

Participatory mapping of invasive species: A demonstration in a coastal lagoon



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ABSTRACT

Invasive species are a growing driver of change across terrestrial and aquatic ecosystems but spatially-explicit information is seldom available for supporting management actions and decision making. Here we conceived and tested a new participatory method to map the distribution of three invasive species (*Callinectes sapidus*, *Procambarus clarkii* and *Oreochromis niloticus*) in the coastal lagoon of Lesina (Italy). Local fishers were asked to draw the distribution of each species on pre-printed maps, indicating districts of the lagoon characterized by different abundance levels. Then, maps were converted to a lattice grid and a Bayesian hierarchical Generalized Additive Modeling was adopted to model species distribution in the lagoon, calculating the coefficient of variation for model fitted values to map fishers agreement about the distribution of each species. We conceived new metrics to evaluate the quality of LEK-based participatory mapping in terms of agreement and consistency among experts. The resulting information provides new insights for spatially informed management across aquatic realms in relation to the increasing ecological and socio-economical pressures posed by biological invaders.

1. Introduction

Participatory mapping refers to a wide range of methodologies, whose general objective is to engage indigenous people in the elicitation of spatial information, compared to conventional cartography, where such information is derived from field measurements [40]. Participatory maps are increasingly employed for a variety of different applications, not only in natural resource management but also in many other domains [13]. Their outcomes can be particularly valuable to investigate patterns and processes fast enough to outrun large-scale ecological surveys, especially in contexts of limited data availability or when action is urgently needed. These conditions are common in conservation sciences, which have recently witnessed an outburst of participatory mapping initiatives throughout the world, in both developing and developed countries [7,13,56]. In fact, information extracted from the knowledge of people living in close relationship with the natural environment can complement, or even replace, ecological sampling, at various spatial and temporal scales [5,16,17]. This expert knowledge, often reported as ‘Local Ecological Knowledge’ (LEK) is currently accessed to estimate a variety of biological and ecological parameters

[20,37,59] in both terrestrial and aquatic systems, where ecological monitoring is particularly demanding [51]. LEK-based surveys indeed overcome the pragmatic constraints that hamper investigating the distribution of aquatic organisms [41], including aquatic invasive species (AIS) [3,4]. These methodologies provide fresh new inputs to conventional cartography [30] and may truly serve the needs of Marine Protected Areas [45], coral reef management [38]; fishing management [35] and provide key information for the conservation of marine [18] and freshwater [53] ecosystems.

Nevertheless, although LEK has been employed to reconstruct invasion dynamics and to investigate temporal variations in invasive species [3], participatory mapping is seldom applied to invasive species [14, 54], especially in aquatic systems where, to the best of our knowledge, no real attempts have been made [54].

This absence probably stems from the skepticism of many conservationists about LEK itself and from their limited experience with these approaches: LEK-based studies, although growing, are relatively recent and play a minor role in conservation. Local experts are often perceived as less “objective” than ecological surveys and many researchers tend to adopt LEK only to complement “real” data obtained from the field.

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Moreover, participatory mapping also requires experience with cartography and research methods from the social sciences (e.g. interviews), further complicating its adoption by the scientific community.

This gap needs to be filled, particularly for invasive species that are a major driver of change [60] and knowing their distribution is considered a priority for conservation planning and adaptation in both terrestrial [24,48] and aquatic systems [31].

A further problem is that, whilst the potential of eliciting information from single experts appears to be large, the quality and validity of the observational data needs to be properly addressed through structured elicitation protocols and appropriate data processing. This aspect is of key importance to improve the accuracy and transparency when expert judgments are used to inform science [32,50].

In this study, we aim to offer a first answer to this need. We tested a participatory mapping methodology with the aim of providing spatially-explicit information on the distribution and abundance of three AIS occurring in a Mediterranean coastal lagoon: *Callinectes sapidus*, *Procambarus clarkii* and *Oreochromis niloticus*. In absence of complementary field data, statistical modeling is employed to measure agreement among experts, providing a first assessment for self-reported spatial data.

2. Materials and methods

2.1. Study area and target species

The Lesina lagoon (Fig. 1), located along the south-western Adriatic coasts (Apulia region, Italy) is a micro-tidal coastal lagoon, characterized by brackish waters (area: 51.4 km²; average depth: 0.7 m; salinity: 11–34 psu; temperature: 7–26 °C) and surrounded by a mosaic of intensive farmlands, urbanized areas, salt marshes and coastal dunes. The lagoon hosts a little community of small-scale fishers that once relied mostly on the European eel (*Anguilla anguilla*) [8], while today they mostly exploit sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*; [12,46]).

