Research article

Citizen science provides added value in the monitoring for coastal non-indigenous species

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A B S T R A C T

Continuous and comprehensive monitoring is one of the most important practices to trace changes in the state of the environment and target management efforts. Yet, governmental resources are often insufficient for monitoring all required environmental parameters, and therefore authorities have started to utilize citizen observations to supplement and increase the scale of monitoring. The aims of the present study were to show the potential of citizen science in environmental monitoring by utilising citizen observations of the non-indigenous Harris mud crab *Rhithropanopeus harrisii* in Finnish waters, where coastal monitoring is insufficient to estimate the distribution and spread of non-indigenous species. Harris mud crab has shown measurable impact locally and is considered invasive. For reporting the status of invasions to national and European authorities and planning for potential eradication efforts, up to date knowledge on NIS ranges are needed. Citizen observations on the species were collected from the first observation onwards between 2009 and 2018, at first via email and later through an active citizen observation web portal (Invasive Alien Species Portal). The outcomes of the study indicate that species-specific citizen observations can be a beneficial addition to supplement national monitoring programs to fulfil legislative reporting requirements and to target potential management. Recognizable species and geographical areas with low biodiversity provide a good opportunity to utilize citizen observations. Moreover, citizen observations may enable distribution assessments for certain species that would otherwise require excessive resources and sampling efforts.

1. Introduction

Environmental monitoring is crucial in providing authorities and scientists information on the state of the environment, as well as revealing changes in species communities and abundances. Generally, the aim of an environmental monitoring program is to provide high quality data cost-effectively with widely acknowledged methods (Lovett et al., 2007). In order to create a comprehensive database of spatial and temporal data assessing the presence and frequency of all species of interest (Ricciardi et al., 2000), successful monitoring programs require a solid funding base, standard measurements and professionals assigned to collect and analyse the samples, as well as interpret the data. Most countries are committed to national monitoring programs since long time series are the key to detecting changes in the environment (Lovett et al., 2007; Lehtiniemi et al., 2015). However, governmental funding is rarely sufficient to cover all environmental parameters, thus monitoring programs are both spatially and temporally limited (Delaney et al., 2008). One parameter often lacking harmonized governmental

monitoring is presence and abundance of non-indigenous species (NIS) (Lehtiniemi et al., 2015), although monitoring their arrivals and spread are required by international legislations (EC, 2008; EC, 2014), and is of great importance to national environmental management.

Public involvement, also known as citizen or community science (non-professional involvement of volunteers), has become more widely used only recently (since the late 20th century) to support environmental monitoring programs (Lodge et al., 2006; Fore et al., 2008; Conrad and Hilchey, 2011), even though ornithologists have utilized citizen-based observations for well over 100 years (Tulloch et al., 2013). The significance of utilising citizen science in environmental monitoring originates from the potential to compensate for the lack of resources to generate comprehensive and up-to-date species presence databases (Delaney et al., 2008). In addition, citizen science can be utilized to update the state of seasonally occurring events, such as migration patterns, blooming events and areal ice thickness (Lovett et al., 2007; Tulloch et al., 2013; Kettunen et al., 2016).

Citizen science can add significant value to monitoring by increasing

the number of observations, as well as their spatial and temporal scale. In particular, volunteers and citizen observers can contribute to more frequent, widespread and cost-efficient monitoring (Bodilis et al., 2014). Potentially the superior characteristic of citizen science, high number of potential observers, is particularly beneficial in the detection of rare, charismatic and non-indigenous species, as well as so called "booming" species that may appear quickly with appropriate environmental conditions (Dickinson et al., 2012). More importantly, citizen-based monitoring enhances rapid detection of ecosystem changes, as for example public members have often been the first to discover new NIS (Lodge et al., 2006). Early detection of NIS enables rapid response practices and can increase public awareness of the issue (Lehtiniemi et al., 2015). Furthermore, most citizen science projects provide monitoring for several species at a time over relatively large geographic areas (Dickinson et al., 2010).

