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Advances in life-history knowledge for 35 seahorse species from community science

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[Corrections added on 23 May 2025, after first online publication: The spelling of the co-author Amanda C.J. Vincent's name has been corrected in this version.]

Abstract

Marine community science presents an important route to gather valuable scientific information while also influencing local management and policy, thus contributing to marine conservation efforts. Because seahorses are cryptic but charismatic species, they are good candidates for engaging diverse people to help overcome the many gaps in biological knowledge. We have synthesized information contributed to the community science project iSeahorse from October 2013 to April 2022 for 35 of 46 known seahorse species. We then compared the obtained results with information in existing IUCN Red List assessments, executed from 2014 to 2017, to explore the potential of iSeahorse in expanding seahorse knowledge. Our results show updated geographic ranges for 7 seahorse species, new habitats described for 24 species, observations outside the previously recorded depth range for 14 species, and new information on sex ratio for 15 species and on pregnancy seasonality for 11 species. As one example of the power of iSeahorse, contributed observations on Coleman's pygmy seahorse (*Hippocampus colemani*) indicated that its geographic range is thousands of square kilometers larger, its habitat more diverse, and its depth range shallower than previously known. It is clear that iSeahorse is expanding knowledge on seahorses to a level that will help improve IUCN Red List assessments. The power of community science for marine conservation in general needs to be fully explored.

KEYWORDS
citizen science, community science, geographic distribution, IUCN Red List, life history, seahorses

1 | INTRODUCTION

Significant changes in marine biodiversity occur due to overexploitation (Jackson et al., 2001), habitat destruction (Pan et al., 2013), pollution (Löhr et al., 2017), and climate change (Easman et al., 2018). Although one of the greatest pressures comes from mismanaged fisheries (Butchart et al., 2010), humans are also generating worrying levels of damage and degradation in marine coastal habitats (Assessment, 2005; Crain et al., 2009). Such areas of seagrasses, corals, mangroves, and macroalgae are highly productive and biologically diverse (Pan et al., 2013). Climate change is also a main driver of range shifts for a number of marine species, affecting conservation and management planning (Donelson et al., 2019). In addition, the introduction of exotic species can have dire effects on populations of endemic species (Anton et al., 2019).

Marine conservation is impaired by a lack of knowledge about most marine life and the lack of resources to study it sufficiently in time and space. Most existing conservation assessments focus on a small subset of target species, primarily restricted by the enormous scale that entails assessing global marine biodiversity (Sala & Knowlton, 2006). The result is a knowledge gap that limits understanding of the processes that affect ocean biology (Morrison et al., 2013). Such limitations constrain efforts to achieve better management of marine ecosystems and a more sustainable use of the ocean (Assessment, 2005). At present, 20,835 of the 150,388 species that have been assessed are classified as Data Deficient in the IUCN Red List, which lacks important information on life histories, geographic distributions, habitat uses, and population dynamics of species.

Marine community science presents an important potential source to gather valuable scientific information (Cigliano et al., 2015), by improving engagement and efforts in marine conservation around the globe (Kelly et al., 2020). Marine community science has the potential to expand the capacity for data collection (Martin et al., 2016), while also influencing local management and policy, and thus contributing to marine conservation efforts (Conrad & Hilchey, 2011; Hyder et al., 2015; Vann-Sander et al., 2016). The importance of community science in achieving these goals is highlighted by successful projects such as Seasearch (based in the UK), where community science was used to support marine protected areas (MPAs) and identify priority species (Hyder et al., 2015). Another good example is Redmap, which collects data on climate-induced shifts in marine species distributions, resulting in over 25 scientific publications on marine climate change (Kelly et al., 2020). Community science may be particularly promising and valuable for charismatic species, which are able to engage a wide set of contributors and prompt more conservation measures (Fontaine et al., 2022).

Seahorses are species of great conservation concern and iconic value as flagship species. These peculiar fishes have been successfully used to help generate MPAs, modify fisheries management, and regulate wildlife trade (Vincent et al., 2011). Seahorses live in coastal areas (Scales, 2010; Vincent et al., 2011; Yasué et al., 2012), with patchy and sparse distributions, small home ranges, low mobility, low fecundity, lengthy parental care, and mate fidelity (Foster & Vincent, 2004). Such life-history characteristics make them vulnerable to anthropogenic disturbances and must be better understood for effective conservation. Despite growing research activity, one-third ($n = 17$) of the currently described 46 seahorse species (Lourie, 2016; Short et al., 2018; Short et al., 2020) is classified as "Data Deficient" according to the latest IUCN Red List assessments (Pollom et al., 2021; IUCN, 2022a).

In 2013, Project Seahorse created iSeahorse, a tool for seahorse science and conservation that is now hosted by iNaturalist. By harnessing the power of "citizen/community scientists," it aims to improve our understanding of these animals and protect them from overfishing and other threats. iSeahorse is a publicly accessible online platform that collects biological and ecological information on seahorse species. Species identification is validated by experts in Seahorse taxonomy, and contributed data can shed light on the distribution, habitat uses, and life history of all species. Researchers can use this information to better understand seahorse behavior and species ranges. Such knowledge can then be used to improve seahorse conservation across the globe.

Our study analyses data gathered on the iSeahorse online platform, compares them with previous IUCN Red List assessments, and assesses the expansion of current knowledge of seahorse biology and ecology. We explore what iSeahorse information can add to the existing knowledge of seahorses. We also use new data from this research (and from other research conducted during the past 10 years) to update IUCN Red List assessments, which are commonly done every 10 years or earlier. Such analyses allow us to evaluate the utility of community science data on seahorses for improved seahorse conservation.

2 | METHODS

2.1 | Data compilation

Data were collated from the iSeahorse database, which is a project hosted on the online iNaturalist platform (https://www.inaturalist.org/projects/iseahorse). We downloaded all available observations on May 18, 2022, and filtered the data by date, including only the observations recorded before April 30, 2022. The resulting downloaded dataset contained 8558 observations initially, of presence-only data from 36 different species.

The 8558 observations were submitted from all around the world by people with scientific and nonscientific backgrounds. Ideally, each observation included a set of standard fields used by iNaturalist, which provided information such as proposed species identification, a picture of the specimen observed (to help validate species identification), date and time of specimen observation, and a geographic location.

When they submitted observations, participants were invited to answer 15 optional questions (Annex 1). From these, the answers from three of the 15 questions were used for this analysis: (1) What was the seahorse(s)' habitat? (2) At what depth (m) did you find the seahorse(s)? (3) What were you doing when you saw the seahorse(s): underwater, fishing, on land?

2.2 | Data validation

We created a standard protocol for data validation to maintain uniformity in the dataset. The validation aimed to determine which data to use, improve data quality, and find and fix errors in the dataset.

Initially, all observations of species that were not in the genus *Hippocampus* or that were clearly of specimens from aquariums (e.g., mentioned in the observations caption, location recorded on land, or was visible in the photo that the specimen was in an aquarium) were excluded from the dataset. The next step was to review the observations that iNaturalist had flagged as "Casual" or "Needs ID." Observations are flagged in iNaturalist as "Casual" if the observation lacks important information (e.g., photo of the specimen or GPS location) and as "Needs ID" if the specimen identification has not yet been validated or if an agreement has not been reached within the iNaturalist community; this process is the "data quality assessment" (iNaturalist). We reviewed all observations flagged as "Casual" and "Needs ID" and categorized them based on the respective issues. Data can be categorized as Confident, Missing Location, Location on Land, and No Confident ID, among others. Observations with "No Confident ID" were discarded and not used for the study.

Some of the observations flagged as "Needs ID" were later identified by one of the authors (E.C.) and recategorized as "Confident." Observations with only missing dates and/or locations were included in the study but excluded from the respective temporal and spatial analysis. All remaining observations, and those categorized as "Research Grade" in iNaturalist, were qualified as "Confident" and used in this study. For all the "Research Grade" observations, the ID had previously been verified by staff members of iSeahorse.

