87 (Delaney et al., 2008). Citizen engagement, however, requires good communication and relations
88 between citizens and scientists/managers and the best outcomes of citizen science are derived from
89 cases where there was mutual respect and benefit for the parties involved. The impact of citizen
90 science on policy making and management seems to depend on the perception of data quality and
91 there is therefore a need to ensure data of a quality that it can be taken up by management (Hyder et
92 al., 2015; Underwood and Chapman, 2006; Vann-Sander et al., 2016).

93

94 In this study, we demonstrate the potential for citizen science to provide long-term data on the
95 occurrence and abundance of fish species in coastal areas around Denmark. We aimed to develop a

96 method to harvest geo-spatial data on fish assemblages through working with the local recreational
97 fishermen who provided data using standard gear, fixed positions and standardized fishing
98 protocols. To demonstrate the advantage of the spatial and temporal coverage provided by this
99 citizen science approach, we focused on catch data of European flounder (*Platichthys flesus*). The
100 current mechanisms for registering and reporting catches are discussed and advantages and pitfalls
101 highlighted.

102 **2 Materials and methods**

103 *2.1 Key-fisher engagement*

104 A volunteer-based program was established in 2002 in Denmark in collaboration with two
105 national recreational fishermen's organizations. With their collaboration, it was possible to recruit
106 "key" recreational fishermen (hereafter key-fishers) who were willing to commit time to regular
107 fishing in order to provide data on coastal fish. At the first meeting with the newly enlisted key-
108 fishers, the ground rules for the fishery were agreed upon. The key-fishers were instructed on how
109 to fill out the catch report and were provided with information on species identification. Annual
110 meetings were held with the volunteer key-fishers to discuss results, problems (gear, fish
111 identification, fishing regulations), review consistent reporting errors, or inform on current events
112 such as new invasive species. Letters were sent to the volunteers at the start of the season, during
113 summer in lieu of the annual meeting and towards the end of the year, together with a small token
114 of appreciation. Key-fishers who had not provided completed catch sheets during a year were
115 contacted at the end of the year to discover the cause and agree on a solution. New key-fishers were
116 recruited in the beginning of each year, where required, to replace or improve the distribution of
117 key-fishers across different areas.

118 2.2 *Fishery*

119 For the period 2002-2004, the fyke net data only were used as the gear used for this type of
120 fishing was similar to the gear used in the subsequent years. The eel fyke net (80/7 with 8 m net
121 between the two traps; Daconet, 2018a) was the standard type used. The gill nets used during 2002-
122 2004 varied too significantly in design to provide comparable data. In 2005, flounder gill nets
123 (monofilament, mesh size: 65 mm, mounted length: 39 m; Daconet, 2018b) were introduced as
124 standard to allow for catch per unit effort (CPUE) comparisons between areas and over time. The
125 program funded the equipment and the chair of one of the fishermen's organizations controlled the
126 purchase and distribution, including on-going replacement of worn out or lost gear.

127 Three gill nets were deployed in sequence, in near-shore locations around sunset and collected at
128 sunrise utilizing small vessels and resulting in soak times of six to twelve hours depending on the
129 season. The fyke nets (three sets) were set for approximately 48 h. The time of deployment and
130 collection was registered. Each key-fisher had a set position for each gear type and fished up to
131 three times per month throughout the year. Key-fishers were strongly encouraged to fish during the
132 first 10 days of the month but some fishing was undertaken outside of this period due to weather
133 constraints and other obligations. The whole catch was registered to the species or family level. To
134 aid in fish identification, each key-fisher was given a Danish handbook with pictures and
135 descriptions of local fish species (Muus and Nielsen, 2006). Total length of all individuals was
136 measured to the nearest cm. In cases where large numbers were caught, the whole catch was divided
137 into sub-samples and one sub-sample was randomly chosen to count number of fish. In these cases,
138 only the length of the largest and smallest fish was provided.

139 Catches and other relevant information were recorded on standardized hardcopy forms, which
140 were mailed to the institute for data entry and quality assurance. In 2014, a web-portal was
141 established for key-fishers to enter their catch-data directly into the institute's database. This web-

142 portal also provided data validation at the time of entry to ensure that fields such as date and time of
143 gear deployment and recovery, observation of invasive species and other observations were
144 recorded. Data validation also provided key-fishers the opportunity to correct erroneous entries by
145 questioning ambiguous values for catch records. Registering and use of the web-portal was
146 voluntary and was rolled out gradually.

147 Each key-fisher was provided with a temperature logger (ONSET HOBO, model UA-001-08),
148 which was attached to a buoy marking the fishing position. In this way, the loggers monitored the
149 water temperature at the fishing position continuously. Where losses from removal of these loggers
150 were high, the loggers were attached to the fishing gear and thus registered water temperature
151 during the fishing event only. Recordings from all loggers were downloaded each year, either at an
152 annual meeting or during the winter non-fishing period.

153 2.3 Data analyses

154 To demonstrate the value of this citizen science data, we focused on flounder catch data. The
155 catch data was organized into 21 areas based on water boundaries established by the Danish
156 Maritime Safety Administration and aggregated to ensure that there was sufficient coverage of
157 fishers per area. CPUE was calculated as the catch divided by the soak time over an aggregating
158 period, e.g. year or month, in a specific area, i.e.

$$159 \quad \text{CPUE}_{a,t} = \frac{1}{n} \sum_{i=1}^n c_i / f_i \quad (1)$$

160 where c_i denotes the catch in numbers and f_i the soaking time that was recorded in fishing instance
161 i ; n is the total number of fishing instances in the current area a and time aggregation t . We report
162 the CPUE in numbers over 48 h of fishing per fyke net and over 12 h of fishing for gill nets, as
163 these were representative soak times for the two gears. Linear regressions of yearly log transformed
164 CPUE of flounder were fitted to identify temporal trends in two of the areas Roskilde Fjord and
165 Isefjord (9 fishers), and Sejerø Bay (6 fishers). The existence of a monotonous temporal trend was

166 additionally tested with a Mann-Kendal test. Generalized additive models (GAM; Wood, 2006)
167 were used to fit the seasonal patterns CPUE along with the overall temporal trends

$$168 \log(I_i) = f_1(m_i) + f_2(t_i) + U(i)_{fisher} + e_i, \quad (2)$$

169 where I_i is the CPUE, m is the month of the year, t is the cumulative time in days from the
170 beginning of the time series, f_1 is a cyclic cubic regression spline, f_2 is a one dimensional thin plate
171 spline, and e_i are independent normally distributed random variables. The individual key-fishers are
172 included as random effects in the model and are represented as penalized regression terms. To test
173 the hypothesis of an existing overall temporal trend a model was fitted without the second smooth
174 $f_2(t_i)$ and the Akaike Information Criterion (AIC) and an F-test were used for model selection.

175 Information on local temperature was obtained from the temperature loggers that had been
176 placed on the sea bottom near one of the fishing positions in the area. Exemplary logger data from
177 two areas were plotted over three years for visual comparisons with monthly CPUE data for
178 flounder.

179 **3 Results**

180 From 2005 to 2016, between 27 and 84 key-fishers participated in the project each year
181 providing 16,445 fishing instances. These key-fishers fished with either gill nets, fyke nets or both.
182 Tables S1-S4 in the supplementary material show the number of fishers and fishing instances per
183 year and gear. The fishing effort increased in 2008 from less than 1000 to greater than 1600
184 instances each year until 2011. Since then it has varied between 1300 and 1500 instances (Fig. 1).
185 The distribution of the fishing positions was mainly focused in the fjords and coastal areas of the
186 inner Danish waters (Fig. 2). Most key-fishers fished from approximately April to November,
187 although some fished year-round except during periods of winter ice cover. Every third year a
188 report was compiled on the data from the previous three years but also included trend data for the

189 whole monitoring period (Kristensen et al., 2014; Sparrevohn et al., 2009; Støttrup et al., 2017,
190 2012). Each report was presented at one of the annual meetings and was sent by mail to those
191 unable to attend.

192 Over the entire period, 96 species were caught in both gears, with 88 species being registered in
193 fyke nets and 46 in gill nets (Table 1). By numbers per effort, flounder was the species most
194 frequently caught in gill nets throughout the whole project period (Fig.3). Conversely, eelpout
195 (*Zoarces viviparous*) was the most frequently caught species in fyke nets at the beginning of the
196 project, but was surpassed by the invasive round goby (*Neogobius melanostomus*). By 2016, round
197 goby was caught at more than double the rate of eelpout, in spite of it only being caught in a small
198 proportion of fished areas (5 out of 21 areas). The first catches of round goby were registered in
199 Bornholm in 2010, with the registrations expanding westward to Fehmarn Belt and northward to
200 Smålandsfarvandet and Køge Bay.

201 Mean annual CPUE from gill net catches of flounder are available from 20 of the 21 areas (Fig.
202 4). For the fyke net catches, the mean annual CPUE data was plotted for three years longer but for
203 two fewer areas (Fig. 5). These annual data consist of catches from fishers who persisted throughout
204 the length of the project as well as those who left and joined throughout. New areas were introduced
205 following two separate campaigns to recruit key-fishers specifically for these areas. The area
206 excluded from Fig. 4 was Smålandsfarvandet due to the recent recruitment of key-fishers, in 2016,
207 and the three areas excluded from Fig. 5 were due to the key-fishers in these areas only using gill
208 nets. It is evident from these figures that some areas exhibit positive temporal trends in CPUE, for
209 example “Roskilde Fjord and Isefjord” and “Sejerø Bay” gill net data (Fig. 4). Linear regressions of
210 the yearly CPUE for flounder in gill nets from these areas confirm the positive trend for Roskilde
211 Fjord and Isefjord (F-test, $F_{1,10} = 10.58$, $p < 0.01$, adjusted $R^2 = 0.47$, Fig. 6a and Fig. S1 in
212 supplementary material), but not for Sejerø Bay (F-test, $F_{1,9} = 4.914$, $p > 0.05$, adjusted $R^2 = 0.28$,

213 Fig. 6b and Fig. S2 in supplementary material). The Mann-Kendal test shows a significant trend in
214 monthly CPUE for Roskilde Fjord and Isefjord ($\tau = 0.14$, $p < 0.001$), but not in Sejerø Bay
215 ($\tau = 0.062$, $p > 0.05$), where the trend does not seem to be linear. GAM models applied to CPUE
216 data show a significant seasonal component and an overall positive temporal trend for both areas
217 (Fig. 6c, d). The full model including both smooths is preferred (Roskilde: AIC = 3553.2, Deviance
218 explained = 41%, Sejerø: AIC = 2379.5, Deviance explained = 51.4%) over the model excluding
219 overall temporal trend (Roskilde: AIC = 3769.0, F-test, $F = 15.023$, $p < 0.0001$; Sejerø: AIC =
220 2604.0, F-test, $F = 15.759$, $p < 0.0001$). Visual inspection of the model residuals does not indicate
221 any violation of the model assumptions, i.e. normality and homoscedasticity (Fig. S3 and S4 in
222 supplementary material).