In general, community-based monitoring approaches include government-managed databases that utilize citizen observations to detect changes in ecosystems, as well as monitoring programs that can be expanded and strengthened with help of committed community groups, such as students and volunteers (Whitelaw et al., 2003). Online databases that enable submitting observations using for example mobile technology, can provide almost unlimited data enabling observers also to share video, photos, field notes and exact location information (Connors et al., 2012; Bonney et al., 2014) with very little effort. The accuracy of these observations can be improved through validation by expert scientists (Thomas et al., 2017), based on either photograph or written descriptions (Starr et al., 2014).

The main limitations with citizen science are often related to preciseness of observations and uneven spatial distribution of potential observers (Wiggins and Crowston, 2011). In particular, the quality of observations decreases if the observed species cannot be easily identified or quantified (Lewandowski and Specht, 2015). These issues tend to be more common when the observed species either occur in low densities (false negatives) or co-exist with other similar-looking species (false positives) (Fitzpatrick et al., 2009).

So far, the number of range expansion studies on aquatic NIS is limited, despite broad utilisation within terrestrial environments (Lowen et al., 2016). Studies of this type are overall very complex to create in aquatic environments, as species dispersal is influenced not only by the presence of favourable habitats, but also by various natural forces (e.g. water currents) and human vectors (e.g. recreational boats) (Bossenbroek et al., 2001).

In the present study, we evaluated the value of citizen science in the monitoring of coastal aquatic NIS as their budget-based monitoring by national authorities is negligible (Ljungberg et al., 2011). Furthermore, we aimed at estimating the distribution for the invasive Harris mud crab (*Rhithropanopeus harrisii*) in Finnish waters. The occurrence of this species is of interest, as Harris mud crab is a relatively new invasive species in the northern Baltic Sea with multiple impacts in the ecosystem (Forsström et al., 2015; Jormalainen et al., 2016; Puntila-Dodd et al., 2019). Knowledge on NIS distribution is essential in targeting potential eradication efforts as well as addressing both national (Finnish law on non-indigenous species) and international (European Marine Strategy Framework Directive (MSFD) and EU Invasive Alien Species Regulation) requirements on the status and management of NIS in Finnish waters.

The value of citizen observations was assessed by comparing the frequencies of citizen observations of Harris mud crab to their known range and presence based on national research and monitoring observation databases. Specific characteristics of citizen science, such as reliability and possible uses for this type of data are also discussed to determine whether citizen science has a role in the monitoring and reporting of coastal aquatic NIS.

2. Materials and methods

2.1. Web service to collect citizen observations

The national platform to collect citizen observations, the Invasive Alien Species (IAS) Portal (https://www.vieraslajit.fi/fi/content/welcome-invasive-alien-species-portal) by the Finnish Museum of Natural History (LUOMUS) collects a variety of information on NIS in one place aiming to raise awareness on the issue. There are sections for current legislation, materials for species identification, management guidance and a form for reporting NIS observations anywhere in Finland (Table 1). Prior to launching the portal, citizens often reported observations directly to researchers either via phone or email.

Currently the reporting form is only available in Finnish, although some materials in the portal are also available in Swedish and English. The service is open to everyone without registration. The citizens reporting their observations are public recreationists (e.g. recreational residents, boaters and hikers). They have not been recruited or trained for making the observations but do it voluntarily out of interest towards nature and after awareness raising campaigns on NIS. They often report observations when they encounter an unusual looking species. go to the internet to look for identification information on the species and encounter the web service. The online form requires the user to fill in certain details about the observation (Table 1), and optionally add a photo, which is the best way of verifying the species identity. The coordinates for the observation are automatically extracted from the location pin marked on the map. The observations of aquatic NIS, such as Harris mud crab, go through a validation step; an assigned expert receives an email notification about the submitted observation, if needed contacts the observer for further information (e.g. asking for a photo of the specimen) and either approves, modifies or disapproves the observation. After the observation has been approved, it can be seen on the online maps in near real time.

2.2. Study area

The Archipelago Sea extends from southwestern coast of Finland to approximately halfway between Finland and Sweden (Åland islands) (Fig. 1). The area can be characterised as an extraordinary sea area due to its' tens of thousands of small islands and a relatively shallow mean depth of 23 m (Finnish Environment Institute, 2018). The Finns have a long-lasting tradition of owning leisure residencies across the rural areas of the country and the Archipelago Sea is particularly known from its' natural value, including thousands of leisure residencies and other recreational activities (e.g. hiking, fishing and boating) (Official statistics of Finland, 2017).