When proceeding with geographical data validation, all selected observations were initially displayed on ArcMap GIS desktop (ESRI, 2011) to detect any signs of inaccuracy. We doubted the accuracy of a certain location for three main reasons: (1) unlikely co-ordinate values (e.g., 0,0); (2) problematic position relative to the map (e.g., at the middle of the ocean or at the center of a country or continent); (3) overly large distance from the species' known geographical distribution (e.g., *Hippocampus guttulatus* Cuvier, 1829, a Mediterranean and Northeast Atlantic species purportedly located in the Caribbean Sea). In these cases, we reviewed the original observation on the iNaturalist website and established an accurate identification. In the case of a recently submitted observation, we generally asked the contributor to verify the location. When an accurate location could not be obtained, the observation was categorized as "Missing Location" in our dataset and discarded from analyses.

All observations that were reported as coming from outside the previously known range, as described in the species' IUCN Red List assessment, were validated by a seahorse taxonomy expert from the IUCN SSC Seahorse, Pipefish, and Seadragon Specialist Group. Once the new identification was definite, we checked whether the reported location was plausible (close to the previously described range or in an area where the animal could habit) and/or whether there were similar records of occurrence of that species in resources other than scientific publications (e.g., gray literature).

iNaturalist has an "obscured" feature that hides, for the protection of traded species, the precise location and generates a random co-ordinate inside a 0.2 × 0.2° cell (iNaturalist, 2022). As the size of these cells will change with latitude, we considered them to be about 20 × 20 km^2 (which is the size when closer to the equator, where most seahorses are found). Whether the observation had an obscured or unobscured location depended on whether or not the contributor had granted permission to see the true location. Some obscured observations created co-ordinates located on land but within 20 km from a body of water. These observations were still used, as the true (unobscured) location could certainly have been in the water. However, co-ordinates located more than 20 km from a body of water were considered unreliable, were not included in the distribution maps, and were categorized as a "Location on Land" in the dataset.

2.3 | iSeahorse data analysis

We undertook an extensive descriptive analysis of all data obtained from the iSeahorse online platform, using visualization tools within RStudio (RStudio Team, 2022) and the ggplot2 package (Wickham, 2016). Our analysis started with a light descriptive analysis of the number of observations (*n*) per species and per data category. We also executed a visualization of the temporal distribution for each of the recorded seahorse species and calculated the response rate for each of the 15 questions asked (Annex 1) during the submission process in iNaturalist.

We compared our results with the latest IUCN Red List assessment publicly available at the time of the study (dating from 2014 to 2017, depending on the species; www.iucnredlist.org) and created summary tables for each trait studied (i.e., geographic distribution, habitat, depth, sex and pregnancy seasonality).

2.3.1 | Geographic distribution

For each species, we mapped distribution (areas where you can find the species) and determined the extent of occurrence (EOO), a parameter that measures the spatial spread of a taxon (Mapping Standards and Data Quality for the IUCN Red List Spatial Data, 2021). It is calculated as the area of a minimum convex polygon that encompasses all the observations, using ArcMap GIS v. 10. For these calculations we also used the obscured observations that appear on land within 20 km from the body of water. For species with 200 iSeahorse observations or more, we created a distribution map and calculated the cumulative EOO per year (starting from the year when the species was last assessed) to observe potential expansions in distribution. We deployed the recommended tool by IUCN, "IUCN EOO Calculator v1_5" (IUCN EOO Calculator, toolbox version 1.5, IUCN-Red List Team, 2015), to determine the EOO and used the model builder tool of ArcMap GIS to obtain the cumulative EOO per year for each species.

For each species, we overlapped iSeahorse-generated geographical distribution with the IUCN Red List distribution maps, using ArcMap GIS. The distribution maps from IUCN were downloaded as polygon-based spatial data from the IUCN individual species webpages. Our objective was to compare the two distributions and identify possible range expansions compared to the last IUCN Red List assessment.

2.3.2 | Habitat

For observations that included habitat data, we calculated the relative proportions in which each category of habitat was reported per

TABLE 1 Habitat categories from iSeahorse and most closely matching habitat categories in the IUCN Red List.

Habitat categories translation	
iSeahorse	**IUCN Red List**
Artificial	15.11 Artificial/Marine—Marine Anthropogenic Structures + 15.12 Artificial/Marine—Mariculture Cages
Coral	9.8 Marine Neritic—Coral Reef
Drifting while attached	No equivalent found
Mangrove	12.7 Mangrove Submerged Roots
Mud	9.6 Marine Neritic—Subtidal Muddy
Open water	No equivalent found
Other (shells, etc.)	9.3 Marine Neritic—Subtidal Loose Rock/Pebble/Gravel
Rock	9.2 Marine Neritic—Subtidal Rock and Rocky Reefs
Rubble	9.3 Marine Neritic—Subtidal Loose Rock/Pebble/Gravel
Sand	9.4 Marine Neritic—Subtidal Sandy
Seagrass	9.9 Marine Neritic—Seagrass (Submerged)
Seaweed/algae	9.7 Marine Neritic—Macroalga/Kelp
Unknown	No equivalent found

species. For reports of habitats that looked unusual for a given species, we reviewed the photo observation and corrected the category if necessary.

The iSeahorse habitat categories were translated to the corresponding IUCN Red List habitat categories (Table 1). We compared the habitats reported in iSeahorse to the identified habitat use per species in its last IUCN Red List assessment.

2.3.3 | Depth

Depth information (in meters) was retrieved from iSeahorse database and used to calculate maximum (max), minimum (min), mean depths, and S.D. for each species. Any extreme or suspicious depths in iSeahorse data were reviewed to see if the observer mentioned how they had been measured and if these were plausible values for that species compared to the known ranges. Depth limits identified from the iSeahorse data analysis were compared to those mentioned in the IUCN Red List assessments.

2.3.4 | Sex and pregnancy seasonality

One of the authors with experience in seahorse field research (M.C.) identified the sex of the seahorse in each photograph submitted and, if a male, the pregnancy state. We then calculated the sex ratio of seahorses. Only verified males and females were used for calculating the sex ratio, and all other observations were discarded (e.g., juveniles or pictures where sex could not be determined). This process was very laborious and time consuming and, therefore, was completed only for 15 species. These species were the ones with the lowest number of observations with photographs (up to *Hippocampus ingens* Girard, 1858, which had 172 observations with photographs). However, we did not include pygmy seahorses as it is too difficult to determine their sex reliably from photographs.

We compared the dates on which pregnant males were observed against the mentioned seasonality in the IUCN Red List assessments, where it was available. In cases where this information was missing, we looked at other sources, such as taxonomy guides (Lourie et al., 2004) and published articles, to be able to compare results.

2.3.5 | Ethics statement

No animal testing was performed during this study.

3 | RESULTS

The resulting downloaded dataset contained 8558 observations initially, of presence-only data from 36 different species. From these, 642 observations were missing basic information (such as ID, location, photo, or date). After our validation process, we were left with 7794 observations with "Confident" IDs that we used for the analysis of 35 species. After the creation of iSeahorse in 2013, the number of observations obtained per year increased steadily (Figure 1). The year 2019 saw the highest number of records, with more than 1337 observations, and the number of observations per year may have shown signs of leveling off from 2020 onward.

We obtained observations from 96 countries, and two distinct jurisdictions (Figure 2), from which 10 countries comprised more than three-quarters (77%) of the observations; Australia (33.3%), Indonesia (10.9%), Philippines (8%), United States (6.3%), Thailand (3.7%), Spain (3.6%), New Zealand (3%), France (2.6%), Cambodia (2.6%), and Kenya (2.5%).

We analysed the number of observations submitted per month for the Northern Hemisphere (higher than 23°N), the Tropics (23°N to 23°S), and the Southern Hemisphere (lower than 23°S) (Figure 3). Northern and Southern Hemispheres both had more observations in their respective summers, showing a seasonality in the submission of observations. In the Tropics there is no clear evidence of seasonality, with slightly fewer numbers of observations from June to September.