Various AIS are currently established in the lagoon, notably the Atlantic blue crab (*Callinectes sapidus*), the red swamp crayfish (*Procambarus clarkii*) and the Nile tilapia (*Oreochromis niloticus*) [21]. All these three species can develop abundant populations, with severe ecological and economic impacts [10,22,25,44,57], but spatial-explicit information is currently unavailable for the Lesina lagoon [21].

2.2. Data collection

Interviews were carried out from February to April 2018. Expert fishers, operating in the Lesina lagoon, were identified through

snowballing and recruited only after having evaluated their experience and availability to share knowledge [15]. This was accomplished by contacting fishers recommended by other expert fishers, substantiating their pluriannual experience and testing their familiarity with the target species.

At the beginning of each interview, the interviewer explained the aims of the study, and respondents agreed to provide information for scientific purposes.

The interview focused on two invasive crustaceans, *C. sapidus*, *P. clarkii*, and one fish, *O. niloticus*, checking for their correct identification through pictures and field guides.

Spatial information was extracted through a *sketch mapping* approach [42], sometimes referred as mental mapping, a method for representing “free drawing” from memory (see also [28]). Fishers were provided with pre-printed maps of the lagoon and they were asked to draw where each species was distributed, indicating with demarcation lines districts of the lagoon characterized by homogeneous levels of abundance. The abundance of each species was rated on an ordinal scale provided by [3, 4] and referred to the fishing period: 0 = *Absent*; 1 = *Rare* (once in a year); 2 = *Occasional* (sometimes in a year); 3 = *Common* (regularly in a year); 4 = *Abundant* (regularly in captures and abundant); 5 = *Dominant* (always in captures and with great abundance). Participatory mapping took approximately 15 min for each participating expert. Following a standard LEK protocol [3,4] we also collected temporal data to trace back the history of these invasions but these data were not presented here.

2.3. Geographical representations and statistical analysis

Each sketch map drawn by the fishers on paper was georeferenced by overlaying a lattice grid (N. 248 cells of 500 × 500 m), obtaining a regular grid of cells with associated values of perceived abundance for the three species.

We mapped the perceived abundance of the three species, and also evaluated the quality of information at hand by means of Bayesian hierarchical models. Notably, we fit a Generalized Additive Mixed Model (GAMM), accounting for differences between fishers in the perceived average abundance of each species, through a random intercept term. Following Plant [52], we modeled the spatial variation in perceived abundance by de-trending for the effect of the latitude and longitude of each cell through a nonparametric random walk term, and then by accounting for the similarity between neighboring cells through a Besag-York-Mollié structure [49,61]. We compared model with and without BYM structure through the Deviance Information Criterion (DIC) and the Widely Applicable Information Criterion (WAIC), deeming models to be more suitable to the data, in case the BYM structure

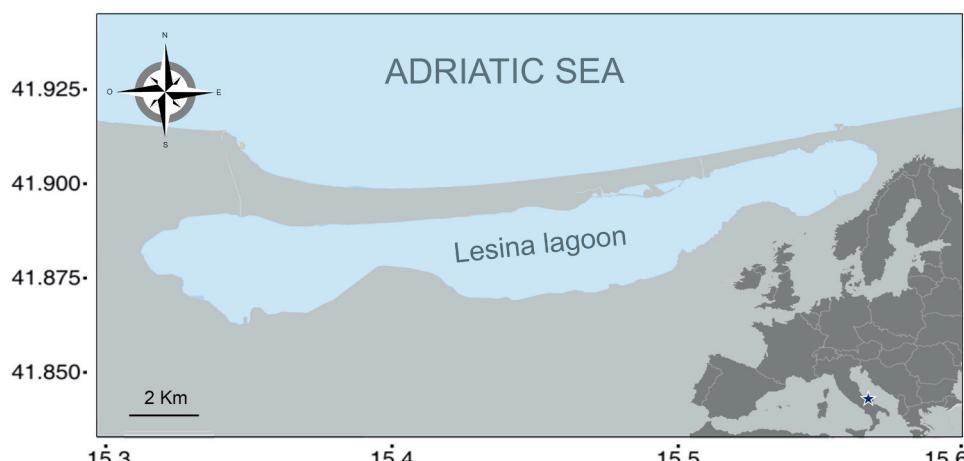


Fig. 1. Map of the study area in the Apulia region (Italy): the Lesina lagoon.

decreased fitness indexes by more than 10 points [62]. Although our data were measured through an ordinal scale, we treated them as if they were generated by a continuous Skewed-Gaussian distribution. We mapped predicted abundance for each cell of the grid, to assess the perceived distribution and abundance of each species in the lagoon.