2.3. Study organism

The native range of the Harris mud crab covers nearly the entire Atlantic coast of North America (Williams, 1984). The species has a

Table 1
Finnish IAS portal observation form details.

Observation information	Additional information
Name of the observer	Photo attachment (add a file)
Email	Means of observation (e.g. trap, fishing net, visual perception)
Phone number	Number of individuals
Date and time of the observation	Mean length
Species	Sampling effort
Coordinates (extracted automatically from the map)	Has the species been cultured?
Name of the location, sea area	Invasion trend (Decreasing/increasing/stable)
	Life stage
	Other information

Fig. 1. Map of the study area.

strong tolerance to various abiotic conditions, and it has invaded over 20 countries worldwide (Roche and Torchin, 2007). After invading the Southern Baltic Sea in the 1930s and 1950s, Harris mud crab did not spread to the northern Baltic Sea until in 2009 to Finland and in 2011 to Estonia, probably via shipping (Kotta and Ojaveer, 2012; Fowler et al., 2013). Harris mud crab can utilize a variety of different habitats in the invaded region, including muddy, sandy and rocky bottoms, as well as seaweed vegetation (Fowler et al., 2013). In addition to the Harris mud crab the only other crab species present in the northern Baltic Sea is the invasive Chinese mitten crab, which can easily be distinguished from the Harris mud crab by the citizens.

2.4. Data analyses

Overall, the aim of the analyses was to reveal the spatial and temporal contribution of citizen observations to the current knowledge on the presence of the invasive Harris mud crab in Finnish waters. Observations evaluated in the present study were divided into research, monitoring and citizen observations. Research observations were reported to the IAS portal by research groups (as indicated by the observer identity), whereas monitoring observations were obtained from the Finnish Environment Institute's database Hertta. Citizen observations were reported by the public (as indicated by the observer identity) using the IAS portal or the previous reporting form. Another relatively clear distinction between citizen and research or monitoring observations was the method of collection. Research and monitoring observations included the use of known sampling equipment or approach (benthic grab, diving, sampling nets, fouling plates). Citizen observations were done during recreational activities (swimming, hiking, fishing, boating). As quality assurance observations without a photo were discarded if the observer was not experienced or if the observation was not described appropriately, which occurred only in few cases.

The frequency and abundance of research/monitoring observations and citizen observations were compared to detect the contribution of citizen observations to the dataset. In addition, as the Harris mud crab observation dataset was spatially continuous, the observations from all sources were mapped to reveal temporal distribution patterns for the species in Finnish waters from 2009 to 2018.

Each observation was mapped as a data point and the distribution of citizen and research/monitoring observations were compared. To assess the distribution based on citizen observations in comparison to research/monitoring observations, the observations were connected using the 'create a polygon' – tool (ArcGIS software, version 10.5.1) and HELCOM marine area 2018 and 1×1km Baltic Sea grid as base maps (HELCOM, 2018). For visual presentation, the study area was divided into 1×1 km grids, every grid containing an observation was painted black for each mapping assessment and these grids were connected by selecting the grids inside the range polygons and painting them in grey.

3. Results

3.1. Observations and the observers

In the Finnish IAS portal, there were 970 observations of aquatic NIS to date, of which 491 were Harris mud crab observations between 2011 and 2018. 460 observations were reported by the public, whereas 31 observations were reported by research groups or individual researchers (Table 2). In addition, 45 monitoring observations were obtained from the national monitoring database. Before the launching of the first version of the portal in 2011, 11 observations were reported to national authorities and researchers via email, the first in 2009 (Fowler et al., 2013). The number of annual observations increased steadily until 2015 and then decreased (Table 2). Throughout the study, citizen observations were more frequent than research and monitoring observations. Citizens provided observations each month except January during the

Table 2
Number of annual Harris mud crab observations reported to the national IAS portal or before portal development by email.

Year	Number of monitoring/research observations	Number of citizen observations
2010	9	11
2011	11	19
2012	6	51
2013	18	69
2014	13	92
2015	10	103
2016	7	38
2017	2	44
2018	0	33
Total	76	460

study period while research and monitoring observations only covered seven months (Fig. 2).