3.1 | Geographic distribution

We calculated the EOO for all species with more than two observations (as per requirement for polygon calculation), determined by EOO calculation methods (29 species; Table 2). We were not able to compare the results with the Red List assessments as there was no

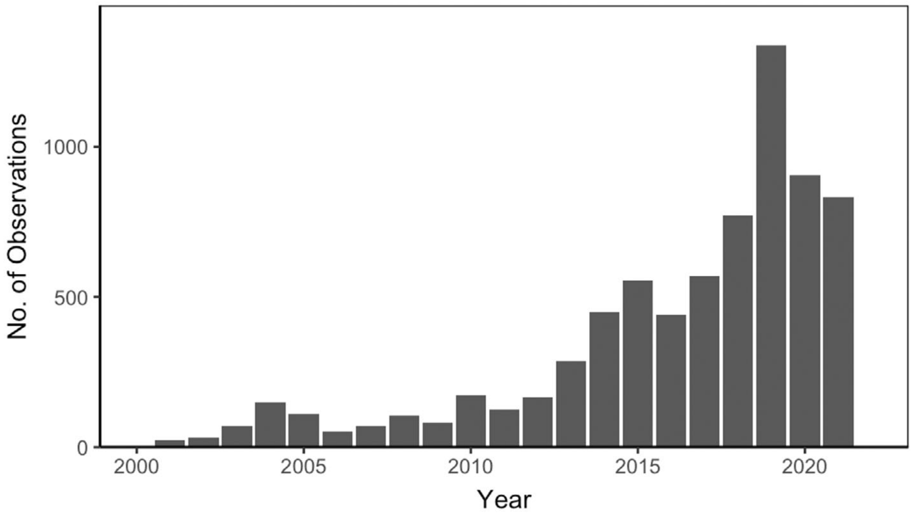

FIGURE 1 Number of observations with confident species ID received each year in iSeahorse, from 2001 to 2021. Observations from 2022 were not included as we had only 4 months available at the time of the analysis.

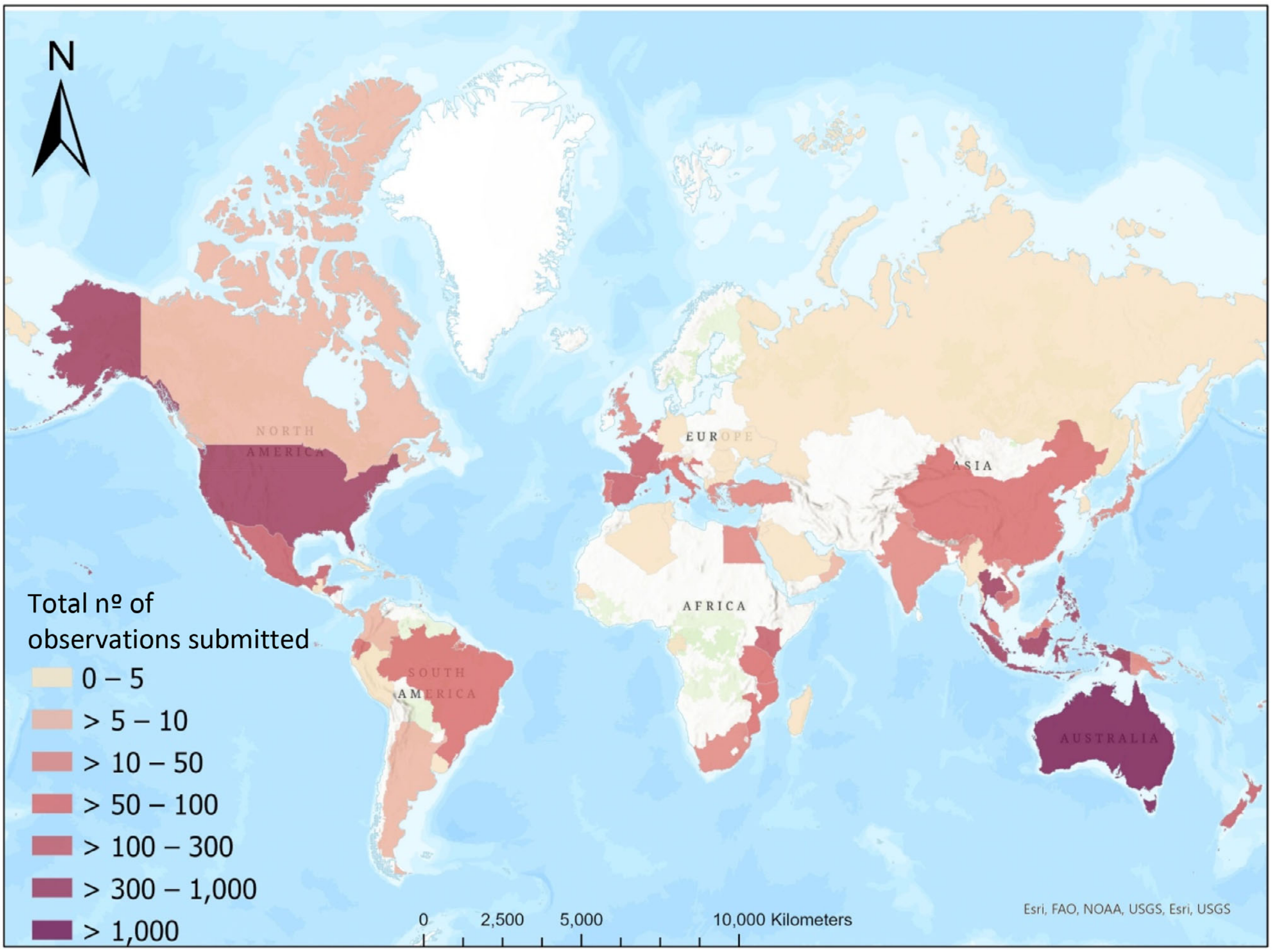

FIGURE 2 World map with an abundance of iSeahorse observations submitted per country. Total $n = 7794$.

available information for each species' EOO. In two cases, the EOO calculations from iSeahorse data showed high probability of being inaccurate. One case is *Hippocampus capensis* Boulanger, 1900, because of its small distribution, which would be strongly affected by the observations presented on land by the iNaturalist obscured feature. The fact that some *H. capensis* observations were located on land might have contributed to an overestimation of the species' EOO, obtaining an EOO of 1316 km^2 (Table 2), whereas the IUCN Red list described an EOO of 300 km^2. Another example of this constraint is *Hippocampus kuda* Bleeker, 1852, for which we were not able to get the minimum convex polygon using the IUCN EOO calculator tool, because of tool limitations.