To measure the level of uncertainty in fishers' evaluation of abundance, as well as about their spatial distribution, we calculated the coefficient of variation (CV) for the predicted values of the model, expressed as the ratio between the standard deviation of predicted values and their average value, for each cell of the grid. The coefficient indicated the relative uncertainty about the abundance of the various species in each cell, ranging between 1 and 100. We plotted CV for each cell of the grid, to map spatial gradients in uncertainty about species abundance and we compared the distribution of the CV between the three species, to appreciate species-specific differences in fishers uncertainty.

Distribution maps were digitalized with QGis (Quantum GIS, 2019) and statistical analyses were carried out with R (R Core Team 2019) and INLA [39]. A complete reproducible dataset and a software code is available on OSF (<https://osf.io/pgjy5/>).

3. Results

Overall, we recruited a total of 25 expert fishers, who unambiguously identified the three species and were able to draw their spatial distribution on the maps. Considering that the community of fishers of the Lesina lagoon is estimated to number about 40 people [8], our interviews covered more than half of the available population. They were 22 professional and 3 recreational fishers, all men, and their age was 50.4 years. Taken together, respondents' experience accounted for a total of 914 years of observations in the lagoon, and average experience was 36.6 years. Three main fishing gears were used by the respondent, mostly trammel nets (23 respondents); traps (21 respondents) and fish weirs locally called 'bertovelli' (9 respondents).

Overall, predicted values from the model (Tables 1 and 2) show that the Atlantic blue crab *C. sapidus* is deemed to have colonized the entire lagoon, with high abundance (Fig. 2, Table 3).

The analysis of the spatial distribution of the CV also indicates that fishers became more uncertain about the species' abundance when considering those part of the lagoon where species were less abundant (Fig. 3). For example, uncertainty about the abundance of *O. niloticus* peaked for that part of the lagoon which was far away from the freshwater inputs where the species was believed to occur.

The analysis of the distribution of CV of the various cells, also revealed differences in fishers' uncertainty about the abundance of each species (Fig. 4): respondents had little uncertainty about the abundance of *C. sapidus* (median CV = 3.9%), but they were more uncertain about *P. clarkii* (median CV = 19.9%) and even more about *O. niloticus* (median CV = 18.4%).

Having treated our ordinal scale as a continuous response, ranging between 0 and 5, predicted values from our model occasionally exceeded the upper interval of the scale (e.g. Fig. 2 for *C. sapidus*, where fitted values had a maximum of about 5.5). However, this did not preclude the interpretation of the map, as our predicted values made the gradient in

Table 1

Fitness indexes of the models without spatial correlation and with a Besag-York-Mollié (BYM) correlation structure: widely applicable information criterion (WAIC), deviance information criterion (DIC).

	WAIC		DIC	
	No spatial correlation	BYM	No spatial correlation	No BYM
<i>C. sapidus</i>	11,439.75	11,364.08	11,434.77	11,341.43
<i>P. clarkii</i>	11,005.16	10,951.95	11,025.91	11,002.19
<i>O. niloticus</i>	10,670.90	10,609.98	10,692.33	10,659.49

Table 2

Coefficients of the generalized additive models for the three species.

Variable	Mean	Lower quartile	Upper quartile
<i>C. sapidus</i>			
Intercept	4.25	3.97	4.59
Precision: longitude	6.85	0.89	0.19
Precision: latitude	17900.00	1296.70	66,500.00
Precision: respondent	2.24	1.736	3.07
<i>P. clarkii</i>			
Variabile	Mean	Lower quartile	Upper quartile
Intercept	0.72	0.503	0.935
Precision: longitude	13,500.00	463.570	55,800.00
Precision: latitude	367.00	29.476	1800.00
Precision: respondent	5.07	2.280	8.80
<i>O. niloticus</i>			
Variabile	Mean	Lower quartile	Upper quartile
Intercept	1.706	1.117	1.294
Precision: longitude	13,800.00	293.089	57,400.00
Precision: latitude	6870.00	725.930	21,300.00
Precision: respondent	0.48	0.24	0.78

the abundance of the three species clear. Values that exceeded the value of 5 should be considered as corresponding to the maximum value of the scale.