The research and monitoring observations were made by 13 different researchers or research groups, whereas citizen observations were reported by 380 individual public observers. The research and monitoring observations were in a few coastal locations of the Archipelago Sea, except one diver observation from the cooling waters of Olkiluoto nuclear power plant, further north along the west coast (Fig. 3). Overall, the range of Harris mud crab was 1617 km^2 when only research and monitoring observations were mapped. Citizen observations, in turn, were significantly more widespread along the study area resulting in the range area of 3093 km^2, which was 52% more than the distribution based on research/monitoring observations only.

3.2. Harris mud crab distribution

Observations of the Harris mud crab were located mainly in the Archipelago Sea and along the southwestern coast of Finland (Fig. 4). The observations of 2011 and 2012 were located mainly around the Port of Turku and Port of Naantali. The spread continued further along the coastline and towards the outer Archipelago Sea until 2016. Some of the latest observations in 2017 and 2018 revealed a secondary spread in the western side of the study area, at Åland Islands. In addition, one research observation was reported in 2017 in the Bothnian Sea, further north of the primary range area, from the cooling waters of the Olkiluoto nuclear power plant.

4. Discussion

Citizen observations have true potential to provide comparable and reliable species-specific presence data to support monitoring, required reporting and targeted management. The number and frequency of citizen observations of the invasive Harris mud crab was much larger than monitoring and research observations combined. At present, there is no harmonized monitoring program targeted directly to assess the presence or spread of aquatic NIS or even for coastal mobile species at large in the Baltic Sea. Thanks to citizen observations, authorities have up-to-date knowledge on the range of this easily recognizable invasive species. Distribution of observations is important to follow in order to target potential management measures e.g. eradication in vulnerable conservation areas or industrial sites, and to report for national and international (EU MSFD and IAS Regulation) legislative acts. Furthermore, the monitoring and research observations presented here have been collected from several national monitoring programs and individual sampling events, which do not classify as sound or representative monitoring.
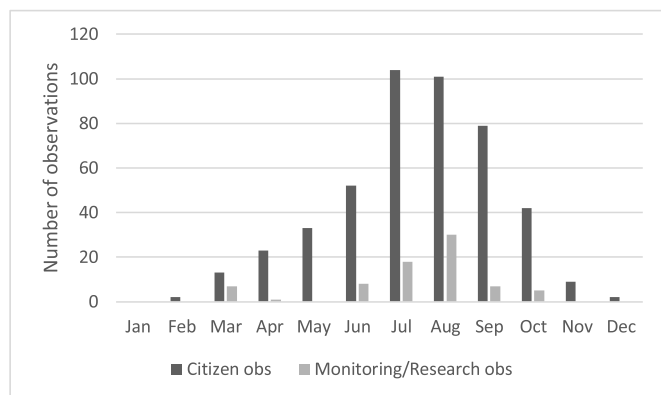

Fig. 2. Monthly frequency of monitoring/research and citizen observations of Harris mud crab reported to the national IAS portal.

### 4.1. Citizen science and environmental monitoring: opportunities and obstacles

Online IAS portals, such as the Finnish portal, can be developed to include a requirement that the location of the observation is chosen from the map provided in the application. The program then extracts the coordinates of the location. This has increased the utilisation of observations in comparison to previously used online forms, where various coordinate systems were used or worse, observers only verbally described the area. Some of the earlier citizen observations submitted via the online form had to be excluded from the study since they had insufficient location information. As expected, the web portal increased the accuracy of citizen observations. An earlier study by Starr et al. (2014) found that mobile devices utilising Global Positioning System (GPS) services have enhanced data collection accuracy significantly in citizen science projects.