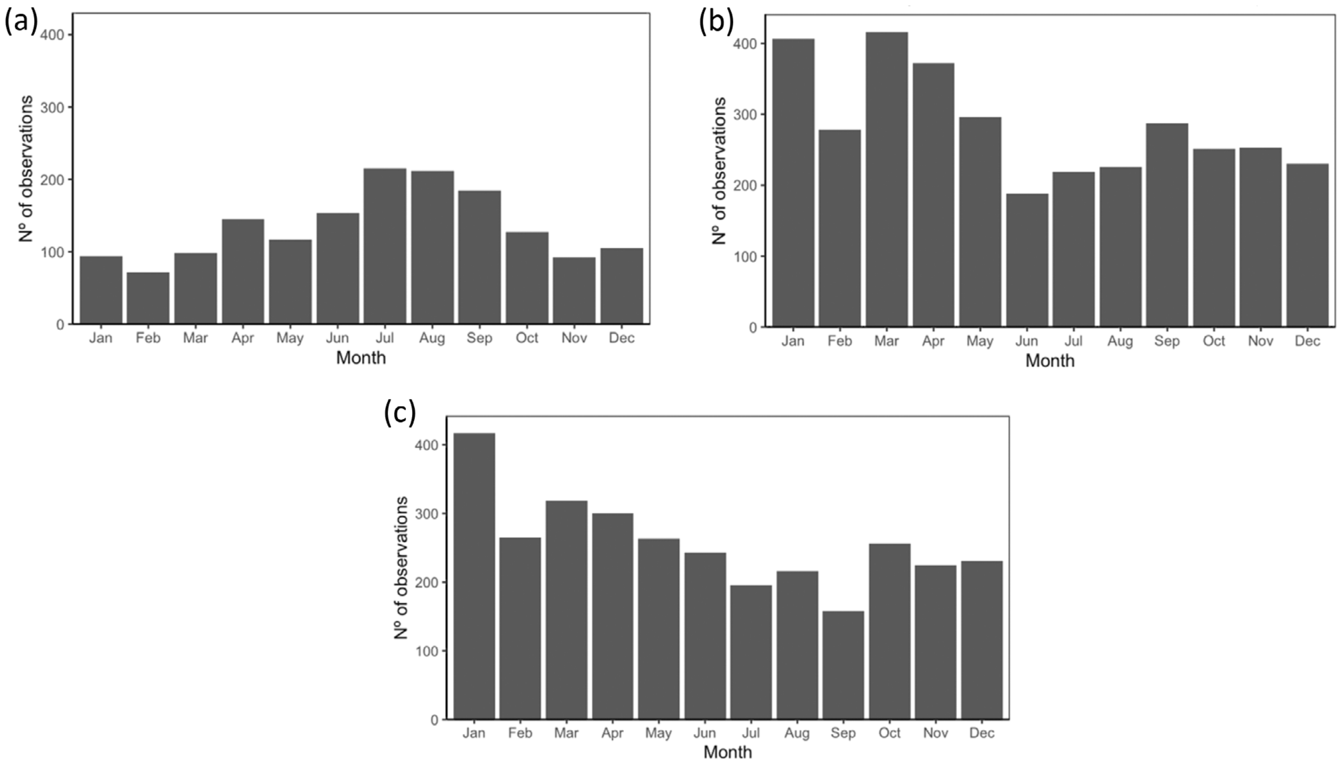

FIGURE 3 Cumulative number of iSeahorse observations received per month in (a) Northern Hemisphere, (b) tropics, and (c) Southern Hemisphere for all years.

TABLE 2 Extent of occurrence (EOO) calculations per species, using the IUCN toolbox for ArcMap GIS.

***Hippocampus* species**	**EOO ($\times$1000 km^2)**	***n***	**Species**	**EOO ($\times$1000 km^2)**	***n***
Hippocampus abdominalis	3097	1521	*Hippocampus ingens*	6896	216
Hippocampus algiricus	3255	17	*Hippocampus japapigu*	—	2
Hippocampus angustus	—	1	*Hippocampus jayakari*	973	44
Hippocampus barbouri	1971	13	*Hippocampus kelloggi*	44,799	58
Hippocampus bargibanti	18,640	433	*Hippocampus kuda*	143,934	596
Hippocampus breviceps	866	241	*Hippocampus mohnikei*	3295	20
Hippocampus camelopardalis	513	45	*Hippocampus patagonicus*	88	11
Hippocampus capensis	1.3	25	*Hippocampus pontohi*	12,835	148
Hippocampus colemani	6856	11	*Hippocampus reidi*	18,018	570
Hippocampus comes	5107	245	*Hippocampus satomiae*	41	4
Hippocampus coronatus	70	6	*Hippocampus sindonis*	3.2	10
Hippocampus denise	11,631	166	*Hippocampus spinosissimus*	7816	197
Hippocampus erectus	30,877	337	*Hippocampus subelongatus*	0.9	430
Hippocampus guttulatus	5702	441	*Hippocampus trimaculatus*	21,834	44
Hippocampus haema	—	2	*Hippocampus whitei*	48	720
Hippocampus hippocampus	12,504	424	*Hippocampus zebra*	—	1
Hippocampus histrix	74,970	571			

Note: Species highlighted in light gray do not have reliable EOO. For *H. capensis*, the uncertainty of some observations might affect the EOO in its small geographic range. For *H. kuda*, because of the process of EOO calculation and the very wide distribution of the species, the EOO obtained is not the smallest convex polygon area.

TABLE 3 Geographic distribution comparison between iSeahorse (iS) observations and IUCN Red List (IUCN RL) range maps.

			Percentage of iS observations that lay outside the IUCN RL mapped range				
***Hippocampus* species**	***n***	**Suspected absences**	**0**	**<25%**	**25%–50%**	**>50%**	**100%**
Hippocampus abdominalis	1525	X		X			
Hippocampus algiricus	17						
Hippocampus angustus	1	X	X				
Hippocampus barbouri	13	X		X			
Hippocampus bargibanti	479	X	X				
Hippocampus breviceps	241	X	X				
Hippocampus camelopardalis	45	X	X				
Hippocampus capensis	25		X				
Hippocampus colemani	9						X
Hippocampus comes	254				X		
Hippocampus coronatus	6	X	X				
Hippocampus denise	182	X		X			
Hippocampus erectus	338	X	X				
Hippocampus guttulatus	453		X				
Hippocampus haema	1						
Hippocampus hippocampus	425		X				
Hippocampus histrix	571	X		X			
Hippocampus ingens	271		X				
Hippocampus japapigu	2						
Hippocampus jayakari	44		X				
Hippocampus kelloggi	59	X		X			
Hippocampus kuda	609			X			
Hippocampus mohnikei	20	X	X				
Hippocampus nalu	1						
Hippocampus patagonicus	11	X	X				
Hippocampus pontohi	155			X			
Hippocampus reidi	580						
Hippocampus satomiae	4					X	
Hippocampus sindonis	11		X				
Hippocampus spinosissimus	204	X	X				
Hippocampus subelongatus	430		X				
Hippocampus trimaculatus	45	X	X				
Hippocampus whitei	720			X			
Hippocampus zebra	1		X				
Hippocampus zosterae	95	X					

Note: Column 3 indicates that the particular species was not reported from some areas of the IUCN Red List mapped range even though other species were observed in those areas. Species with gray bars are the ones with no IUCN Red List geographic information.

We found that iSeahorse observations for 11 species fell outside the range described by their IUCN Red List assessments (Table 3).

Hippocampus abdominalis Lesson, 1827 and *Hippocampus whitei* Bleeker, 1855 had observations that only slightly expanded the range when compared to the IUCN Red List range. Therefore, for this study, these were not considered as range expansions and were instead regarded as slight alterations of the borders of the already-known range.

In the case of *Hippocampus colemani* Kuiter, 2003, all the observations in iSeahorse appeared outside the IUCN Red List range, which is restricted to a small zone. This indicates a new range for *H. colemani* that we hadn't detected before. Many of the observations of *Hippocampus satomiae* Lourie & Kuiter, 2008 were also outside the range reported in the IUCN Red List, suggesting another possible range extension (Annexes 2 and 3).