4. Discussion

Here we adopted the practice of mental mapping, which plays an important role in geography [6], but which has never been applied before to the study of biological invaders. Therefore, this study provides a first demonstration that LEK could represent a valuable source of information for the participatory mapping of non indigenous species. We showed how spatially explicit LEK, collected from multiple experts without deliberation, can be evaluated by researchers, in terms of ecological plausibility and in terms of differences in expert evaluations.

Through face-to-face interviews we enabled local experts to project their mental maps into a georeferenced space. Drawing demarcation lines on a pre-printed map of the lagoon was a very easy task for the small-scale fishers of Lesina, requiring minimum assistance from researchers. We believe that, due to its simplicity, this approach can be suitable for broad adoption across different cultures and social contexts (including those with reduced literacy), this aspect being a key requisite for large scale monitoring and planning [1]. For these reasons, participatory mapping is worth exploring in those aquatic environments where tracing the abundance and spatial distribution of species is particularly difficult [26,36] and where biological invasions typically outrun ecological sampling with consequent lags in the information chain (*sensu* [2]). Another benefit of this method is that participants were actively involved in the research framework, which is one of the core themes for co-management and informational governance [33,43].

Our study took sketch mapping one step further, as we translated a hand-drawn map into a discrete grid of values, which could be analyzed quantitatively as lattice data to: i) summarize fishers' judgments through statistical modeling, testing for the ecological significance of spatial patterns, and ii) highlight species-specific differences and spatial patterns in fishers' uncertainty.

Summarizing experts' judgments through statistical modeling was a parsimonious approach to explore spatial patterns of abundance. Fitting a hierarchical model provided us with a map of fitted values for the abundance of the three species, enabling us to test if these patterns aligned with species-specific ecological requirements. This method allowed us to check the reliability of LEK data, in absence of other kind of spatial information about the distribution of species, and it requires summarizing observed data with a statistical model. In this study, the spatial distribution and abundance of the three species in the lagoon aligned well with their ecological requirements. Indeed *C. sapidus* was reported to be generally widespread, as expected for a marine species in