223 Flounder are caught during the winter months in the fjord, although at lower CPUE than during
224 the summer months, and peaking during springtime (Fig. 7). A similar peak around June is
225 observed in Sejerø Bay in all three years but no data are available over the winter months. The
226 temperature data, worked up from the loggers provided, show that the spring water temperature in
227 Roskilde Fjord and Isefjord warms up earlier and reaches higher values than in the open coastal bay
228 of Sejerø (Fig. 7).

229 **4 Discussion**

230 With limited resources for coastal fish monitoring, engaging citizens or a focus group of capable
231 and motivated citizens, can provide a cost-effective means of data collection and even increase
232 spatial and temporal scales (Fairclough et al., 2014). It is possible that the coastal marine ecology
233 and environmental sciences can benefit to the same degree as the analogous terrestrial sciences,
234 which have been highly successful in engaging citizens (Kosmala et al., 2016). The level of
235 coordination and communication achieved during this program has proven sufficient to ensure its

236 persistence. Whilst there have been challenges in this approach to data collection, they were easily
237 overcome once properly identified. Furthermore, the citizen science approach taken here has
238 increased social capital by prompting on the one hand a deeper understanding of scientific work and
239 on the other, greater appreciation of local experience. This has led to increased knowledge and
240 awareness of the marine and coastal environment through interaction between the scientists and the
241 focus group of citizens.

242 *4.1 Data application*

243 Several species are both commonly caught and easy to identify. With the CPUE time-series,
244 seasonal and geographical population trends are monitored over large spatial and temporal scales. In
245 terrestrial systems, volunteer collected data are widespread and have proven effective for exploring
246 spatial variation in phenological trends in birds (Newson et al., 2016) and for establishing early
247 warning systems on climate induced changes in biodiversity (Barnard et al., 2017). The data from
248 citizen science projects help fill data gaps in understudied areas (Hyder et al., 2016). In the marine
249 environment, good coverage survey data on fish abundance is available (e.g. in Europe; ICES,
250 2017) but this data does not extend to the shoreline and excludes fjords and estuaries. Combining
251 coastal fish data from studies such as this with the offshore data from established scientific fishing
252 surveys provides new opportunities to explore questions on fish ecology, fish population dynamics
253 and life-history connectivity. Further, the impact of climate change on coastal fish distributions can
254 be explored at large spatial scales, where important processes not detectable at local scales may
255 dominate dynamics.

256 *4.1.1 Long term trends*

257 The CPUE data on flounder was used to develop fish indicators for HELCOM (HELCOM,
258 2017). The data can be classified as fisheries independent, because the key-fishers are requested to
259 fish within a narrow period on a monthly basis using standardized gear.

260 Annual CPUE data has also been used by fisheries managers to address local conflicts between
261 anglers targeting sea trout and gill net recreational fishermen. The latter were attributed high by-
262 catches of sea trout and thus blamed for the absence of this species of fish in the area (first author
263 observations and M. Christoffersen, pers. comm.).

264 4.1.2 *Seasonal trends*

265 The sampling undertaken by the key-fishers spans the entire year. The data provides information
266 on the timing and location of juvenile migration into summer growth habitats (or nurseries) and the
267 temporal and spatial overlap with adult conspecifics in coastal habitats. These data have the
268 potential to explore how environmental drivers influence the timing of these juvenile migrations.

269 Shallow nearshore areas constitute juvenile growth habitats (nurseries) for many fish species,
270 particularly flatfish (Able and Fodrie, 2015; Gibson, 1994). Flounder, in particular, occupies the
271 very shallow habitats that provide good conditions for growth, survival and recruitment (Andersen
272 et al., 2005; Carl et al., 2008; Florin et al., 2009; Martinsson and Nissling, 2011). Without a citizen
273 science approach it may only be possible to study such seasonal events in a limited geographic area
274 and for a limited number of years (e.g. Freitas et al., 2016; Souza et al., 2013). Flatfish, such as
275 plaice *Pleuornectes platessa* (Freitas et al., 2016) and flounder (Muus, 1967) move offshore to
276 deeper waters during autumn, although a smaller percentage of the juvenile flounder are observed to
277 winter in the shallow estuaries (Muus, 1967). With the key-fisher data, we can confirm the
278 overwintering of flounder in the shallow coastal fjords and bays, where fishing has taken place year
279 round. The percentage that remain in the fjord is, however, uncertain. The lower catches during
280 winter could either be due to reduced metabolic scope, hence mobility (Holt and Jørgensen, 2015)
281 and thus lower encounter rate with the passive gear, or due to movement of a larger portion of the
282 population out of the fjord (Muus, 1967).

283 The temporal distribution of the data combined with more sophisticated modelling may help
284 increase the accuracy of the fish indicators used to assess the health of coastal systems (HELCOM,
285 2017). Only the data from August were used for the indicators in order to align the sampling time
286 with monitoring programs conducted by the other HELCOM contracting parties from around the
287 Baltic Sea. However, the coastal waters around Denmark are very shallow and water temperature in
288 the bays and fjords are highest in June - August. Temperature optimum for flounder is 20°C, with a
289 temperature tolerance range to 26°C (Freitas et al., 2007). High summer temperatures approaching,
290 or even surpassing, the upper limits of tolerance may cause flounder to move offshore to cooler
291 waters as was suggested for the absence of plaice in the tidal flats of the German Wadden Sea (Teal
292 et al., 2012). Alternatively, flounder activity may be downregulated with a reduction in metabolic
293 scope (Duthie, 1982) and thus less likely to encounter the passive gear. Sampling over several
294 months may improve accuracy in assessing the development of the population over the years. In
295 combination with a model that considers seasonal variation, a significant positive trend in the
296 development of the flounder population was observed for Sejerø Bay that could not otherwise be
297 observed using a linear regression or only the data for August.

298 *4.1.3 Spatial coverage*

299 The broad temporal and spatial coverage provides a good overview of the species most
300 commonly found in inner Danish waters. The dominant species flounder, eel and eelpout were
301 caught in all areas and in all years, reflecting their physiological tolerance to the high fluctuations in
302 salinity and temperature that characterize the shallow coastal areas of the inner Danish waters
303 (Madsen and Højerslev, 2009). Site-specific detailed data, provided by the temperature loggers,
304 show differences in the progressive spring warming of coastal waters in the bays or fjords that are
305 not detected via other monitoring or modelling techniques. These local differences in the timing and
306 absolute increases of temperature may be important for an early start of, and for prolonging, the

307 summer growth season. Risk of mortality, especially in the early life stages, decreases with
308 increasing fish size (Beverton and Iles, 1992), meaning warmer local temperatures may convey a
309 two-fold benefit of increased growth and survival.

310 The broad geographic distribution of the sampling also allows for early detection and mapping of
311 invasive species. The round goby was first noticed in the Gulf of Gdansk in 1990 (Skóra and
312 Stolarski, 1996), where it established itself before spreading further into the Baltic Sea. The first
313 specimen was observed around the island of Bornholm in 2008 (Azour et al., 2015) and started
314 occurring in the key-fisher data in 2010. It is only caught in the fyke nets and even though it is only
315 caught in a few areas in the southeastern part of Denmark and Bornholm, it is caught in such
316 abundance that it now tops the catch records, in terms of number. It continues to spread into the
317 Danish inner waters at a rate of approximately 30 km per year (Azour et al., 2015; Behrens et al.,
318 2017). As of 2016, the key-fisher data shows round goby inhabiting the southern part of the Sound
319 (Faxe Bay) and the Great Belt (Smålandsfarvandet).

320 *4.1.4 Cultural services*

321 Whilst small-scale commercial fishers and recreational fishers share a common resource, the
322 former are often limited in their exploitation by quotas set by managers considering scientific
323 advice (output controls) and the latter only by a range of effort restrictions (input controls). In areas
324 with restricted commercial quotas, catches from the recreational sector may thus be proportionally
325 high (Olesen and Storr-Paulsen, 2015) and be ecologically significant, counteracting the effects of
326 commercial fishery management (Hyder et al., 2018; McPhee et al., 2002). Only commercial
327 catches are included in most stock assessments. High and unreported recreational catches may
328 therefore, in some areas hinder our ability to sustainably manage fish stocks. For example, in
329 Germany recreational catches of cod in the western Baltic Sea were estimated to constitute up to
330 70% of the German commercial cod landings (Strehlow et al., 2012). Marine recreational fishing is

331 gaining interest as an important source of income for national economies (Hyder et al., 2018;
332 Toivonen et al., 2004). There is growing concern about the increasing effort within the recreational
333 fisheries, which rival commercial catches for many fish stocks including depleted or threatened
334 stocks (Coleman et al., 2004; Olesen and Storr-Paulsen, 2015). In Denmark, estimates of
335 recreational catches are only conducted for a few species (cod, eel and sea trout) and rely on off-site
336 interview surveys (Olesen and Storr-Paulsen, 2015). In order to improve estimates of recreational
337 catches, the ongoing project REKREA is combining eel CPUE from the key-fisher data with
338 estimates of recreational effort, but the need to include recreational catches in stock assessment may
339 lead to new measures being introduced to register all recreational catches.

340 4.2 Challenges

341 4.2.1 Fish identification

342 The accuracy of fish identification varied among the volunteers. Several species are easily
343 recognizable and familiar to the key-fishers, such as the most common flatfish flounder, plaice, sole
344 *Solea solea* and turbot *Psetta maxima* and species such as cod, eel and eelpout. The higher
345 taxonomic categories were generally easier to identify especially if physical characteristics differed
346 substantially. There was a tendency for participants to misidentify rarely occurring species, species
347 with limited distributions and invasive species, which they had not yet encountered. In many cases,
348 pictures were taken, or fish were frozen for later expert verification or identification. The species
349 that were often problematic were sculpins (*Cottoidea*), gurnards (*Triglidae*), wrasses (*Labridae*),
350 gobies (*Gobidae*) and some gadoids (*Gadidae*). Certain species could be ruled out; for example
351 three-bearded rockling (*Gaidropsarus vulgaris*) does not spawn around Denmark and generally
352 only larger specimens of this species are caught (Muus and Nielsen, 2006; Henrik Carl, pers.
353 comm.). It can easily be confused with four-bearded rockling (*Enchelyopus cimbrius*) or five-
354 bearded rockling (*Ciliata mustela*). From the size of the fish, it could be deduced that the specimens

355 registered were most likely not three-bearded rockling and were corrected to rockling spp. For other
356 species, expert judgement based on likelihood of occurrence relative to species distribution was
357 applied. A few participants are retired professionals, whose species recognition skills can be relied
358 upon. However, even for these participants, some species remain difficult to identify without
359 specific equipment, and are registered at the family level, e.g. the small gobies (*Gobidae*). For these
360 reasons, the data collected is not recommended for monitoring biodiversity. Fish identification
361 courses were held with the key-fishers in 2015 and 2016 targeting those species that were difficult
362 to identify.