We calculated the EOO per year for species with more than 200 observations, starting from the year of the most recent IUCN Red List assessment. For almost all species, the EOO gradually increased over the years, until between 2019 and 2021 when the EOO

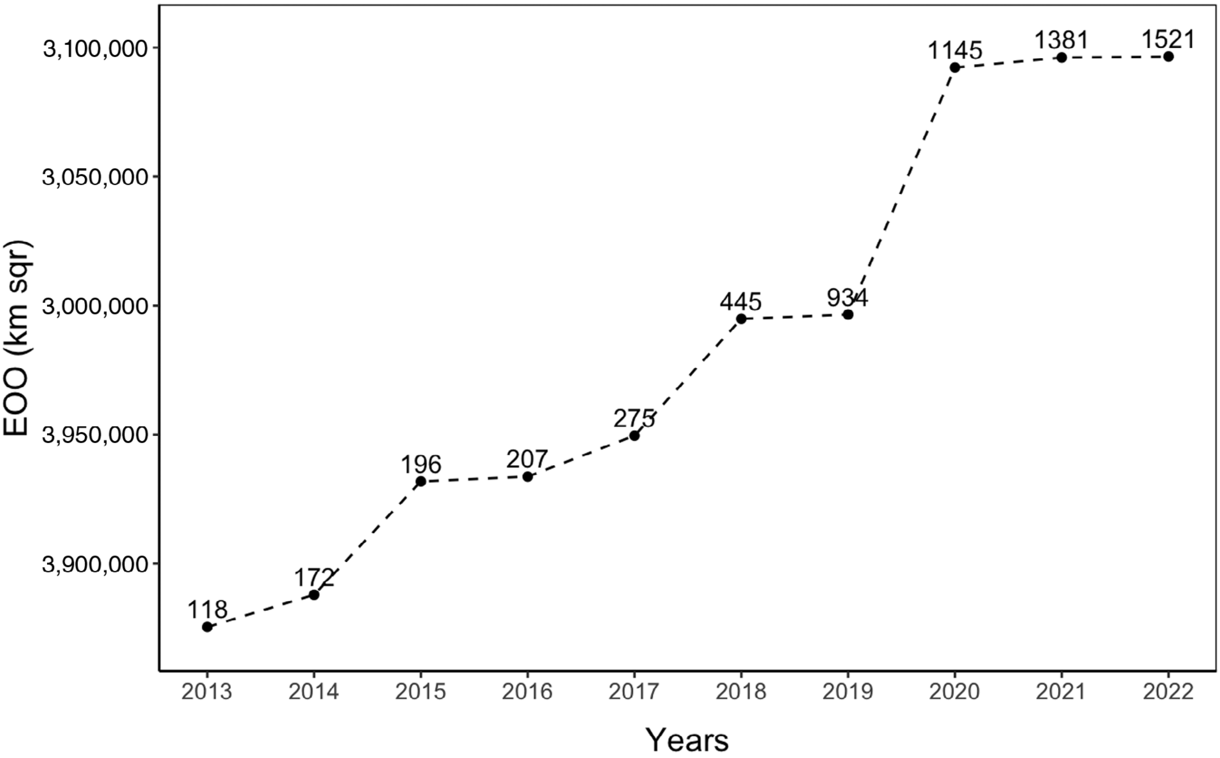

FIGURE 4 Cumulative extent of occurrence (EOO) (km^2) per year for *Hippocampus abdominalis* between 2013 and 2022. The cumulative total number of observations through time as of that year is included in the graph above each data point.

stabilized, even though there was no decrease in the average number of observations received during that period of time. A clear example of this trend is *H. abdominalis'* EOOs (Figure 4).

3.2 | Habitat

The habitats most commonly reported across all species were coral reef (24%), subtidal sandy (18%), macroalga/kelp (14%), subtidal loose rock/pebble/gravel (10%), and seagrass (10%) (Figure 5). Of the 7794 Confident observations, 2524 (32.4%) had information about habitat.

We compared the habitat types reported in iSeahorse with those presented in the IUCN Red List assessment for each species. iSeahorse provided observations in one to six new habitats for 80% of species ($n = 24/30$) (Table 4) compared to those in Red List assessments.

The species with the highest number of new habitats reported were *Hippocampus comes* Cantor, 1849; *Hippocampus histrix* Kaup, 1856; *H. kuda*; *Hippocampus kelloggi* Jordan & Snyder, 1901; and *Hippocampus spinossisimus* Weber, 1913, each with five to six new habitats. In some cases, the newly described habitats were reported more often than previously described habitats, as was the case for *H. histrix* (Annex 4). Three of the most underreported habitats by the IUCN compared to iSeahorse reported habitats were rock, rubble, and artificial habitats.

3.3 | Depth

Of the 7794 confident observations, 2343 (30%) of the observations had depth information (Figure 6). Across all species, the minimum depth reported was 0.16 m and the maximum was 60 m (mean = 7.7 m; median = 6 m). A total of 3172 observations stated how the observation was obtained, with most of the observations coming from recreational diving (96%), which is usually limited to depths of 40 m. The remaining observations were obtained either on land (2%) or from fishing (2%).

iSeahorse data placed seven species at shallower depths than the previous range described by the IUCN Red List, and six species at greater depths. The remaining species' recorded depths in iSeahorse were inside the described range by the IUCN Red List (Table 5).

For species found in depths outside the IUCN Red List range, the difference was usually 5–15 m shallower or deeper. The exceptions were *H. kelloggi* and *H. kuda*, where iSeahorse data extended the depth range for both minimum and maximum depth considerably, between 20 and 25 m.

3.4 | Sex and pregnancy

We identified the sex in the observed photographs of seahorses for 15 species. The sex ratio varied from female- to male-biased, ranging between 0% and 70% male across all species.

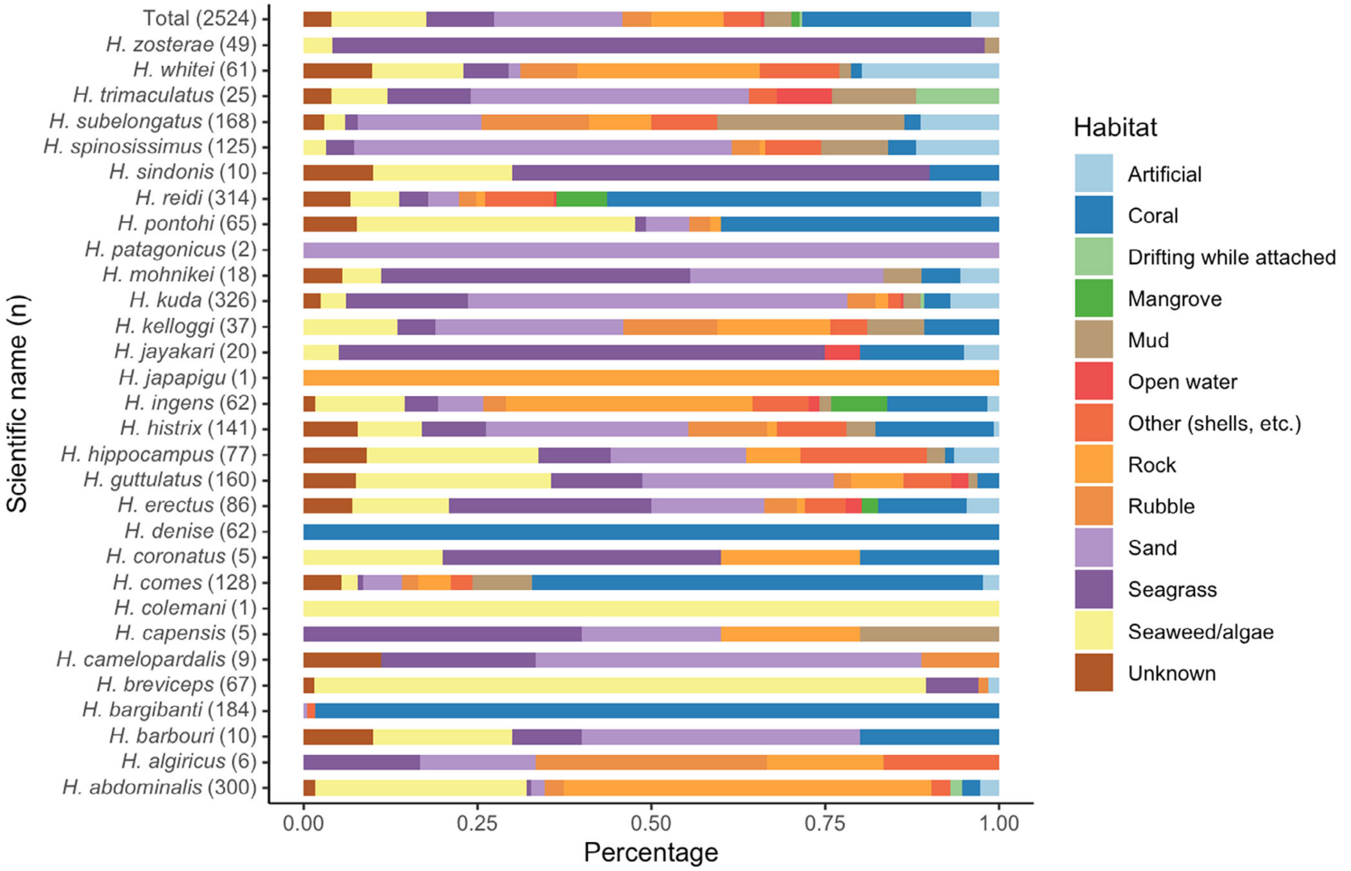

FIGURE 5 Habitat occupancy reported for each species (%). *n* = number of observations with habitat information for each species. Habitat categories are provided by iSeahorse. Information was obtained from one of the 15 extra questions provided to the contributors during the submission process.