Citizen science platforms are easy to create and allow collecting a wide range of information. The Finnish IAS portal enables reporting the exact number of individuals, but some users have also described the abundance of the species in their observation reports. Furthermore, users can provide information on size, life stage and how the specimen was collected (e.g. entangled in fishing net). Obviously, all this information cannot be requested as most observers are not able to distinguish all species characteristics and they are not trained for this. Nevertheless, the estimated number of individuals plays a key role, as it indicates whether it was a singular observation, or the species was abundant, indicating establishment into a larger area and increased risk of nuisance (Dickinson et al., 2012). This also provides authorities information on potential "hot spots" that are vulnerable to invasion, e.g. coastal industrial sites using seawater cooling systems (Crall et al., 2015), and provides information where to target management actions. For example, after the observation of the Harris mud crab in the cooling waters of the power plant (see Fig. 4F) effective surveillance was started to prevent disruptions in the functioning of the plant.

Co-occurrence with other species can provide useful information on the impacts of NIS on the local environment (Crall et al., 2012). Regarding the present study, several observers reported native fish, such as perch (*Perca fluviatilis*, Linnaeus 1758) feeding on Harris mud crab. The predation by local perches appears common, as various observations indicated several juvenile and adult crabs found in the guts. Conclusions may be however limited to fish species of economic value or recreational interest, as other demersal fish species, such as sculpins and cyprinids have been also found to prey on Harris mud crab (Puntila-Dodd et al., 2019), which were not reported in the observations of the present study.

Data reliability is usually one of the main concerns in citizen science projects, often originating from the process of species identification and verification of the observations (Lewandowski and Specht, 2015; Thomas et al., 2017). Some of the previous citizen science studies, such as Nerbonne et al. (2008), Fitzpatrick et al. (2009) and Dickinson et al. (2010) have found contradicting results regarding the effect of volunteer or observer experience in species identification, noting that correct species identification is also closely related to the difficulty of identification of the target species (Crall et al., 2011; Gardiner et al., 2012).

In the present study, all citizen observations were verified by an expert prior to entering into the IAS database. Experiences from the portal showed that observations can be verified in a quick and appropriate manner, as the IAS portal enables photo attachments. This is a recommended procedure for future citizen science portals as well. The northern Baltic Sea is especially vulnerable to new species invasions due to wide variation in environmental conditions (Davis et al., 2001), absence of certain native taxa, such as crabs (Ojaveer et al., 2007) and species-poor communities in general (Leppäkoski and Olenin, 2000; Paavola et al., 2005). As the area lacks native crabs, species identification is quite straightforward. The geography of the area may therefore have a large impact on the applicability of citizen observations. The
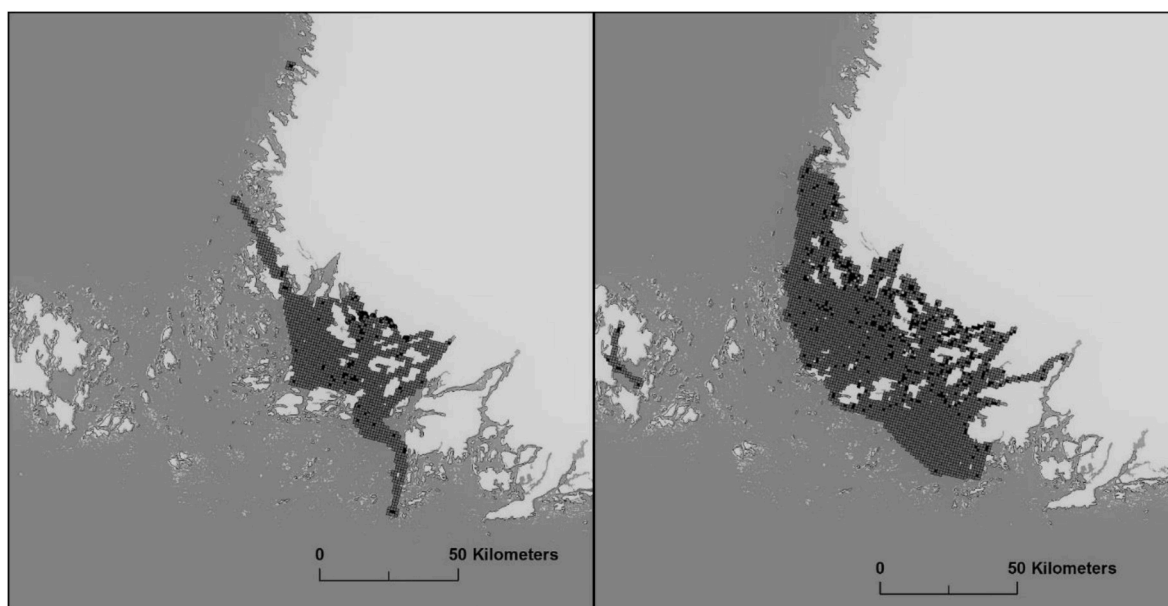
Fig. 3. Harris mud crab distribution maps based on the research/monitoring observations (left figure) and citizen observations (right figure) of the crab made until 2018. Black cells represent grids where the species was observed, and dark grey cells present the estimated range boundaries.