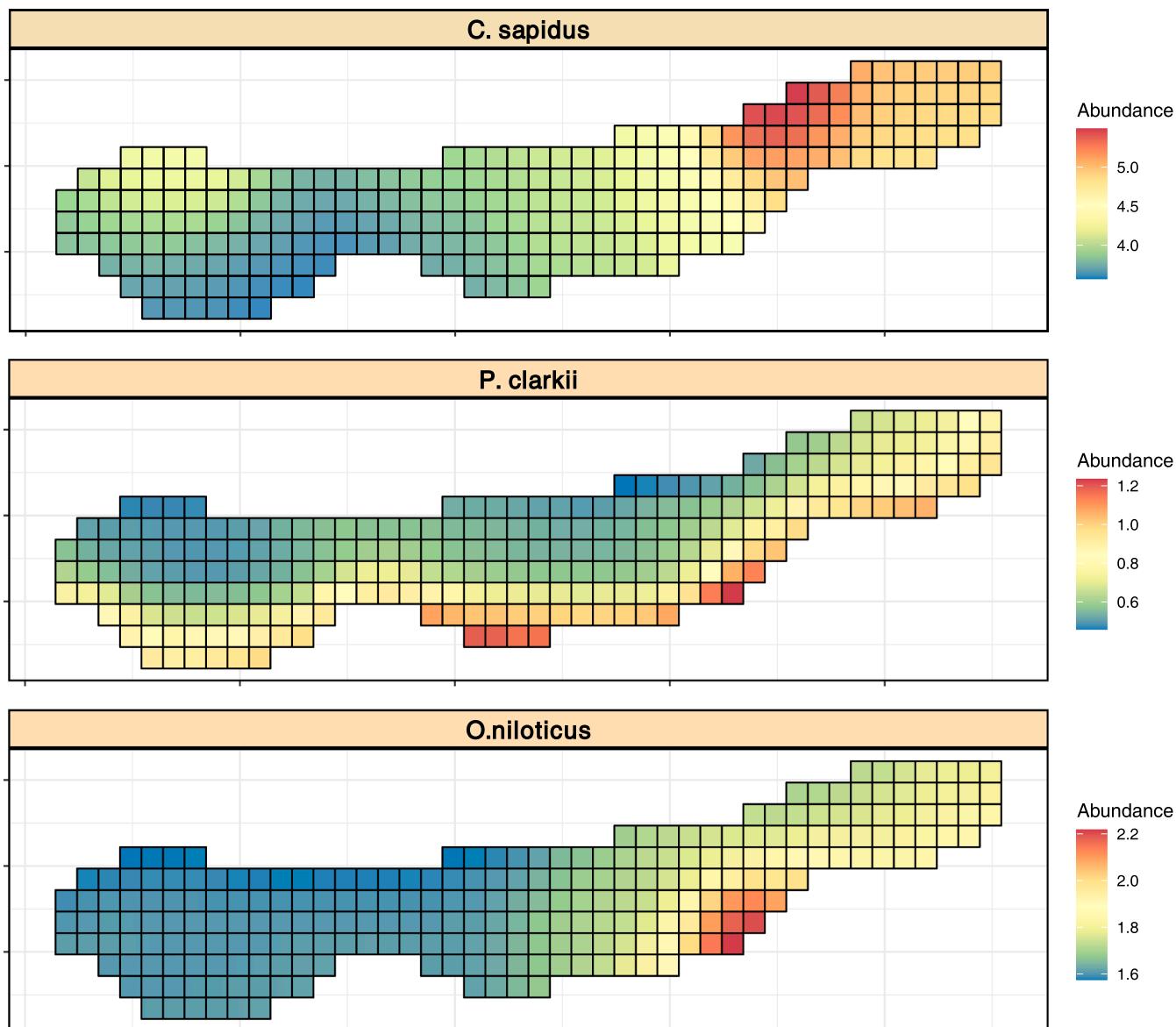


Fig. 2. Perceived abundances of three exotic species in the Lesina lagoon. Predicted values from the spatially-correlated models: *C. sapidus* (a), *P. clarkii* (b) and *O. niloticus* (c). Abundances ranged from 0 = "Absent", 1 = "Rare", 2 = "Occasional", 3 = "Common", 4 = "Abundant" to 5 = "Dominant". Values exceeding 5 (dark red) should be considered as corresponding to the maximum value of the scale). Note the different scale used in the three maps to appreciate the considerable differences in perceived abundance, with *C. sapidus* being much more abundant than *P. clarkii* and *O. niloticus*.

Table 3

Perceived abundances of three exotic species in the Lesina lagoon. Values are expressed as percentage of the total area according to the six classes of Abundance, from "Absent" to "Dominant".

Species	Absent	Rare	Occasional	Common	Abundant	Dominant
<i>C. sapidus</i>	0	4.6	11	25.8	37.4	21.2
<i>P. clarkii</i>	77.6	1.3	10.1	4.0	3.6	3.4
<i>O. niloticus</i>	51.1	13.1	13.2	3.9	11.6	7.1

a brackish lagoon, and more abundant close to the area of the lagoon with a saltmarsh, rich in aquatic plants that are important as nurseries [58]. On the contrary, *P. clarkii* and *O. niloticus* were reported to occur at low abundance and only close to freshwater inputs from the inland, as it would be expected given their low tolerance to high salinities which in the lagoon exceed the limits of the two species, *P. clarkii* and *O. niloticus* [9].

Analyzing the CV of model predictions also revealed differences in expert judgments about the three species. Appreciating these differences

might be important to quantify the reliability of abundance estimates and decide whether to adopt the extracted knowledge as a source of information. We found that the agreement was very high for *C. sapidus* while it decreased for *P. clarkii* and *O. niloticus*. We therefore considered that the maps for *C. sapidus* were highly reliable. At the same time, appropriate metrics to evaluate the reliability of information related to *P. clarkii* and *O. niloticus* were provided in a clear and objective way. These species-specific differences in expert evaluations can have multiple explanations. For example, we should consider that different