363 4.2.2 *Selectivity of gear*

364 No single gear type is considered universal. Trawls are the main gear type used in fishing
365 surveys for fish assessments (e.g. International Bottom Trawl Survey), but these gear types are not
366 easy to apply in coastal areas due to the presence of biogenic habitats or other technical reasons.
367 Survey gill nets and fyke nets are proposed for monitoring the relative abundance of indicator
368 species in Baltic Sea coastal areas (Neuman et al., 1999). These gears are static and catches rely on
369 fish mobility during soak times. Due to different levels of activity throughout a day, catch rates in
370 these passive gears likely vary. In the preliminary analyses presented here, we do not account for
371 this. However, potential solutions may be found through considering CPUE on a “net-night” basis,
372 or calculating CPUE on a per hour basis but independently for night and day periods.

373 Data on fish species and species population structure is limited by the gear selectivity of the gill
374 net used. In this case, where only one-sized gill nets were used (65 mm), juveniles, small bodied or
375 eel-like species were under- or not represented. The gear is highly selective towards maximizing
376 catches of the legally sized flounder, which is above 25.5 cm in the Kattegat area and 23 cm in the
377 Belt Seas and western Baltic Sea area. Information on gill net selection for European flounder is not
378 available, but if data for other flatfish species are applied, the maximal selection should be around

379 six or seven times the bar length (Holst and Moth-Poulsen, 1995) which would be at fish sizes of
380 20-23 cm. From 2005-2016, less than 7 % of all the flounder caught in gill nets each year measured
381 < 23 cm. A similar result was obtained on American plaice (*Hippoglossoides platessoides*) with gill
382 nets of 68 mm mesh size, where < 3 % of the catches were below the maximal selection size
383 (Hovgård, 1996). This could be due to either larger fish being randomly entangled in the gear or
384 that the gill net selectivity for flatfishes needs more consideration. Since catchability of the smaller
385 individuals is low, it is reasonable to assume that catches of the smaller flounder would be highly
386 variable. To compensate for this, CPUE for flounder > 14 cm was used to generate the HELCOM
387 fish indicators (HELCOM, 2017).

388 Fyke nets are rarely used for long-term monitoring (Hinz, 1989). However, fyke nets sample eel-
389 like species and juveniles of many species such as flounder and cod. Furthermore, in most areas of
390 this study the fyke nets caught a higher number of species than the gill nets.

391 4.2.3 *Other sources of bias.*

392 Standard fishing gear and a protocol developed in collaboration with the key-fishers were
393 implemented to reduce bias. However, bias cannot be eliminated and occurs for example, in the
394 uneven number of key-fishers in each area, resulting in variable effort. This is further exacerbated
395 by intermittent leave from the project due to health issues or other obligations inevitably
396 experienced by the volunteer key-fishers.

397 4.3 *Social capital*

398 In order for a citizen science project to be successful and to maintain its longevity, there needs to
399 be a mutual benefit for all involved (Vann-Sander et al., 2016). This is what underpins social
400 capital. For the scientist and managers, the focus group (in this case the recreational fishers) could
401 provide useful data with the strengths and disadvantages as discussed above and apparently typical
402 of this type of monitoring (Danielsen et al., 2009). Distinctive to this type of monitoring (Danielsen

403 et al., 2009), the costs to participating fishermen is considerable as each contributes with volunteer
404 hours as well as fuel and other materials. Although no comprehensive social science study has as
405 yet been conducted to demonstrate tangible benefits and understand motivation for their long-term
406 participation, anecdotal evidence reveals a number of aspects. One major change has been the shift
407 from public complaints from the recreational and commercial coastal fishermen to capacity building
408 and participation in problem solving. Capacity building is best gained from citizen science projects
409 where locals are involved in data interpretation and its uses, but can also be gained from the type of
410 monitoring described in this study (Danielsen et al., 2009). In this case, citizens impacted by a
411 situation channeled their energies to data collection, and to finding sustainable solutions through
412 working collaboratively with the scientists. Capacity building was generated through annual
413 meetings held in September each year, with various lectures on requested marine science topics as
414 well as other invited lectures on safety at sea and other relevant issues. Further, one-on-one
415 interviews were held with all involved. This communication resulted in growing awareness of the
416 importance of a healthy coastal system and how their behavior may impact the system, providing a
417 basis for change in attitudes in local communities (Danielsen et al., 2009). From the interviews, the
418 scientists gained awareness of local problems, which initiated several projects. An example of this
419 was the Nørre Fjord project, which aimed to restore a fjord area affected by historic sand mining
420 activities, confounded by more recent eutrophication (Kristensen et al., 2015; Poulsen et al., 2012).
421 The project has provided these key fishers with a contact point to scientists where they could
422 discuss or obtain advice on local environmental concerns.

423 A requisite for participation in the project was full compliance to national fishing regulations.
424 This led to key-fishers becoming ambassadors for responsible recreational fishing. Additionally,
425 following several discussions on safety at sea in small vessels, key-fishers became ambassadors for
426 safety at sea, endorsed by a commitment to use life jackets whilst on the water. The increase in

427 social capital, as a result of this project is thus reflected in the improved knowledge base for all
428 parties, increased communication between fishermen and scientists, greater trust, collaboration and
429 participation in science projects aimed at resolving local environmental problems and the creation
430 of a stewardship ethic.

431 Several key-fishers have contributed to the project since its outset in 2002. Through this project,
432 key fishers are able to double their fishing efforts. In some areas, a larger fishing effort allows them
433 to catch a reasonable number of minimum size fish for family consumption (they are not allowed to
434 sell their catch). The annual token gifts are much appreciated but, in our view, the publication of a
435 paper report every third year that acknowledges their efforts and the regular use of data by scientists
436 in their advice to management are the main motivational factors to continue to contribute to science.
437 It is viewed by these authors that regular, open communication with the volunteers is pivotal for
438 continued engagement. A social science study would, however, be needed to document the
439 fishermen's motivation to join and remain involved in the project, the benefits and social capital
440 gained and potential behavioral changes.

441 **5 Conclusion**

442 The citizen science approach taken in this study has not only provided data on coastal fish in
443 areas previously not considered in standard surveys but has also provided data of higher temporal
444 resolution and over a spatial scale not possible to attain with institute monitoring resources. This
445 study has provided data and findings to inform national evidence based policy advice, and helped
446 meet international monitoring obligations. It has generated spin-off research projects and continues
447 to inform research on fundamental ecological concepts. The key-fishers have ensured the success
448 of this project and in the process become ambassadors for sustainable coastal environments,
449 responsible fishing and safety at sea. We, the authors, hope that our description and findings

450 encourage others to consider broader societal engagement in their research and that this paper helps
451 in overcoming some of the initial challenges of establishing such a project.

452

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466 **References.**

467 Able, K.W., Fodrie, F.J., 2015. Distribution and dynamics of habitat use by juvenile and adult
468 flatfishes, in: Gibson, R.N., Nash, R.D., Geffen, A.J. (Eds.), *Flatfishes: Biology and*
469 *Exploitation: Second Edition*. John Wiley and Sons Ltd., pp. 242–282.
470 <https://doi.org/10.1002/9781118501153.ch10>

471 Airoldi, L., Beck, M.W., 2007. Loss, status and Trends for Coastal Marine Habitats of Europe.
472 *Oceanogr. Mar. Biol. An Annu. Rev.* 45, 345–405. https://doi.org/Book_Doi
473 [10.1201/9781420050943](https://doi.org/10.1201/9781420050943)

474 Andersen, A.K., Schou, J., Sparrevohn, C.R., Nicolajsen, H., Støttrup, J.G., 2005. The quality of
475 release habitat for reared juvenile flounder, *Platichthys flesus*, with respect to salinity and
476 depth. *Fish. Manag. Ecol.* 12, 211–219. <https://doi.org/10.1111/j.1365-2400.2005.00444.x>

477 Azour, F., van Deurs, M., Behrens, J., Carl, H., Hüssy, K., Greisen, K., Ebert, R., Møller, P.R.,
478 2015. Invasion rate and population characteristics of the round goby *Neogobius melanostomus*:
479 Effects of density and invasion history. *Aquat. Biol.* 24. <https://doi.org/10.3354/ab00634>

480 Barausse, A., Michieli, A., Riginella, E., Palmeri, L., Mazzoldi, C., 2011. Long-term changes in
481 community composition and life-history traits in a highly exploited basin (northern Adriatic
482 Sea): The role of environment and anthropogenic pressures. *J. Fish Biol.* 79, 1453–1486.
483 <https://doi.org/10.1111/j.1095-8649.2011.03139.x>

484 Barnard, P., Altwegg, R., Ebrahim, I., Underhill, L.G., 2017. Early warning systems for biodiversity
485 in southern Africa – How much can citizen science mitigate imperfect data? *Biol. Conserv.*
486 208, 183–188. <https://doi.org/10.1016/j.biocon.2016.09.011>

487 Behrens, J.W., Van Deurs, M., Christensen, E.A.F., 2017. Evaluating dispersal potential of an
488 invasive fish by the use of aerobic scope and osmoregulation capacity. *PLoS One* 12, 1–19.
489 <https://doi.org/10.1371/journal.pone.0176038>

490 Beverton, R.J.H., Iles, T.C., 1992. II. Comparison of mortality rates and construction of life table
491 for 0-group plaice. *Netherlands J. Sea Res.* 29, 49–59. [https://doi.org/10.1016/0077-](https://doi.org/10.1016/0077-7579(92)90007-2)
492 [7579\(92\)90007-2](https://doi.org/10.1016/0077-7579(92)90007-2)

493 Borja, A., 2005. The European water framework directive: A challenge for nearshore, coastal and
494 continental shelf research. *Cont. Shelf Res.* 25, 1768–1783.
495 <https://doi.org/10.1016/j.csr.2005.05.004>

496 Borja, A., Bricker, S.B., Dauer, D.M., Demetriades, N.T., Ferreira, J.G., Forbes, A.T., Hutchings,
497 P., Jia, X., Kenchington, R., Marques, J.C., Zhu, C., 2008. Overview of integrative tools and

498 methods in assessing ecological integrity in estuarine and coastal systems worldwide. *Mar.*
499 *Pollut. Bull.* 56, 1519–1537. <https://doi.org/10.1016/j.marpolbul.2008.07.005>

500 Carl, J.D., Sparrevohn, C.R., Nicolajsen, H., Støttrup, J.G., 2008. Substratum selection by juvenile
501 flounder *Platichthys flesus* (L.): Effect of ephemeral filamentous macroalgae. *J. Fish Biol.* 72,
502 2570–2578. <https://doi.org/10.1111/j.1095-8649.2008.01866.x>

503 Chin, A., 2014. “Hunting porcupines”: Citizen scientists contribute new knowledge about rare coral
504 reef species. *Pacific Conserv. Biol.* 20, 48–53.