We found no relationship between the number of observed seahorses and the sex ratio for the set of species we assessed. However, the species with the greatest number of observations for sex (*H. ingens*) did have the most balanced sex ratio (Table 6). Calculations of sex ratio were compromised in species with small sample sizes. For species with the most balanced ratios (ratios between 60% and 40%), three species were slightly female-biased, and three species were slightly male-biased. The species with the most observations obtained are the ones with the most confident sex ratio calculations.

The three species with apparent female sex ratio biases—*H. kelloggi*, *Hippocampus trimaculatus* Leach, 1814, and *Hippocampus zosterae* Jordan & Gilbert, 1882—had relatively low sample sizes at 45, 36, and 53, respectively.

For some species, we found juveniles among the observations. The iSeahorse data for *H. capensis* noted seven juveniles observed in February, *H. ingens* had 19 juveniles observed throughout the year, and *Hippocampus patagonicus* Piacentino & Luzzatto, 2004, had six juveniles observed between February and March.

We obtained information about the occurrence of pregnant males for 11 of the 15 species studied. Only two of these species (*Hippocampus coronatus* Temminck & Schlegel, 1850, and *Hippocampus mohnikei* Bleeker, 1853) had corresponding information reported in IUCN Red List assessments. For these two, iSeahorse data extended the breeding season compared to what was previously described (Table 7). For three species, we compared the seasonality to data from a definitive review (Lourie et al.,2004), and iSeahorse data again extended the breeding season.

With the information obtained from iSeahorse, there is no clear pattern on seasons in which seahorses tend to breed, whether in the summer or the winter. For species in the Northern Hemisphere, there are occurrences of breeding throughout the year, with somewhat more occurrences in the spring. Seahorses are found breeding throughout all seasons for the Tropical species. We lacked information to assess the breeding season for species in the Southern Hemisphere.

4 | DISCUSSION

Analysis of iSeahorse data reveals that this marine community science project provided valuable data for very-understudied seahorse species. Early iSeahorse data contributed to the first full set of IUCN Red List assessments for seahorses, completed between 2014 and 2017. Our new information on geographic distribution, habitat, depth, sex,

TABLE 4 New habitats noted in iSeahorse observations (X), compared to habitats noted in the IUCN Red List assessments for each species (using the IUCN Red List habitat categories).

***Hippocampus* species**	***n***	**9.2—Subtidal Rock and Rocky Reefs**	**9.3—Loose Rock/Pebble/Gravel**	**9.4—Subtidal Sandy**	**9.6—Subtidal Muddy**	**9.7—Macroalga/Kelp**	**9.8—Coral Reef**	**9.9—Seagrass**	**15.11/15.12—Artificial Marine**	**No New Habitats Detected**
Hippocampus abdominalis	300		X	X			X			
Hippocampus algiricus	8									X
Hippocampus barbourin	12			X		X	X			
Hippocampus bargibanti	184									X
Hippocampus breviceps	67		X						X	
Hippocampus camelopardalis	9		X	X						
Hippocampus capensis	5	X		X	X					
Hippocampus colemani	1					X				
Hippocampus comes	128	X	X	X	X	X			X	
Hippocampus coronatus	5									X
Hippocampus denise	62									X
Hippocampus erectus	86		X	X		X			X	
Hippocampus guttulatus	160	X					X			
Hippocampus hippocampus	77							X	X	
Hippocampus histrix	141	X	X	X	X				X	
Hippocampus ingens	62		X		X			X	X	
Hippocampus japapigu	2									X
Hippocampus jayakari	20						X		X	
Hippocampus kelloggi	37	X	X	X		X		X		
Hippocampus kuda	326	X	X	X		X	X		X	
Hippocampus mohnikei	18			X	X	X			X	
Hippocampus patagonicus	2			X						
Hippocampus pontohi	65	X	X	X			X	X		
Hippocampus reidi	314		X	X					X	
Hippocampus sindonis	10									X
	125	X	X		X			X	X	

(Continues)

TABLE 4 (Continued)

Hippocampus species	*n*	9.2—Subtidal Rock and Rocky Reefs	9.3—Loose Rock/Pebble/Gravel	9.4—Subtidal Sandy	9.6—Subtidal Muddy	9.7—Macroalga/Kelp	9.8—Coral Reef	9.9—Seagrass	15.11/15.12—Artificial Marine	No New Habitats Detected
Hippocampus spinosissimus										
Hippocampus subelongatus	168		X	X			X			
Hippocampus trimaculatus	25							X		
Hippocampus whitei	61	X	X						X	
Hippocampus zosterae	49				X					

Note: *n* = the total number of observations with habitat information. Species highlighted in light gray when no new habitats detected in iSeahorse observations.

and pregnancy obtained with iSeahorse will be used to update the current IUCN Red List Assessments (IUCN, 2022b). For the 17 seahorse species that are currently assessed as Data Deficient in the IUCN Red List, new iSeahorse data have now provided information for 10 of them, with different degrees of detail. Moreover, our iSeahorse analysis has contributed information for three species that have not yet been assessed for the IUCN Red List.

iSeahorse grew considerably from its creation, in line with a general increase in marine community science (Sandahl & Tøttrup, 2020). However, it appears that the COVID-19 pandemic reduced the number of observations received, probably as people traveled and dived less (Kieran, 2021), affecting both years 2020 and 2021. As similarly reported elsewhere for other taxa, the areas with the most iSeahorse observations are Southeast Asia, Australia, the Caribbean, and Europe; all are areas with high diving activity, more use of iNaturalist platform, and/or more active outreach by iSeahorse (Kelly et al., 2020; Sandahl & Tøttrup, 2020).

Data collected from iSeahorse have contributed to updating the geographic distribution of nine species and to adjusting or confirming information for the remaining species. For example, *H. colemani* had only previously been reported from Lord Howe Island (Kuiter, 2003), but iSeahorse sightings of this species occurred in Japan, Indonesia, and the north of Australia. *H. colemani* and *H. satomiae* are both pygmy seahorse species, the smallest seahorse species, which explains why they were not previously detected in these areas. Even for a relatively well-studied seahorse species, *H. comes*, almost half of iSeahorse observations were reported as coming from outside the IUCN Red List range (Lim, 2015), with new discoveries in Thailand and Indonesia. As seahorses have broad geographic distributions, are spatially patchy, and occur at low densities (Foster & Vincent, 2004; Lourie et al., 2016), the collected observations have helped provide a better idea of their occurrence and occupancy. With the help of community contributors, we were able to sample on a broader scale, had higher probabilities of detecting range shifts, and were able to observe rare or cryptic species (i.e., seahorses) (Tiralongo et al., 2020) that with traditional monitoring procedures would be more difficult to detect (DiBattista et al., 2021). However, iNaturalist observation provides several types of geographic precision, and this might have introduced some small biases when analysing the distribution.