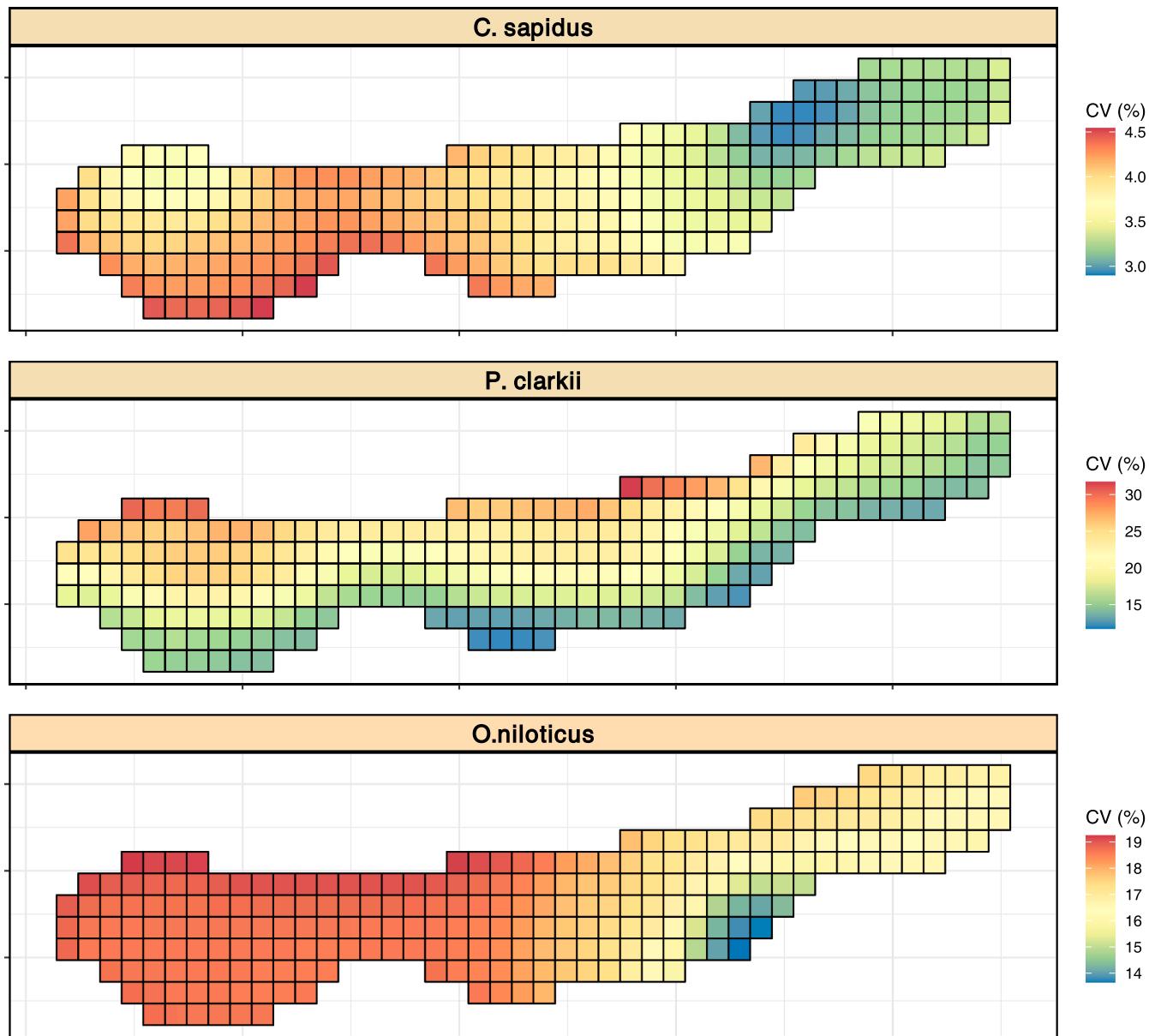


Fig. 3. Coefficient of variation of predicted values from the spatially correlated models: *C. sapidus* (a), *P. clarkii* (b) and *O. niloticus* (c). The coefficient of variation ranges between 0% and 100%.