505 Coleman, F.C., Figueira, W.F., Ueland, J.S., Crowder, L.B., 2004. The impact of United States
506 recreational fisheries on marine fish populations. *Science* (80-.). 305, 1958–1960.
507 <https://doi.org/10.1126/science.1100397>

508 Commonwealth of Australia, 2006. A Guide to the Integrated Marine and Coastal Regionalisation
509 of Australia Version 4.0. [WWW Document]. Dep. Environ. Heritage, Canberra, Aust. URL
510 [http://www.environment.gov.au/resource/guide-integrated-marine-and-coastal-regionalisation-](http://www.environment.gov.au/resource/guide-integrated-marine-and-coastal-regionalisation-australia-version-40-june-2006-imcra)
511 [australia-version-40-june-2006-imcra](http://www.environment.gov.au/resource/guide-integrated-marine-and-coastal-regionalisation-australia-version-40-june-2006-imcra) (accessed 9.28.17).

512 Daconet, 2018a. Daconet [WWW Document]. URL [https://www.daconet.com/standard-](https://www.daconet.com/standard-catalogue/fykes-and-pots/eel-fyke/dbl-aaleruse-80-7-m-8mtr-rad-staalb-knudeloestbagg-nr-5dh)
513 [catalogue/fykes-and-pots/eel-fyke/dbl-aaleruse-80-7-m-8mtr-rad-staalb-knudeloestbagg-nr-5dh](https://www.daconet.com/standard-catalogue/fykes-and-pots/eel-fyke/dbl-aaleruse-80-7-m-8mtr-rad-staalb-knudeloestbagg-nr-5dh)
514 (accessed 4.13.18).

515 Daconet, 2018b. Daconet [WWW Document]. URL [https://www.daconet.com/standard-](https://www.daconet.com/standard-catalogue/fishing-nets/mounted-nets/plaice-nets/hobby-fishermen/mont-roedspaettegarn-0-24-65mm-8-ma-2400kn)
516 [catalogue/fishing-nets/mounted-nets/plaice-nets/hobby-fishermen/mont-roedspaettegarn-0-24-](https://www.daconet.com/standard-catalogue/fishing-nets/mounted-nets/plaice-nets/hobby-fishermen/mont-roedspaettegarn-0-24-65mm-8-ma-2400kn)
517 [65mm-8-ma-2400kn](https://www.daconet.com/standard-catalogue/fishing-nets/mounted-nets/plaice-nets/hobby-fishermen/mont-roedspaettegarn-0-24-65mm-8-ma-2400kn) (accessed 4.13.18).

518 Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P.G., Alviola, P.,
519 Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeldså, J., Holt, S., Hübertz,
520 H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda,
521 R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jørgensen, E., Yonten, D., 2009. Local

522 participation in natural resource monitoring: A characterization of approaches. *Conserv. Biol.*
523 23, 31–42. <https://doi.org/10.1111/j.1523-1739.2008.01063.x>

524 Deegan, L.A., Finn, J.T., Ayvazian, S.G., Ryder-Kieffer, C.A., Buonaccorsi, J., 2016. Development
525 and Validation of an Estuarine Biotic Integrity Index. *Estuaries* 20, 601–617.

526 Delaney, D.G., Sperling, C.D., Adams, C.S., Leung, B., 2008. Marine invasive species: Validation
527 of citizen science and implications for national monitoring networks. *Biol. Invasions* 10, 117–
528 128. <https://doi.org/10.1007/s10530-007-9114-0>

529 Duthie, G.G., 1982. The respiratory metabolism of temperature-adapted flatfish at rest and during
530 swimming activity and the use of anaerobic metabolism at moderate swimming speeds. *J. Exp.*
531 *Biol.* 97, 359–373.

532 Dutz, J., Støttrup, J.G., Stenberg, C., Munk, P., 2016. Recent trends in the abundance of plaice
533 *Pleuronectes platessa* and cod *Gadus morhua* in shallow coastal waters of the Northeastern
534 Atlantic continental shelf – a review. *Mar. Biol. Res.* 0, 1–12.
535 <https://doi.org/10.1080/17451000.2016.1210806>

536 EU, 2016. Commission Implementing Decision (EU) 2016/1251 of 12. July 2016 adopting a
537 multiannual Union programme for the collection, management and use of data in the fisheries
538 and aquaculture sectors for the period 2017-2019, 2016/4329.

539 European Parliament and Council of the European Union, 2000. Directive 2000/60/EC of the
540 European Parliament and of the council of 23 October 2000 establishing a framework for
541 community action in the field of water policy [WWW Document]. URL [http://eur-](http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32000L0060)
542 [lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32000L0060](http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32000L0060) (accessed 10.19.17).

543 Fairclough, D. V, Brown, J.I., Carlish, B.J., Crisafulli, B.M., Keay, I.S., 2014. assessments with
544 citizen science. <https://doi.org/10.1038/srep07249>

545 Ferreira, J.G., Vale, C., Soares, C. V., Salas, F., Stacey, P.E., Bricker, S.B., Silva, M.C., Marques,

546 J.C., 2007. Monitoring of coastal and transitional waters under the E.U. Water Framework
547 Directive. *Environ. Monit. Assess.* 135, 195–216. <https://doi.org/10.1007/s10661-007-9643-0>

548 Florin, A.B., Sundblad, G., Bergström, U., 2009. Characterisation of juvenile flatfish habitats in the
549 Baltic Sea. *Estuar. Coast. Shelf Sci.* 82, 294–300. <https://doi.org/10.1016/j.ecss.2009.01.012>

550 Freitas, V., Campos, J., Fonds, M., Van der Veer, H.W., 2007. Potential impact of temperature
551 change on epibenthic predator-bivalve prey interactions in temperate estuaries. *J. Therm. Biol.*
552 32, 328–340. <https://doi.org/10.1016/j.jtherbio.2007.04.004>

553 Freitas, V., Witte, J.I.J., Tulp, I., Veer, H.W. Van Der, 2016. Shifts in nursery habitat utilization by
554 0-group plaice in the western Dutch Wadden Sea. *J. Sea Res.* 111, 65–75.
555 <https://doi.org/10.1016/j.seares.2015.12.011>

556 Gibson, R.N., 1994. Impact of habitat quality and quantity on the recruitment of juvenile flatfishes.
557 *Netherlands J. Sea Res.* 32, 191–206. [https://doi.org/10.1016/0077-7579\(94\)90040-X](https://doi.org/10.1016/0077-7579(94)90040-X)

558 Hallett, C.S., Valesini, F.J., Clarke, K.R., Hesp, S.A., Hoeksema, S.D., 2012. Development and
559 validation of fish-based, multimetric indices for assessing the ecological health of Western
560 Australian estuaries. *Estuar. Coast. Shelf Sci.* 104–105, 102–113.
561 <https://doi.org/10.1016/j.ecss.2012.03.006>

562 Halpern, B.S., Selkoe, K.A., Micheli, F., Kappel, C. V., 2007. Evaluating and ranking the
563 vulnerability of global marine ecosystems to anthropogenic threats. *Conserv. Biol.* 21, 1301–
564 1315. <https://doi.org/10.1111/j.1523-1739.2007.00752.x>

565 Hattam, C., Atkins, J.P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., Burdon, D., De Groot, R.,
566 Hoefnagel, E., Nunes, P.A.L.D., Piwowarczyk, J., Sastre, S., Austen, M.C., 2015. Marine
567 ecosystem services: Linking indicators to their classification. *Ecol. Indic.* 49, 61–75.
568 <https://doi.org/10.1016/j.ecolind.2014.09.026>

569 HELCOM, 2017. Abundance of coastal fish key species. HELCOM core indicator report [WWW

570 Document]. [http://www.helcom.fi/baltic-sea-trends/indicators/abundance-of-key-coastal-fish-](http://www.helcom.fi/baltic-sea-trends/indicators/abundance-of-key-coastal-fish-species)
571 species.

572 HELCOM, 2015. Guidelines for coastal fish monitoring sampling methods of HELCOM. Helsinki,
573 Finland.

574 Henriques, S., Pais, M.P., Batista, M.I., Costa, M.J., Cabral, H.N., 2013. Response of fish-based
575 metrics to anthropogenic pressures in temperate rocky reefs. *Ecol. Indic.* 25, 65–76.
576 <https://doi.org/10.1016/j.ecolind.2012.09.003>

577 Hinz, V., 1989. Monitoring the fish fauna in the Wadden Sea with special reference to different
578 fishing methods and effects of wind and light on catches. *Helgolander Meeresuntersuchung* 43,
579 447–459.

580 Holst, R., Moth-Poulsen, T., 1995. Numerical recipes and statistical methods for gillnet selectivity.
581 ICES C. 1995/B18.

582 Holt, R.E., Jørgensen, C., 2015. Climate change in fish : effects of respiratory constraints on
583 optimal life history and behaviour. *Biol. Lett.* 11, 20141032.
584 <https://doi.org/http://dx.doi.org/10.1098/rsbl.2014.1032>

585 Hovgård, H., 1996. Effect of twine diameter on fishing power of experimental gill nets used in
586 Greenland waters. *Can. J. Fish. Aquat. Sci.* 53, 1014–1017.

587 Hyder, K., Townhill, B., Anderson, L.G., Delany, J., Pinnegar, J.K., 2015. Can citizen science
588 contribute to the evidence-base that underpins marine policy? *Mar. Policy* 59, 112–120.
589 <https://doi.org/10.1016/j.marpol.2015.04.022>

590 Hyder, K., Weltersbach, M.S., Armstrong, M., Ferter, K., Townhill, B., Ahvonen, A., Arlinghaus,
591 R., Baikov, A., Bellanger, M., Birzaks, J., Borch, T., Cambie, G., de Graaf, M., Diogo,
592 H.M.C., Dziemian, Ł., Gordoia, A., Grzebielec, R., Hartill, B., Kagervall, A., Kapiris, K.,
593 Karlsson, M., Kleiven, A.R., Lejk, A.M., Levrel, H., Lovell, S., Lyle, J., Moilanen, P.,

594 Monkman, G., Morales-Nin, B., Mugerza, E., Martinez, R., O'Reilly, P., Olesen, H.J.,
595 Papadopoulos, A., Pita, P., Radford, Z., Radtke, K., Roche, W., Rocklin, D., Ruiz, J., Scougal,
596 C., Silvestri, R., Skov, C., Steinback, S., Sundelöf, A., Svagzdys, A., Turnbull, D., van der
597 Hammen, T., van Voorhees, D., van Winsen, F., Verleye, T., Veiga, P., Vølstad, J.H., Zarauz,
598 L., Zolubas, T., Strehlow, H. V., 2018. Recreational sea fishing in Europe in a global
599 context—Participation rates, fishing effort, expenditure, and implications for monitoring and
600 assessment. *Fish Fish.* 19, 225–243. <https://doi.org/10.1111/faf.12251>

601 Hyder, K., Wright, S., Kirby, M., Brant, J., 2016. The role of citizen science in monitoring small-
602 scale pollution events. *Mar. Pollut. Bull.* 0–1. <https://doi.org/10.1016/j.marpolbul.2017.04.038>

603 ICES, 2017. ICES DATRAS database [WWW Document].

604 Karr, J.R., 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6, 21–27.
605 [https://doi.org/10.1577/1548-8446\(1981\)006<0021](https://doi.org/10.1577/1548-8446(1981)006<0021)

606 Korpinen, S., Meski, L., Andersen, J.H., Laamanen, M., 2012. Human pressures and their potential
607 impact on the Baltic Sea ecosystem. *Ecol. Indic.* 15, 105–114.
608 <https://doi.org/10.1016/j.ecolind.2011.09.023>

609 Kosmala, M., Wiggins, A., Swanson, A., Simmons, B., 2016. Assessing data quality in citizen
610 science. *Front. Ecol. Environ.* 14, 551–560. <https://doi.org/10.1002/fee.1436>

611 Kristensen, A.L.D., Støttrup, J.G., Andersen, S.K., Degel, H., 2014. Registrering af fangster i de
612 danske kystområder med standardredskaber. Nøglefiskerrapport 2011-2013. DTU Aqua-raport
613 nr. 286-2014.