Although iSeahorse observations are proving useful, we note two challenges in fully evaluating the value of the data on distribution. The first challenge is that distribution maps from IUCN Red List assessments, seemingly good reference points for our data, were actually rather problematic: some maps were unreliable; others were missing altogether; and many were originally created with inputs of early iSeahorse data, so they were not independent references for our new analysis. Even so, with verification from a seahorse expert, we found recorded seahorse sightings in areas where species were not previously known. The second challenge was that many observations were obscured (using the iNaturalist feature) and did not provide the real location, affecting some of the ranges and EOO calculations. Finally, there is also a limitation with not having an effort metric, which might lead to a lack of observation in an area not because the species is not there but because the community doesn't dive there.

For most seahorse species, the sightings revealed new habitats and depth ranges that had not yet been documented in the IUCN Red List assessments. That said, some of the habitats we identify as missing in the Red List had already been detected by other studies, as for *H. kuda* and *Hippocampus subelongatus* Castelnau, 1873 (Dody et al., 2021; Kalisiak et al., 2022; Lourie et al., 2004). The appearance of new seahorse habitats across multiple studies demonstrates that we may still be missing important habitat information for species assessed in the IUCN Red List. Our findings on the proportions of habitat type used by each species could give further insight into seahorse habitat preferences. When it came to depth, the maximum depth of observations was limited by diver access, yet new knowledge still emerged. Nonetheless, we learned, for instance, *H. kelloggi* can be found at shallower depths than indicated in the IUCN Red List (Harasti, 2017), whereas *Hippocampus camelopardalis* Bianconi, 1854, can be found deeper.

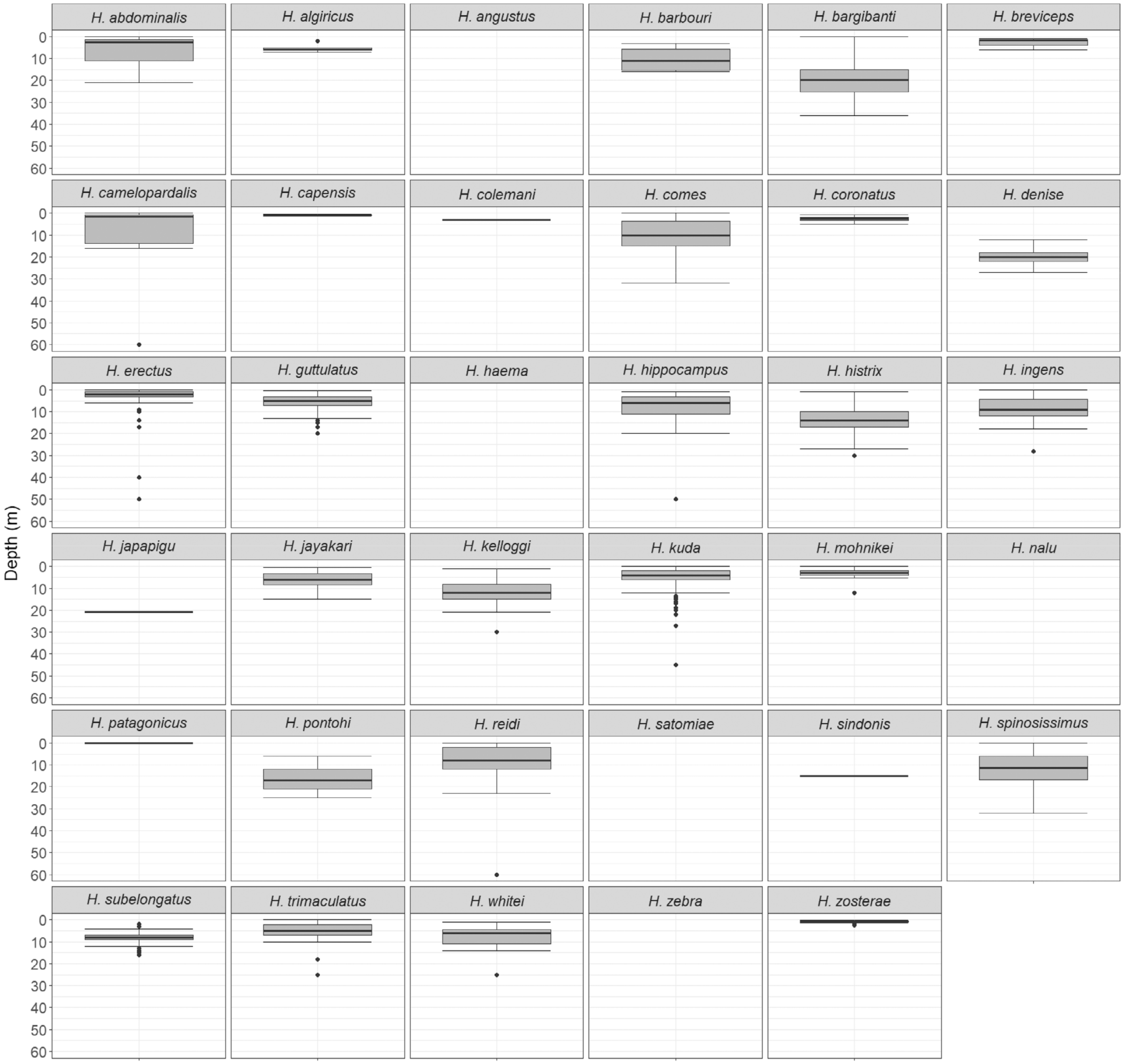

FIGURE 6 Depth ranges of iSeahorse observations (confident ID), represented in box plots per each species. Box plot shows the first quartile (upper limit of the box) and the third quartile (lower limit of the box), the median is given by the bold line inside the box, and whiskers represent the maximum and minimum values. Dots outside the box and whiskers are outliers.

Information on sex ratio and pregnancies indicates that community science sightings are probably more reliable when we are seeking to know the possible timings of a seahorse individual activity. However, this can be challenging when studying population parameters. In particular, the haphazard nature of community sightings in time and space is likely better for detecting pregnancy than for evaluating sex ratios. For the small sample sizes that we analyzed for sex ratio, sightings were generally female-biased, even though equal sex ratios have been documented in wild populations for 7 of the 15 species analyzed (Dody et al., 2021; Moreau & Vincent, 2004; Perante et al., 2002; Smith et al., 2012). As well, iSeahorse sightings were male-biased for *H. capensis* and female-biased for *H zosterae*, whereas field studies have found variable sex ratios in time and space for both species (Claassens & Harasti, 2020; Rose et al., 2019). Given the random sampling in iSeahorse, it is perhaps not unlikely that some sex ratios in the community science dataset did agree with previous studies, for *H. mohnikei* (Qin et al., 2017) and *H. trimaculatus* (Murugan, 2011). Despite all the uncertainty, however, the findings lead us to wonder whether the sex ratios of observations were female-biased because males hid more carefully with their load of embryos. When it comes to male pregnancies, iSeahorse data were also obtained haphazardly but provided important information about the bounds of known

TABLE 5 Depth described in iSeahorse (iS) observations compared to the International Union for Conservation of Nature's Red List (IUCN RL) depth ranges, indicating the species with observations either shallower or deeper than the IUCN RL range, with the exact difference in meters.