northern Baltic Sea, as well as the Baltic Sea as a whole, might serve as a suitable sea region to utilize citizen observations on aquatic NIS, since the risk of misidentification to other similar-looking species is low compared to more diverse areas.

Other limitations of citizen produced data arise from observer bias; the search effort differs between observers, observers may be geographically unevenly distributed and can fail to detect the species present (Fitzpatrick et al., 2009; Hochachka et al., 2012; Strien et al., 2013). Furthermore, the observers might have tendencies to report only species of interest, instead of reporting all species detected, leading to a potential reporting bias (Strien et al., 2013). Of these artefacts, geographical bias probably affected the most the outcomes of this study. The areas of recreational interest dictate where the species has been observed by citizens (e.g. close to the shores). Interestingly, coastal areas are currently monitored poorly and therefore citizen observations are particularly valuable.

The citizen observations of Harris mud crab were most frequent in the Archipelago Sea, which was expected as it was first detected in 2009 nearby Naantali (Fowler et al., 2013). This only partially reflects their actual range, since the coastal Archipelago Sea also holds the most leisure residencies in Finland (Official Statistics of Finland, 2017). Therefore, the recreational use of this area is also likely higher than for example the region of Satakunta, north of the Archipelago Sea. There are approximately 2,3 leisure residencies per km^2 in Satakunta, compared to almost 4,6 per km^2 in the Archipelago Sea. Additionally, leisure residencies in Satakunta are divided between inland and coastal residencies, whereas most leisure residencies in the Archipelago Sea are located closer to the coastline or on one of the over 40,000 islands.

The effect of observer bias in the study is relatively challenging to estimate based on the little additional information provided by the observers, but it is likely that it is low in the case of distinguishable species, such as Harris mud crab. However, when the species is either too small to detect or too challenging to identify, observer biases may result in poor data quality. On the other hand, reporting bias affects volunteer-based studies where the reporting of multiple species using a designated sampling protocol is required, but can be considered minimal if the observers report only the presence of the observed species as in our study. Harris mud crab appears charismatic in the Archipelago Sea and probably is over-reported by the non-trained recreationists compared to other NIS in the area.

It is essential to highlight that citizen observations on NIS alone, are obviously insufficient for monitoring of species presence or distribution. Furthermore, they rarely reveal information on species abundance or biomass. However, citizen observations serve as a great and cost-efficient addition complementing national monitoring efforts, especially in a situation where funding for national monitoring is inadequate. We compiled the research and monitoring observations from several different databases, but without citizen observations our view on the true frequency and spatial coverage of the species would be much thinner and less reliable. Citizen observations also revealed the secondary range of the crab from the autonomous region of Åland islands, where to Finnish national coastal monitoring efforts do not extend.

4.2. Distribution range

The quality of environmental monitoring and the study of the impacts of regional or global change on biodiversity have increased significantly with recent developments in technology, but often fail to provide continuous datasets for range expansion assessments (Devictor et al., 2010). Studies estimating the increase of spread for a species (e.g. Kotta et al., 2016) benefit from large amounts of data even with relatively low information content in comparison to low numbers of high-quality data (Munson et al., 2010). Citizen science can contribute to this type of studies by creating an opportunity for researchers to obtain large amounts of data at minimum cost (Hochachka et al., 2012). Furthermore, citizen observations are particularly useful to fill the gaps in the often-understudied fringe areas (Crall et al., 2012, 2015).