614 Kristensen, L.D., Stenberg, C., Støttrup, J.G., Poulsen, L.K., Christensen, H.T., Dolmer, P., Landes,
615 A., Røjbek, M., Thorsen, S.W., Holmer, M., Deurs, M. V., Grønkjær, P., 2015. Establishment
616 of blue mussel beds to enhance fish habitats. *Appl. Ecol. Environ. Res.* 13.
617 https://doi.org/10.15666/aeer/1303_783798

618 Lotze, H.K., 2006. Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas.
619 Science (80-.). 312, 1806–1809. <https://doi.org/10.1126/science.1128035>

620 Madsen, K.S., Højerslev, N.K., 2009. Long-term temperature and salinity records from the Baltic
621 Sea transition zone. *Boreal Environ. Res.* 14, 125–131.

622 Martinsson, J., Nissling, A., 2011. Nursery area utilization by turbot (*Psetta maxima*) and flounder
623 (*Platichthys flesus*) at Gotland, central Baltic Sea. *Boreal Environ. Res.* 16, 60–70.

624 McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Cook-Patton, S.C.,
625 Evans, D.M., French, R.A., Parrish, J.K., Phillips, T.B., Ryan, S.F., Shanley, L.A., Shirk, J.L.,
626 Stepenuck, K.F., Weltzin, J.F., Wiggins, A., Boyle, O.D., Briggs, R.D., Chapin, S.F., Hewitt,
627 D.A., Preuss, P.W., Soukup, M.A., 2017. Citizen science can improve conservation science,
628 natural resource management, and environmental protection. *Biol. Conserv.* 208, 15–28.
629 <https://doi.org/10.1016/j.biocon.2016.05.015>

630 McPhee, D., Leadbitter, D., Skilleter, G., 2002. Swallowing the bait: is recreational fishing in
631 Australia ecologically sustainable? *Pacific Conserv. Biol.* 8, 40–51.

632 Muus, B.J., 1967. The fauna of Danish estuaries and lagoons. Distribution and ecology of
633 dominating species in the shallow reaches of the mesohaline zone. *Meddelelser fra Danmarks*
634 *Fiskeri- og Havundersøgelser*, Bind 5, Nr. 1.

635 Muus, B.J., Nielsen, J.G., 2006. *Havfisk og fiskeri i Nordvesteuropa*, 6th ed. Gyldendal,
636 Copenhagen, Denmark.

637 Natale, F., Carvalho, N., Paulrud, A., 2015. Defining small-scale fisheries in the EU on the basis of
638 their operational range of activity The Swedish fleet as a case study. *Fish. Res.* 164, 286–292.
639 <https://doi.org/10.1016/j.fishres.2014.12.013>

640 Neuman, E., Sandström, O., Thoresson, G., 1999. Guidelines for coastal fish monitoring. *Natl.*
641 *Board Fish. Inst. Coast. Res. Öregrund, Sweden* 44.

642 Newson, S.E., Moran, N.J., Musgrove, A.J., Pearce-Higgins, J.W., Gillings, S., Atkinson, P.W.,
643 Miler, R., Grantham, M.J., Baillie, S.R., 2016. Long-term change in spring and autumn
644 migration phenology of common migrant breeding birds in Britain: results from large-scale
645 citizen science bird recording schemes. *Ibis* (Lond. 1859). 158, 481–495.
646 <https://doi.org/10.1111/ibi.12367>

647 O’Meara, T.A., Hillman, J.R., Thrush, S.F., 2017. Rising tides, cumulative impacts and cascading
648 changes to estuarine ecosystem functions. *Sci. Rep.* 7, 10218. [https://doi.org/10.1038/s41598-](https://doi.org/10.1038/s41598-017-11058-7)
649 [017-11058-7](https://doi.org/10.1038/s41598-017-11058-7)

650 Olesen, H.J., Storr-Paulsen, M., 2015. Eel, cod and sea trout harvest in Danish recreational fishing
651 during 2011. *DTU Aqua Rep.* 253-2012 28 pp.

652 Olsson, J., Bergström, L., Gårdmark, A., 2012. Abiotic drivers of coastal fish community change
653 during four decades in the Baltic Sea. *ICES J. Mar. Sci.* 69, 961–970.

654 Poulsen, L.K., Christensen, H.T., Stenberg, C., Kristensen, L.D., Thorsen, S.W., Røjbek, M.,
655 Holmer, M., Landes, A., Andersen, S.K., Dolmer, P., Geitner, K., Gram, V., Holm, N.,
656 Holmer, M., Knudsen, J., Knudsen, M., Støttrup, J.G., 2012. Slutrapport for Projekt BioRev
657 2010-2012. *DTU Aqua-rapport* 251-2012.

658 Seitz, R.D., Wennhage, H., Bergström, U., Lipcius, R.N., Ysebaert, T., 2014. Ecological value of
659 coastal habitats for commercially and Ecologically Important Species. *ICES J. Mar. Sci.* 71,
660 648–665.

661 Skóra, K.E., Stolarski, J., 1996. *Neogobius melanostomus* (Pallas 1811) a new immigrant species in
662 Baltic Sea, in: Styczynska-Jurewicz, E. (Ed.), *Estuarine Ecosystems and Species. Proc 2nd Int*
663 *Estuary Symp, Gdańsk, 18–22 October 1993. Iss Mar Biol Centre Gdynia 1*, pp. 101–108.

664 Souza, A.T., Dias, E., Nogueira, A., Campos, J., Marques, J.C., Martins, I., 2013. Population
665 ecology and habitat preferences of juvenile flounder *Platichthys flesus* (Actinopterygii:

666 Pleuronectidae) in a temperate estuary. *J. Sea Res.* 79, 60–69.
667 <https://doi.org/10.1016/j.seares.2013.01.005>

668 Sparrevohn, C.R., Nicolajsen, H., Kristensen, L., Støttrup, J.G., 2009. Registrering af fangster i de
669 danske kystområder med standardredskaber fra 2005-2007 Nøglefiskerrapporten 2005-2007
670 78.

671 Støttrup, J.G., Andersen, S.K., Kokkalis, A., Christoffersen, M., Pedersen, E.M.F., 2017.
672 Registrering af fangster i de danske kystområder med standardredskaber Nøglefiskerrapport
673 2014-2016 Registrering af fangster i de danske kystområder med standardredskaber
674 Nøglefiskerrapport for 2014-2016. DTU Aqua-rapport nr. 320-2017.

675 Støttrup, J.G., Lund, H.S., Kindt-Larsen, L., Egekvist, J., Munk, P., Stenberg, C., 2014. KYSTFISK
676 I. Kortlægning af de kystnære fiske- bestandenes udvikling på basis af fiskernes egne
677 observationer i perioden fra 1980 'erne til 2013. DTU Aqua Rep. 278-2014 52.

678 Støttrup, J.G., Sparrevohn, C.R., Nicolajsen, H., Kristensen, L.D., 2012. Registrering af fangster i
679 de danske kystområder med standardredskaber. Nøglefiskerrapporten for årene 2008-2010.
680 DTU Aqua Rep. 252, 95.

681 Strehlow, H. V., Schultz, N., Zimmermann, Christopher Hammer, C., 2012. Cod catches taken by
682 the German recreational fishery in the western Baltic Sea, 2005–2010: implications for stock
683 assessment and management. *ICES J. Mar. Sci.* 69, 1769–1780.

684 Teal, L.R., van Hal, R., van Kooten, T., Ruardij, P., Rijnsdorp, A.D., 2012. Bio-energetics
685 underpins the spatial response of North Sea plaice (*Pleuronectes platessa* L.) and sole (*Solea*
686 *solea* L.) to climate change. *Glob. Chang. Biol.* 18, 3291–3305. [https://doi.org/10.1111/j.1365-](https://doi.org/10.1111/j.1365-2486.2012.02795.x)
687 [2486.2012.02795.x](https://doi.org/10.1111/j.1365-2486.2012.02795.x)

688 Toivonen, A.L., Roth, E., Navrud, S., Gudbergsson, G., Appelblad, H., Bengtsson, B., Tuunainen,
689 P., 2004. The economic value of recreational fisheries in Nordic countries. *Fish. Manag. Ecol.*

690 11, 1–14. <https://doi.org/Doi.10.1046/J.1365-2400.2003.00376.X>

691 Underwood, A.J., Chapman, M.G., 2006. Conservation of coastal organisms depends on scientific
692 realism , not community “ monitoring ” 20–37.

693 Vann-Sander, S., Clifton, J., Harvey, E., 2016. Can citizen science work? Perceptions of the role
694 and utility of citizen science in a marine policy and management context. *Mar. Policy* 72, 82–
695 93. <https://doi.org/10.1016/j.marpol.2016.06.026>

696 Vasconcelos, R.P., Reis-Santos, P., Fonseca, V., Maia, A., Ruano, M., França, S., Vinagre, C.,
697 Costa, M.J., Cabral, H., 2007. Assessing anthropogenic pressures on estuarine fish nurseries
698 along the Portuguese coast: A multi-metric index and conceptual approach. *Sci. Total Environ.*
699 374, 199–215. <https://doi.org/10.1016/j.scitotenv.2006.12.048>

700 Wood, S., 2006. *Generalized Additive Models: An Introduction with R*. CRC Press.

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703 **Table 1.** List of fish species caught in the gill nets (G) and fyke nets (F) over the period 2005-2016
 704 and 2002-2016 respectively.