				Depth distribution comparison of iSeahorse (iS) observations with IUCN Red List assessments	
***Hippocampus* species**	***n***	**IUCN Red List depth range (m)**	**iS reported depth range (m)**	**Shallower than IUCN Red List minimum depth (m)**	**Deeper than IUCN Red List maximum depth (m)**
Hippocampus abdominalis	642	0–104	0–21		
Hippocampus algiricus	4	0–25	2–7		
Hippocampus barbouri	8	0–10	3–16		6
Hippocampus bargibanti	84	5–40	0–36	5	
Hippocampus breviceps	74	0–15	1–6		
Hippocampus camelopardalis	8	0–45	0–60		15
Hippocampus capensis	3	0.5–20	0.5–1		
Hippocampus colemani	1	4–12	3	1	
Hippocampus comes	94	0–20	0–32		12
Hippocampus coronatus	4	0–20	0.8–5		
Hippocampus denise	22	7–100	12–27		
Hippocampus erectus	74	0–100	0–50		
Hippocampus guttulatus	100	0–30	0.2–20		
Hippocampus hippocampus	43	0–60	1–50		
Hippocampus histrix	77	0–82	1–30		
Hippocampus ingens	54	1–60	0–28	1	
Hippocampus jayakari	44	0–20	0.31–15		
Hippocampus kelloggi	29	20–150	1–30	19	
Hippocampus kuda	293	0–55	0–45		
Hippocampus mohnikei	14	0–10	0–12		2
Hippocampus patagonicus	1	0–120	0		
Hippocampus pontohi	42	11–25	6–25	5	
Hippocampus reidi	134	0–55	0–60		5
Hippocampus sindonis	1	0–75	15		
Hippocampus spinosissimus	110	8–70	0.16–32	7.84	

TABLE 5 (Continued)

				Depth distribution comparison of iSeahorse (iS) observations with IUCN Red List assessments	
***Hippocampus* species**	***n***	**IUCN Red List depth range (m)**	**iS reported depth range (m)**	**Shallower than IUCN Red List minimum depth (m)**	**Deeper than IUCN Red List maximum depth (m)**
Hippocampus subelongatus	286	0–25	2–16		
Hippocampus trimaculatus	25	10–100	0–25	10	
Hippocampus whitei	61	0–12	1–25		13
Hippocampus zosterae	47	0–10	0.3–2.3		

Note: *n* = total number of observations with depth information.

TABLE 6 Female and male percentages observed for each of the species analysed.

		Proportion of each sex	
***Hippocampus* species**	***n***	**Female (%)**	**Male (%)**
Hippocampus algiricus	14	28.6	71.4
Hippocampus angustus	1	100.0	0
Hippocampus barbouri	9	44.4	55.6
Hippocampus camelopardalis	29	55.2	44.8
Hippocampus capensis	11	45.4	55.6
Hippocampus coronatus	6	66.7	33.3
Hippocampus ingens	172	57.6	42.4
Hippocampus jayakari	39	46.1	53.9
Hippocampus kelloggi	45	80.0	20.0
Hippocampus mohnikei	14	57.1	42.9
Hippocampus patagonicus	6	83.3	16.7
Hippocampus sindonis	10	50.0	50.0
Hippocampus trimaculatus	36	72.2	27.8
Hippocampus zebra	1	100.0	0
Hippocampus zostera	53	62.3	37.7

Note: *n* = sum of all females and males observed.

breeding seasons. For some species, iSeahorse sightings acted to confirm the known timing of breeding—as in the year-round breeding of *H. zosterae* (Rose et al., 2019) and *H. mohnikei* (Otsuka et al., 2009)—but, for other species, iSeahorse provided valuable new understanding of when pregnant males could be found, such as *Hippocampus algiricus* Kaup, 1856; *Hippocampus jayakari* Boulanger, 1900; or and *H. kelloggi*. We still need to consider that pregnancy seasonality results might be affected by the seasonality of when diving activity is higher.

Our study with iSeahorse observations met limitations often encountered in community science (Bird et al., 2014; Noviello et al., 2021), like observations without full information, problematic sampling effectiveness, clustered sampling (Boakes et al., 2010; DiBattista et al., 2021), and changes in volunteer effort over time (Robinson et al., 2018). iSeahorse dependency on diving meant that observations were clumped: (1) in particular parts of the ocean, usually closer to urban and MPAs (Luck et al., 2004); (2) in particular seasons when diving was more common; and (3) in particular habitats and depths where diving most occurred.

Although it was rewarding to obtain a considerable amount of information from iSeahorse sightings, such findings will not change the result of the IUCN Red List assessments for the studied species. First, the status of most seahorse species has been determined under Criterion A, which is based on population numbers. Our findings do not support such analyses, especially given the dearth of data on survey efforts, which would be vital to infer changes in abundance over time. Second, as seahorses have broad geographic distributions, their assessment does not usually emerge from Criterion B spatial restrictions (Foster & Vincent, 2004; Lourie et al., 2016). In any case, ranges for seahorse species are large enough that their conservation status would not be affected by the geographic range expansion (EOO in IUCN Red List terminology) with iSeahorse data. Further, our iSeahorse data did not allow any calculation of habitat use or a redefined area of occupancy in IUCN Red List terminology.

Forging ahead, iSeahorse data will continue to add value as the number of sightings increases and as resources become available to probe the sex ratio and timing of male pregnancies for the more frequently cited species. It would be particularly helpful if contributors were able to add more information on depth, habitat, or precise location to future the documentation of sightings and/or to reduce the number of observations with obscured locations. Such enhanced contributions may become more likely as participants see their data being used in meaningful ways to expand biological knowledge and inform conservation efforts, as we have sought to do in this paper.

This study has demonstrated the value of community science in advancing seahorse knowledge, by helping bridge gaps that arise partly from the seahorses' limited movement, crypsis, and patchy distributions. Seahorses are very much the sort of charismatic species that benefit from community science, as with other species like elasmobranchs (Bargnesi et al., 2020; Noviello et al., 2021). Seahorses gain yet more from having many sets of eyes seeking them because

TABLE 7 Breading seasonality per species.

Hippocampus species	*n* males	% males that are pregnant	iSeahorse	International Union for Conservation of Nature Red List	Other research
Hippocampus coronatus	2	50.0	May	June to November	June to July[a]
Hippocampus jayakari	21	61.9	September to April	—	
Hippocampus mohnikei	6	83.3	February, March, July, October	May to September	
Hippocampus sindonis	5	60	January, May	—	
Hippocampus algiricus	10	40	February, March, September	—	
Hippocampus barbouri	5	4	August, September, October	—	
Hippocampus ingens	73	26.0	January to October	—	
Hippocampus kelloggi	9	33.3	February, May, September	—	
Hippocampus trimaculatus	10	20	April, August	—	March to October[b]
Hippocampus zosterae	20	45	February to April and August to October	—	February to November[c]
Hippocampus angustus	0	0			
Hippocampus camelopardalis	13	7.7	August	—	
Hippocampus capensis	6	0		December to February	September to April[d]
Hippocampus patagonicus	1	0		March to August	
Hippocampus zebra	0	0		—	

Note: Species highlighted in blue are in the northern hemisphere. Species highlighted in orange are in tropical locations, crossing the equator. Species in green are in the southern hemisphere.

[a] Masuda et al. (1984).

[b] Truong and Nga (1995).

[c] Strawn (1958).

[d] Lockyear et al. (1997).

they are cryptic enough to make even formal research challenging. Because seahorses serve as flagship species, improving their conservation will help create MPAs, modify fisheries, and regulate wildlife trade. Other community science projects, like the initiative for Australasian fishes (Roberts et al., 2022), have also been able to fill important gaps for rare, less abundant, or cryptic species. The results from all these efforts show the importance of promoting marine community science and the important role it can play in conservation, by generating knowledge and mobilizing engagement and action.

It is vital to acknowledge the existing knowledge gaps that represent a challenge to effective conservation efforts. As we strive to protect and restore the marine environment, it is necessary to prioritize interdisciplinary research, collaboration, and innovation, as using community science. The impacts on the marine environment, including pollution, climate change, and overexploitation, are of serious concern and demand immediate action. With enhanced knowledge and collective efforts, we can develop evidence-based strategies that promote sustainable management and the long-term health of our marine environments. The significance of marine conservation cannot be overstated given its pivotal role in preserving the health and vitality of our oceans for the benefit of future generations.

AUTHOR CONTRIBUTION

Elsa Camins: Conceptualization, data collection, investigation, analysis, writing, review and editing. **Lily M. Stanton:** Data collection, investigation, analysis, review and editing. **Miguel Correia:** investigation, analysis, writing, review and editing. **Sarah J. Foster and Heather J. Koldewey:** Conceptualization, data collection, writing, review and funding. **Amanda C. J. Vincent:** Conceptualization, data collection, investigation, analysis, writing, review, editing and funding.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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