However, for proper range expansion assessments or species distribution models also absence data would be needed (Peron et al., 2016), which is not always possible to collect from non-trained recreationists. As the present study was not conducted with educated volunteers, active citizens can only report the presence of the species when they encounter them. Therefore, it is impossible to accurately measure the spatial coverage or annual range expansion of the species. Nevertheless, the Archipelago Sea is one of the most densely island-oriented archipelagos in the world (Finnish Environment Institute, 2018), and the monitoring of the entire area for species presence would require remarkable efforts from national researchers, not to mention the rest of the Finnish territorial waters. Citizen observations are a great addition to existing monitoring data, even though geographically biased presence-only data
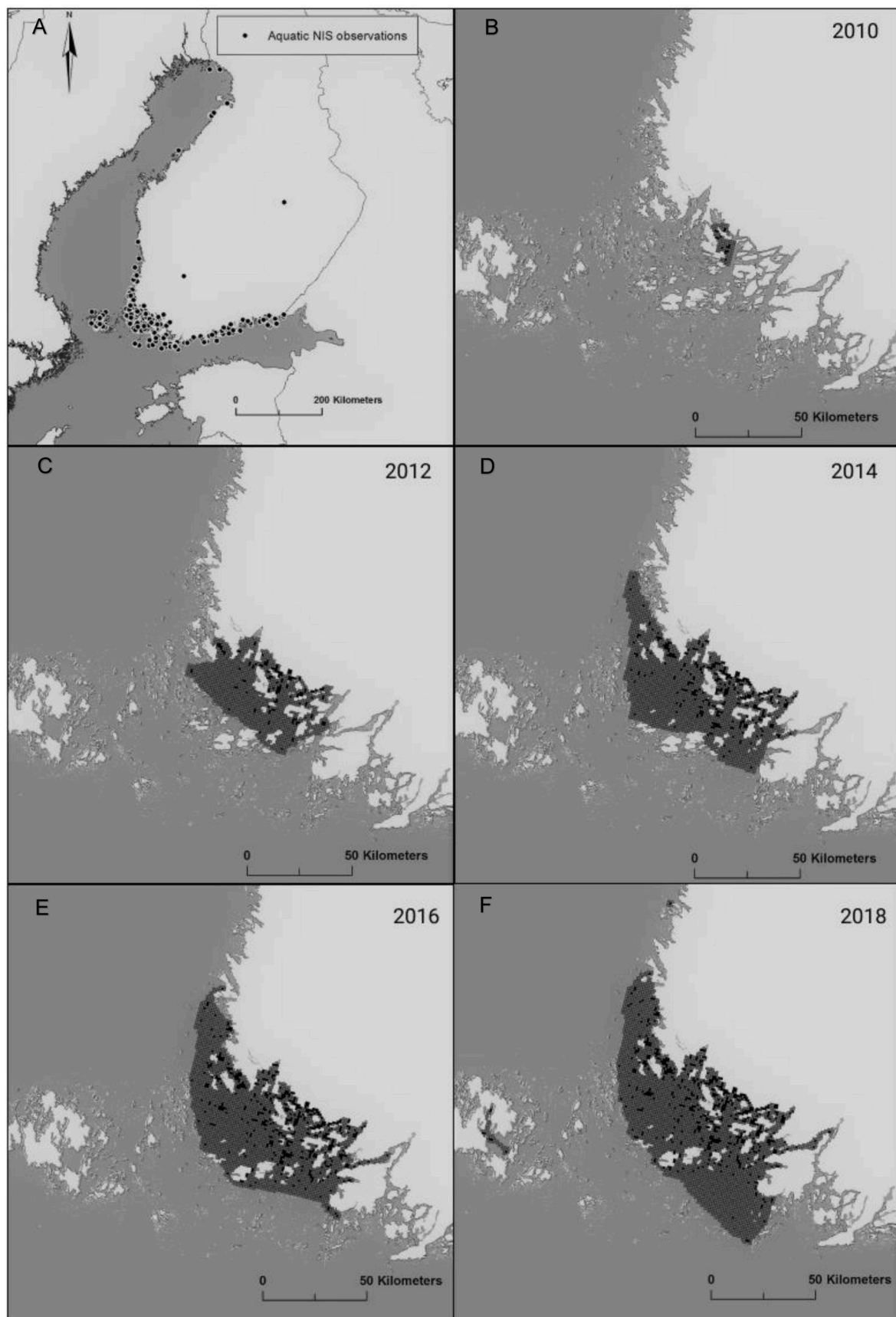
Fig. 4. A) presents the study area and all aquatic NIS observations from coastal habitats reported to the national IAS portal. B–F) are showing distribution maps for Harris mud crab *Rhithropanopeus harrisii* in Finnish waters between 2010 and 2018 after every two years. Black cells represent grids where the species was observed, and dark grey cells present the estimated range boundaries.

need to be evaluated with caution.