Species	Gear	Species	Gear
Allis shad (<i>Alosa alosa</i>)	G, F	Perch (<i>Perca fluviatilis</i>)	G, F
Bass (<i>Dicentrarchus labrax</i>)	G, F	Pikeperch (<i>Sander lucioperca</i>)	F
Black goby (<i>Gobius niger</i>)	F	Plaice (<i>Pleuronectes platessa</i>)	G, F
Bleak (<i>Alburnus alburnus</i>)	F	Pogge(armed bullhead) (<i>Agonus cataphractus</i>)	G, F
Bream (<i>Abramis brama</i>)	G, F	Pollack (<i>Pollachius pollachius</i>)	G, F
Brill (<i>Scophthalmus rhombus</i>)	G, F	Poor -cod (<i>Trisopterus minutus</i>)	F
Broad -nosed pipefish (<i>Syngnathus typhle</i>)	G, F	Powan/European whitefish (<i>Coregonus lavaretus</i>)	G, F
Butter fish (<i>Pholis gunnellus</i>)	F	Rainbow trout (<i>Oncorhynchus mykiss</i>)	G, F
Carps (<i>Cyprinidae</i>)	F	Red gurnard (<i>Trigla lucerna</i>)	G
Catfish (<i>Anarhichas lupus</i>)	F	Roach (<i>Rutilus rutilus</i>)	G, F
Cod (<i>Gadus morhua</i>)	G, F	Round goby (<i>Neogobius melanostomus</i>)	F
Common dab (<i>Limanda limanda</i>)	G, F	Rudd (<i>Scardinius erythrophthalmus</i>)	G, F
Common dragonet (<i>Callionymus lyra</i>)	G, F	Saithe (<i>Pollachius virens</i>)	G, F
Common goby (<i>Pomatoschistus microps</i>)	F	Salmon (<i>Salmo salar</i>)	G, F
Corkwing (<i>Symphodus melops</i>)	F	Sand eels (<i>Ammodytes</i>)	G, F
Eel (<i>Anguilla anguilla</i>)	G, F	Sand goby (<i>Pomatoschistus minutus</i>)	F
Eelpout (<i>Zoarces viviparus</i>)	G, F	Sculpin (<i>Myoxocephalus scorpius</i>)	G, F
European smelt (<i>Osmerus eperlanus</i>)	G, F	Sculpin (<i>Triglops murrayi</i>)	F
Five -bearded rockling (<i>Ciliata mustella</i>)	F	Sea lamprey (<i>Petromyzon marinus</i>)	F
Flounder (<i>Platichthys flesus</i>)	G, F	Sea(ninespine) -stickleback (<i>Pungitius pungitius</i>)	F
Four -bearded rockling (<i>Enchelyopus cimbrius</i>)	F	Sea scorpion (<i>Taurulus bubalis</i>)	G, F
Garfish (<i>Belone belone</i>)	G, F	Sea trout (<i>Salmo trutta</i>)	G, F
Goldsinny wrasse (<i>Ctenolabrus rupestris</i>)	F	Shanny (<i>Blennius pholis</i>)	F
Greater forkbeard (<i>Phycis blennoides</i>)	F	Smallmouthed wrasse (<i>centrolabrus exletus</i>)	F
Greater weever fish (<i>Trachinus draco</i>)	G, F	Snake pipefish (<i>Entelurus aequoreus</i>)	F
Great pipefish (<i>Syngnathus acus</i>)	F	Sole (<i>Solea solea</i>)	G, F
Grey gurnard (<i>Eutrigla gurnardus</i>)	G	Sprat (<i>Sprattus sprattus</i>)	G, F
Haddock (<i>Melanogrammus aeglefinus</i>)	G, F	Straightnose pipefish (<i>Nerophis ophidion</i>)	F
Hake (<i>Merluccius merluccius</i>)	F	Tench (<i>Tinca tinca</i>)	G
Herring (<i>Clupea harengus</i>)	G, F	Ten spined stickleback (<i>Spinachia spinachia</i>)	G, F
Horse mackerel (<i>Trachurus trachurus</i>)	G, F	Thick lipped mullet (<i>Mugil cephalus</i>)	G, F
Lampreys (<i>Petromyzontinae</i>)	F	Three -spined stickleback (<i>Gasterosteus aculeatus</i>)	G, F
Lemon sole (<i>Microstomus kitt</i>)	G, F	Topknot (<i>Zeugopterus punctatus</i>)	F
Lesser forkbeard (<i>Raniceps raninus</i>)	F	Transperant goby (<i>Aphia minuta</i>)	F
Lesser pipefish (<i>Syngnathus rostellatus</i>)	F	Tub gurnard (<i>Aspitrigla cuculus</i>)	F
Lesser spotted dogfish (<i>Scyliorhinus canicula</i>)	F	Turbot (<i>Psetta maxima</i>)	G, F
Ling (<i>Molva molva</i>)	F	Tusk (<i>Brosme brosme</i>)	F
Lumpfish (<i>Cyclopterus lumpus</i>)	G, F	Twaite shad (<i>Alosa fallax</i>)	G, F
Mackerel (<i>Scomber scombrus</i>)	G, F	Whiting (<i>Merlangius merlangus</i>)	G, F
Monk (<i>Lophius piscatorius</i>)	F	Witch (<i>Glyptocephalus cynoglossus</i>)	G, F
Northern pike (<i>Esox lucius</i>)	G, F	Wrasses (<i>Labridae</i> sp.)	G, F

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708 Figure Captions

709 Fig. 1. Number of fishing instances undertaken using gill nets and fyke nets during the period 2005-2016.

710 Fig. 2. Map of Denmark showing area divisions (light grey areas with area numbers) and fishing positions
711 (black dots) where either fyke nets (a) or gill nets (b) were deployed. Positions shown are those that were
712 active at least one year since 2002. The island shown inset is Bornholm, situated further to the east in the
713 southern Baltic Sea. 1. Open west coast, 2. Northern Limfjord, 3. Skive Fjord and Lovns Broad, 4. Western
714 Limfjord, 5. Nissum Fjord, 6. Ringkøbing Fjord, 7. Bornholm, 8. Aalborg Bay and Læsø, 9. Mariager and
715 Horsens Fjords, 10. Aarhus Bay, 11. Vejle Fjord, 12. Odense Fjord, 13. Little Belt, 14. Fyns archipelago, 15.
716 Sejerø Bay, 16. Great Belt and Kerteminde Fjord, 17. Smålandsfarvandet, 18. Fehmarn Belt, 19. Roskilde
717 Fjord and Isefjord, 20. Sound and Faxe Bay, and 21. Præstø Fjord.

718 Fig. 3. Total catch, in number of individuals, for the five most abundant species caught in gill nets (a, c) and
719 fyke nets (b, d) in 2005 (a, b) and 2016 (c, d) before and after the invasion of the round goby in the western
720 Baltic Sea area.

721 Fig. 4. Annual average of catch per unit effort (CPUE; numbers per 12 h, error bars: 95% CI) of flounder
722 (*Platichthys flesus*) in gill nets (2005-2016). Smålandsfarvandet is not presented because it has too few data
723 points.

724 Fig. 5. Annual average catch per unit effort (CPUE; numbers per 48 h, error bars: 95% CI) of flounder
725 (*Platichthys flesus*) in fyke nets (2002-2016). Nissum Fjord and Ringkøbing Fjord are not presented because
726 they have too few data points.

727 Fig. 6. Annual average catch per unit effort (CPUE, error bars: one standard error) in numbers per 12 h of
728 flounder (*Platichthys flesus*) caught in gill nets in Roskilde Fjord and Isefjord (a), and Sejerø Bay (b) with
729 linear regressions (mean: solid line, 95% confidence interval: shaded area). Weekly CPUE of flounder in
730 Roskilde Fjord and Isefjord (c) and Sejerø Bay (d) with fitted Generalised Additive Mixed Model (total mean:
731 solid line, trend: dashed line, 95% CI: shaded area). High CPUE values are omitted; their positions are
732 denoted with vertical lines in the top of the plots.

733 Fig. 7. Monthly average catch per unit effort (CPUE; numbers per 12 h) of flounder (*Platichthys flesus*)
734 caught in gill nets in Roskilde Fjord and Isefjord (solid line) and Sejerø Bay (dashed line) during the last three
735 years (above) with local temperature from the provided loggers (below).

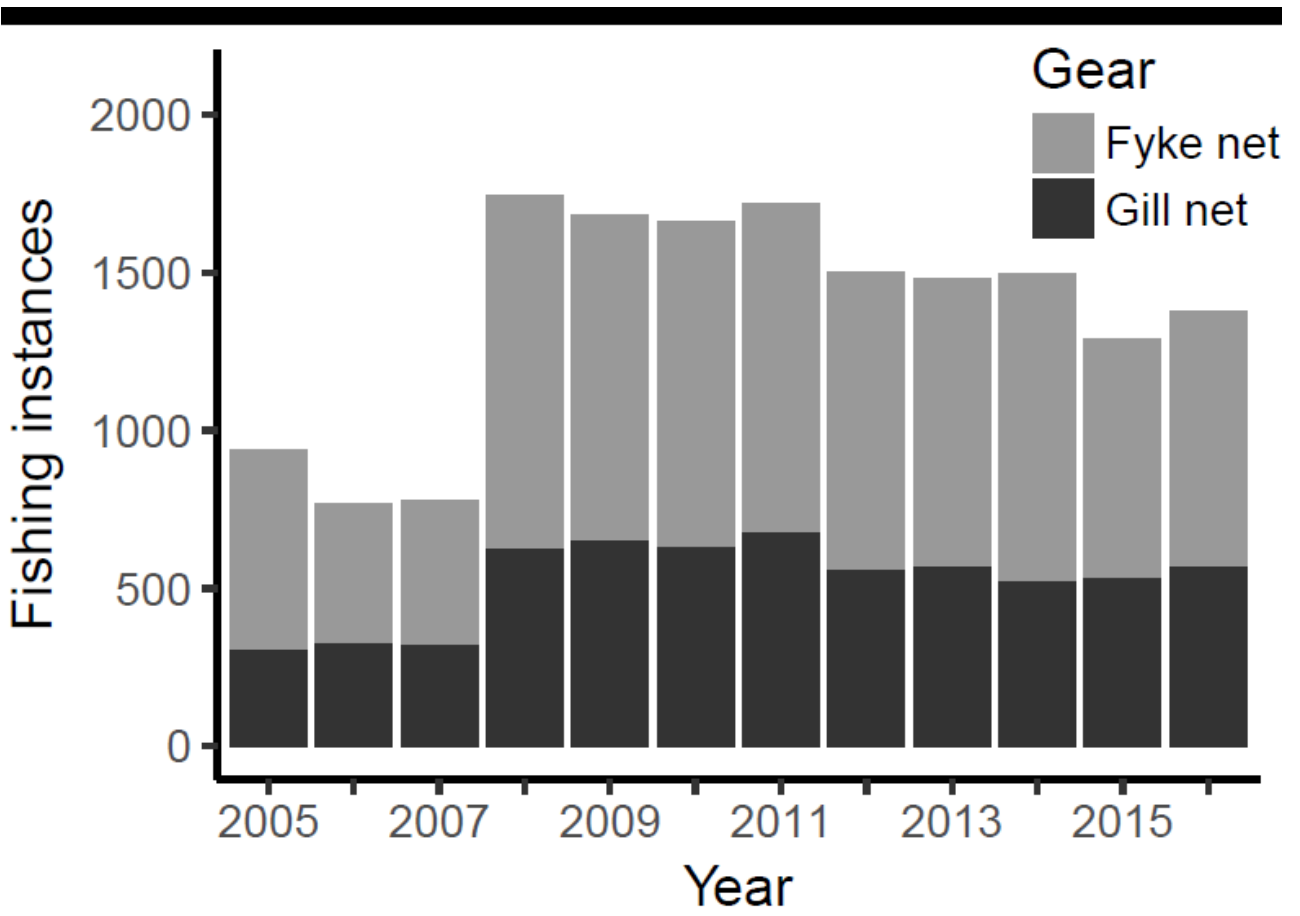
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740 Figure 1.