species could be characterized by different levels of detectability [3] and the observational processes which generate the individual's ecological knowledge of an individual is influenced by a variety of on-ground conditions [34], with visible variations along the spatial scale, as illustrated by our geographical projections of CV (Fig. 3). Also, as a hierarchical model produces higher values of the CV for those cells where abundance scores were more heterogeneous, mapping the spatial distribution of the CV of model prediction can highlight spatial patterns in expert disagreement. Few LEK-based studies focus on expert disagreement, which could nevertheless be fundamental for assessing the quality of LEK [17]. In participatory mapping, identifying those areas where respondents' evaluations differ, might be highly informative about the observational process behind LEK and important for its integration with ecological surveys. In our case study, the CV of model predictions had a relatively scarce spatial variation, because the lagoon was shallow and small, with respondents that moved across it homogeneously. However, larger areas, deeper waters, or heterogeneous seabeds, could lead fishers exploiting different habitats and using different types of fishing gears

with consequent variation in individual knowledge and appreciation of fishing resources [27]. This would result in variable levels of disagreement about species distribution and abundance, and in higher values of the CV.

Our approach also mitigates one major flaw of interviews and questionnaires for expert elicitation, namely the lack of deliberation between experts. Deliberation is fundamental to understand if, how much, and why experts agree over a certain topic [32,37]. Unfortunately, when experts are not gathered together, like in many LEK studies based on interviews, deliberation does not occur and most researchers deem impossible to evaluate the information at hand. We showed that this idea is misleading: through statistical modeling it is possible to partially evaluate what is elicited from experts. In our case we found coherent spatial patterns in the evaluation of the abundance of the three species in the lagoon which, for *C. sapidus*, also had relatively modest errors of prediction. The LEK generated information about *C. sapidus* was therefore deemed to be highly reliable for ecological mapping. Our case study focused on participatory mapping but we believe that a similar

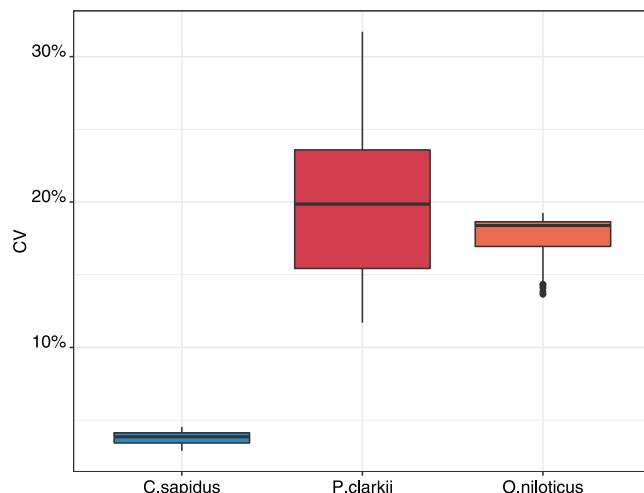


Fig. 4. Distribution of the coefficient of variation (CV) of predicted values from the spatially correlated models for the three species. The coefficient of variation ranges between 0% and 100%.

approach can also be potentially useful for evaluating time-series and other kind of LEK-generated information.

It must be acknowledged that our case study also has some clear simplifications. First and foremost the scale and the accessibility of the study area: the Lesina lagoon is relatively small (51.4 km^2) and shallow with fishers operating across the entire area. This enabled us to easily combine multiple distribution maps and to compare expert LEK, but future research could develop participatory mapping protocols combining experts with partially overlapped fishing areas. Also worth exploring is the extent to which confidence in LEK varies at increasing distances from the core fishing area.

5. Conclusions

Much evolution has taken place in the theory and practice of participatory science and expert engagement in conservation biology [19,47]. Many different methods, such matrix scoring, causal-linkage or diagramming, have been adopted and used by conservationists all over the world. Due to the need for spatially explicit information in invasive species monitoring and management, our experience highlights the potential benefits that could result from a structured participatory mapping methodology based on a rigorous and transparent evaluation of LEK-generated information. Improving the scientific quality of spatial representations, such practices could be better and more widely used for the needs of conservation and adaptive management in a period of rapid ecological changes.

CRediT authorship contribution statement

Ernesto Azzurro: Conceptualization, Methodology, Data curation, Writing, Supervision. **Jacopo Cerri:** Statistical analyses, Data curation, Conceptualization, Data analysis, Writing.

Ethical statement

Data collection was confidential, as interviewers did not record any sensitive personal information about respondents. At the beginning of the interview, respondents were informed about the purposes of the study and gave informed consensus to use the provided information for scientific purposes.

Declaration of Competing Interest

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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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2021.104412](https://doi.org/10.1016/j.marpol.2021.104412).

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