The species could be present virtually anywhere inside of the mapped areas, as the Archipelago Sea is relatively shallow with a mean depth of 23 m and the species has been found in all local habitat types including rocky, sandy and muddy bottoms, as well as unvegetated and vegetated areas (Fowler et al., 2013). Therefore, predictive modelling approaches (e.g. MaxEnt) would provide very little for future species range expansion estimation (see Liversage et al., 2019).

The mapped ranges for Harris mud crab were irregularly shaped, which is typical for species distribution areas (Kot et al., 1996). The range of the species presented here is probably relatively close to the true current range of the species in Finnish waters, as other aquatic NIS have been observed and reported to the portal from the surrounding areas in similar habitats (see Fig. 4A), nevertheless the Harris mud crab has not been reported there. The secondary range of the species in the Åland Islands is relatively new (first observation in 2017) and it will be interesting to see how the distribution of this population increases in the future. A few live individuals have been found from seaweed (*Fucus vesiculosus*) samples further north of the primary range area in the Olkiluoto nuclear power plant environment, and it remains to be seen if this population also spreads further.

Harris mud crab larvae are meroplanktonic migrating daily in a stratified flow pattern to avoid predation and limit horizontal passive transport (Cronin and Forward, 1986). In other words, the larvae are pelagic but tend to regulate natural transport, mainly to survive and remain in the preferred areas of the estuary. The relatively fast increase in distribution of Harris mud crab in the Archipelago Sea was probably due to spatial habitat heterogeneity and lack of competitors in the invaded area (Hastings et al., 2005). Overall, there are no native crab species in the Archipelago Sea and the area provides various types of sheltered habitats, as well as several sessile and mobile macro-invertebrates for Harris mud crab to feed on (Fowler et al., 2013; Forsström et al., 2015). Therefore, the latest range updates of Harris mud crab presented here seem to match relatively well the known habitat preferences of the species from invaded areas in the northern Baltic Sea (Nurkse et al., 2015; Riipinen et al., 2017).

5. Conclusions

Citizen science usefully contributes to the monitoring of NIS, but it is essential to remember that these types of data are not flawless, have inherent biases and do not translate directly to a precise range expansion assessment of a species. Still, citizen science can provide a cost-efficient practice to collect presence-only data on distinctly recognizable species, and often gives information that otherwise would be out of the reach of researchers and authorities. We have shown that citizen science may provide useful data, which can be utilized in targeting management e.g. eradication actions to stop further spread in vulnerable areas when IAS is concerned, and in reporting for national and international legislative requirements. Utilisation opportunities of citizen observations increase in species-poor environments where the chance of misidentification is low. The next step could be adding a possibility to report citizen observations on a larger, continental or global online portal, where NIS occurrences could be seen in different sea areas simultaneously and at a larger geographical scale (e.g. in AquaNIS portal, http://www.corpi.ku.lt/databases/index.php/aquanis/). Even though projects of this size are challenging and require more resources for verification, portals at least on a regional scale (e.g. Baltic Sea) could potentially enable assessments on behavioural patterns and detect causal connections of such species in various environmental conditions and ecosystems.

Credit author statement

All authors have participated in the research and article preparation; **Lehtiniemi** was responsible of the research (Conceptualization, supervision, Project administration), was a founder of the collection of the citizen observations, contributed to the ms writing and revision, and is responsible for the final format.

Outinen was responsible of the range expansion analyses (Visualization, Formal analysis) and contributed to the ms writing and revision.

Puntila-Dodd is responsible of the original idea to utilize citizen observations to assess NIS range expansions (Methodology), and she contributed to the ms writing and revision.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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