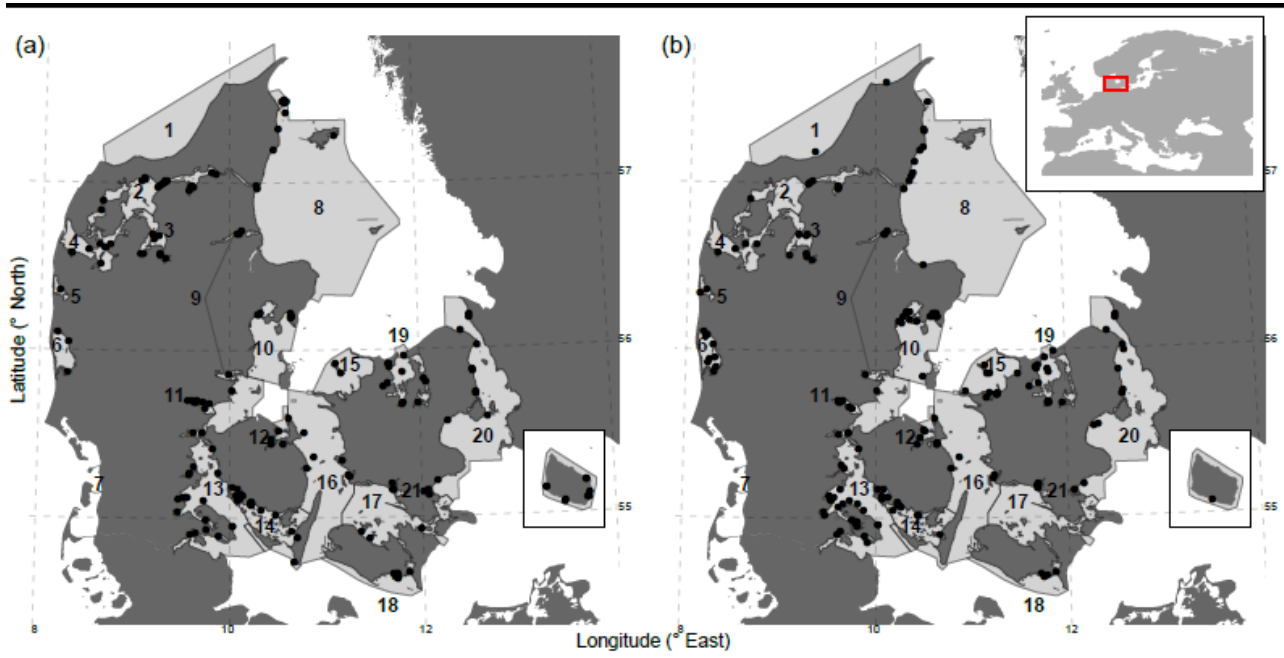


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744 Figure 2.

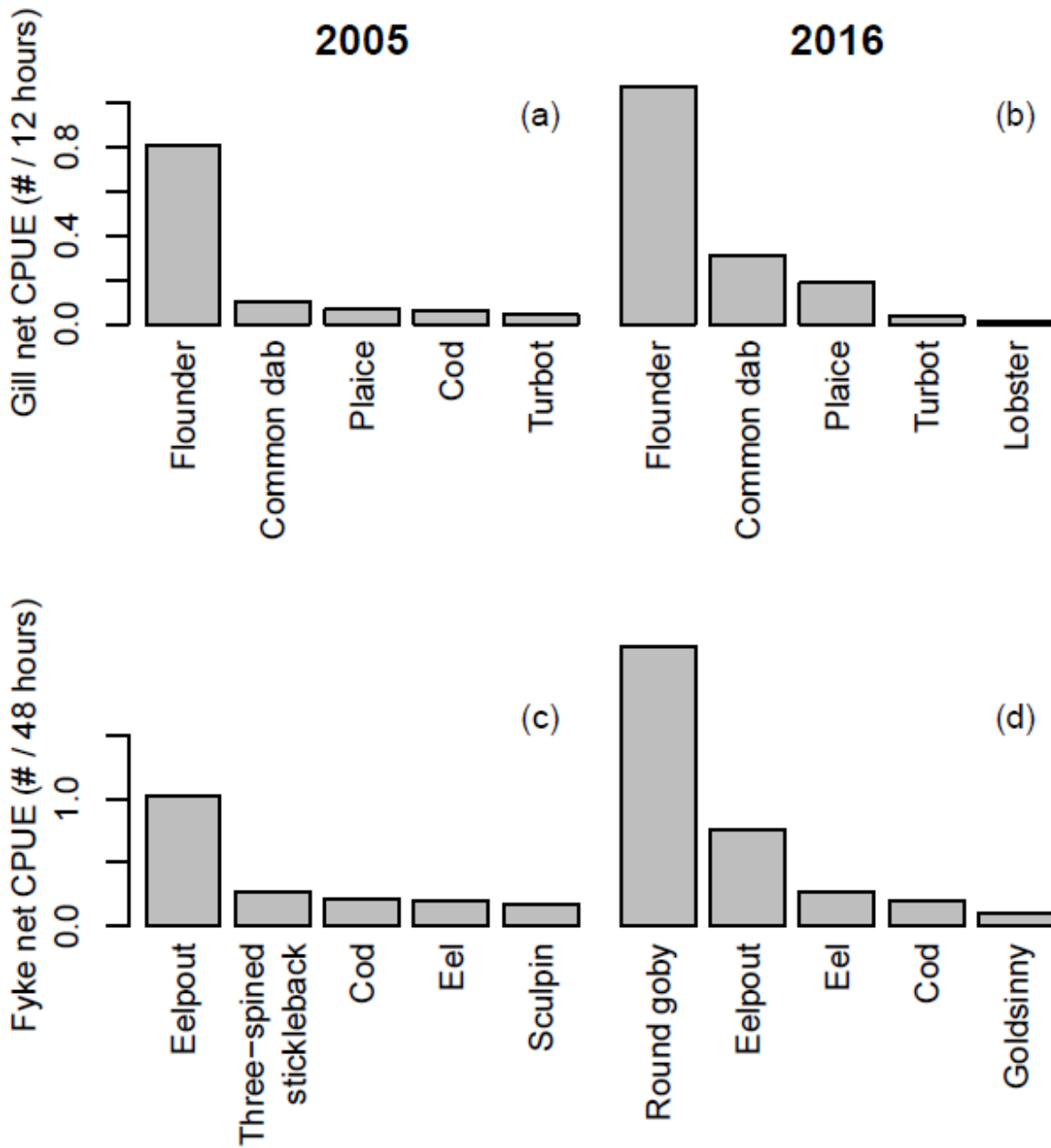


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747 Figure 3.

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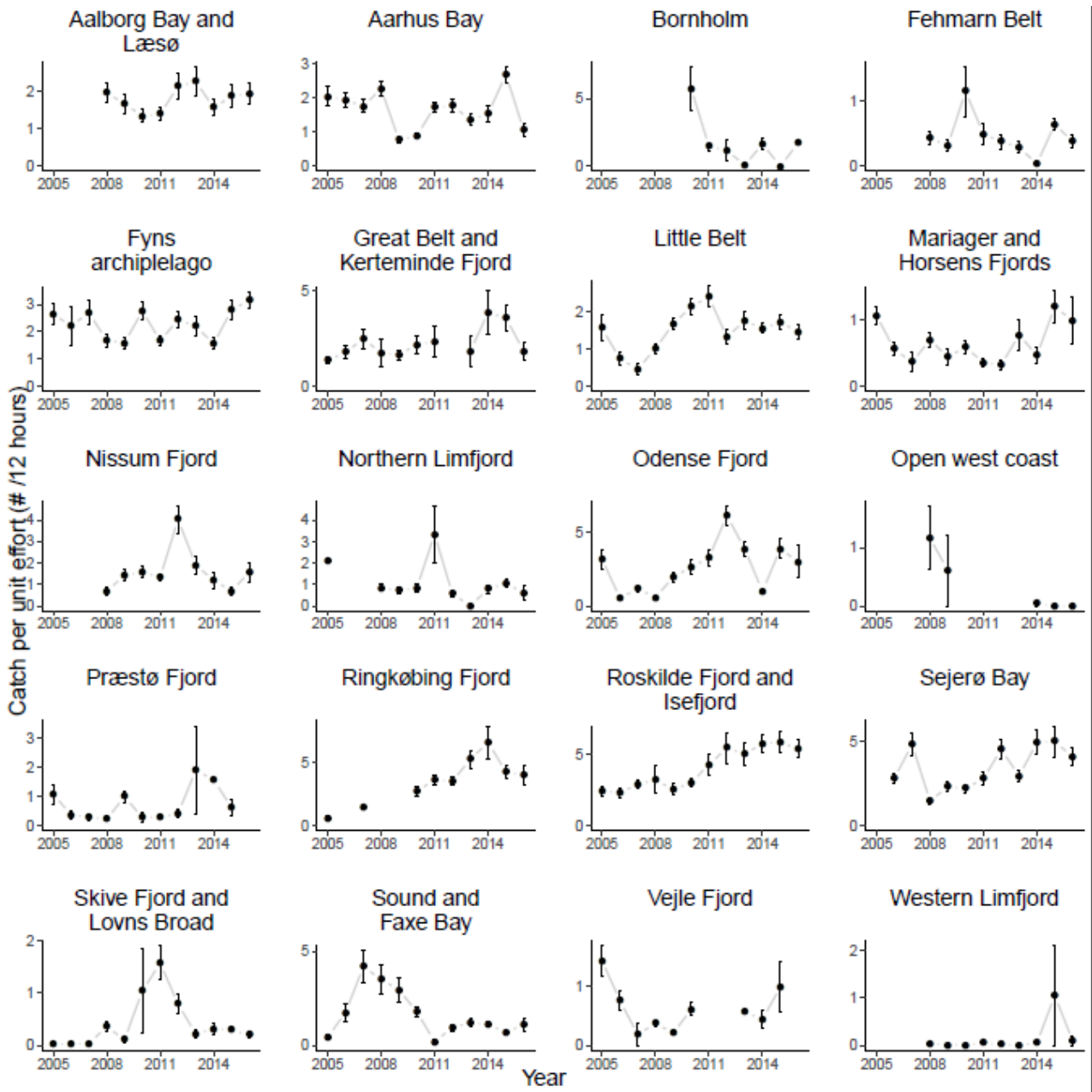
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754 Figure 4.



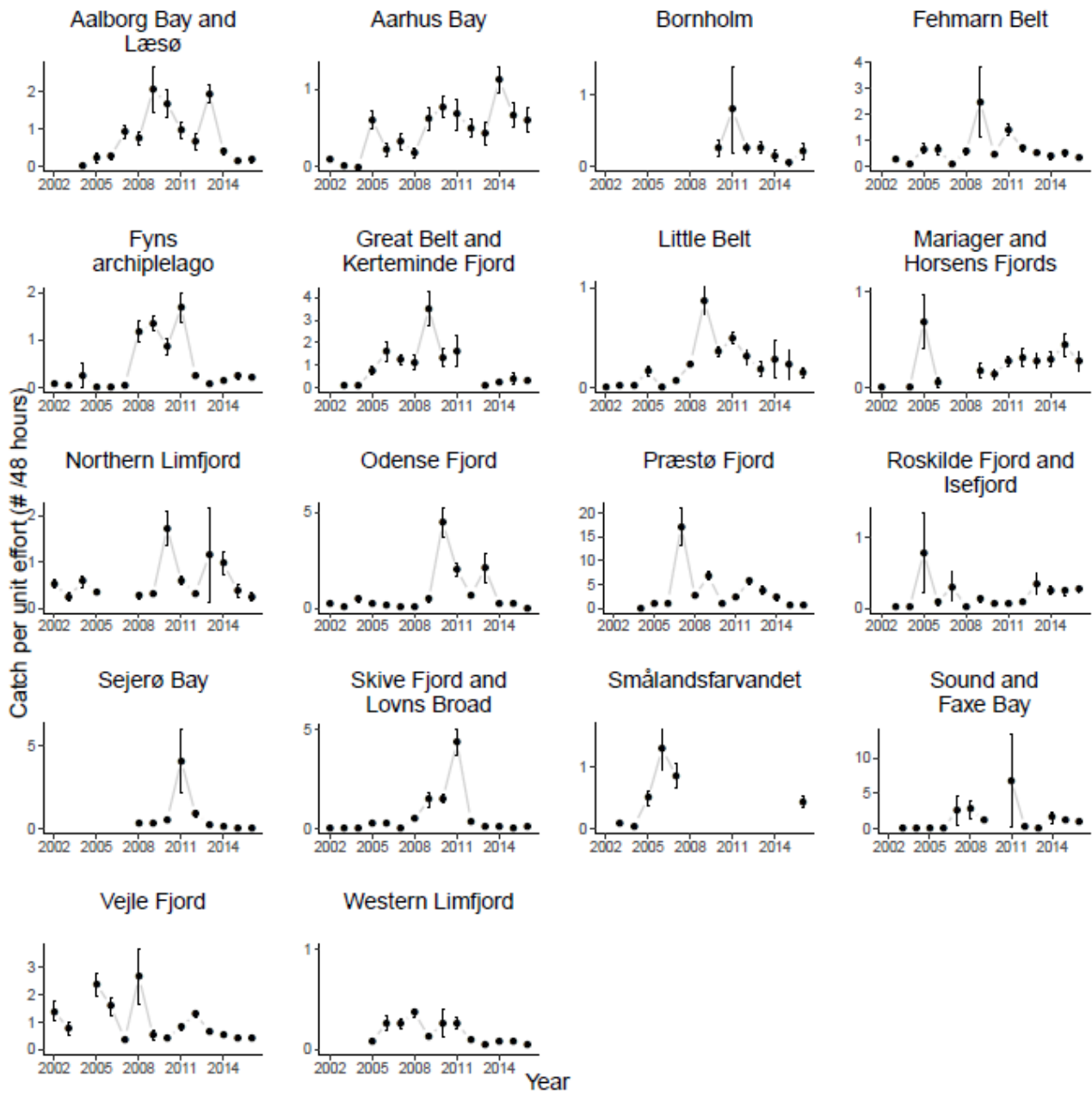
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759 Figure 5.

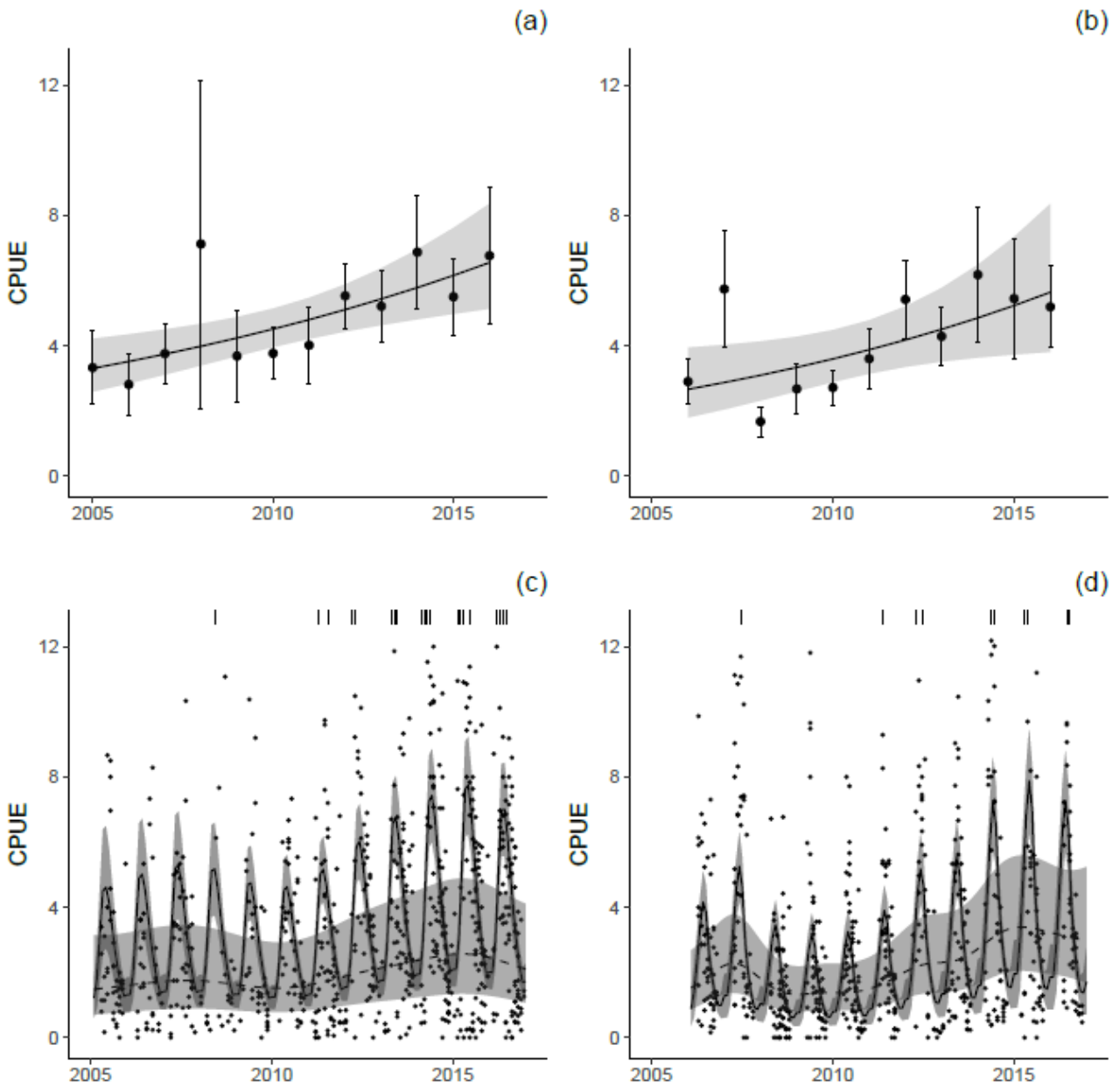


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763 Figure 6.



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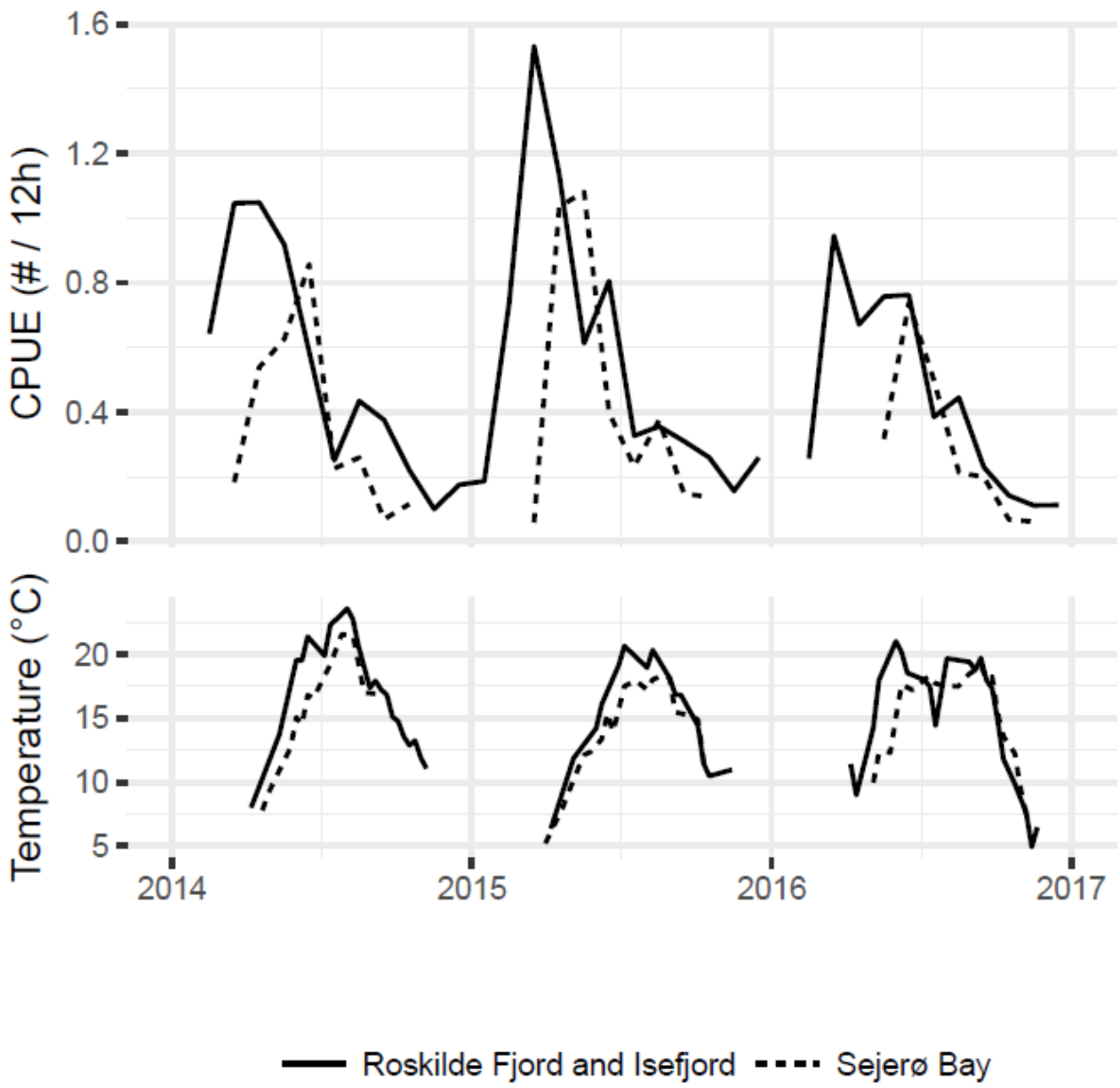
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770 Figure 7.



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