Non-native species are a global issue for marine protected areas

Josephine C. Iacarella, Dominique Saheed, Anya Dunham, & Natalie C. Ban

September 2019

Non-native species are a global issue for marine protected areas

Josephine C Iacarella[1*], Dominique Saheed[2], Anya Dunham[3], and Natalie C Ban[2]

The global extent of marine protected areas (MPAs) is increasing as nations strive to meet UN conservation targets, yet non-native species (NNS) are a critically overlooked stressor that threatens MPA conservation goals. Despite evidence that marine NNS affect protected species and habitats, there is limited understanding of the pervasiveness of this threat and the extent to which resource managers are responding to it. We disseminated a questionnaire targeting MPA practitioners and scientists to determine the overall state of knowledge and perception of NNS in MPAs. We received 151 responses from individuals in 47 countries and territories, including a total of 116 MPAs of which 73 were reported to have NNS present. Although NNS are a prevalent issue in MPAs and are the subject of some monitoring, management, and research, preventative measures are largely absent, so that more focused attention on NNS will be required to achieve conservation goals.

Front Ecol Environ 2019; 17(9): 495–501, doi:10.1002/fee.2100

Marine protected areas (MPAs) reduce biodiversity declines by mitigating anthropogenic impacts, including overfishing, habitat degradation, and, to some extent, climate change (Roberts *et al.* 2017). MPAs that prevent extractive activities increase fish biomass and diversity of large, predatory fishes (Edgar *et al.* 2014). There has been a substantial increase in MPAs (ranging from lightly to fully protected) following the international agreement to protect 10% of the ocean by 2020 (Aichi Target #11, Sustainable Development Goal #14) (Lubchenco and Grorud-Colvert 2015). As of August 2019, MPAs cover 4.8% of the global ocean (www.mpaatlas.org). However, adequate human and financial resources to manage and mitigate anthropogenic impacts within MPAs are critical for protection to be effective (Gill *et al.* 2017).

Non-native species (NNS) are a major threat to marine biodiversity (Molnar *et al.* 2008), but are often overlooked as an anthropogenic stressor that may hinder the conservation efforts of MPAs. There are several documented cases of marine NNS deterring conservation goals. For instance, NNS have altered invertebrate community composition (Kaplan *et al.* 2018), outcompeted native species (Gallagher *et al.* 2017), and restructured benthic habitat (Coma *et al.* 2011) in MPAs in Canada, Ireland, and the Mediterranean, respectively. The Dutch–German–Danish Wadden Sea MPA contains 66 NNS, whose diverse presence, without considering impact, compromises the conservation goal of maintaining the ecosystem in its natural state (Buschbaum *et al.* 2012). The spread of NNS from unprotected areas into MPAs is highly probable owing to the lack of physical barriers (ie hydrographic, abiotic) across large spatial scales in marine systems, the high dispersal capability of marine species, and the potent vectors of species transport (eg via shipping; Simberloff 2000).

MPAs and NNS are burgeoning topics (Mačić *et al.* 2018), but there has been little research on the effects of NNS on MPAs, or on the effects of protection efforts on the invasion and impacts of NNS. Protected areas are expected to have heightened resilience and resistance to stressors, including NNS. However, several studies to date have shown that the reduction of human activities in MPAs has variable effects on NNS populations (Burfeind *et al.* 2013; Giakoumi and Pey 2017). These inconsistent responses are likely due in part to insufficient research for analyzing overarching trends but also to complex interactions with native species. NNS may be suppressed by direct competition and predation but in other cases have thrived when newer MPAs have less dominant native populations (Caselle *et al.* 2018) or when predation on native species has increased space resources for NNS (Coma *et al.* 2011). The complexity of shifting interactions between NNS and native species as population pressures change with protection makes it difficult to predict outcomes.

Despite the challenges and threats that NNS pose for MPAs, they are rarely considered in conservation planning. Across biomes, 3.2% of conservation plans considered NNS when selecting the area to conserve (Mačić *et al.* 2018), and only 2.5% of marine conservation plans explicitly accounted for NNS (Giakoumi *et al.* 2016). Of the few plans that explicitly considered NNS, most excluded invaded areas from the planning process, though a small subset designated the protection of areas already impacted by NNS; in these cases, one plan did not distinguish NNS from native species in its biodiversity targets, while others prioritized invaded areas for management

[1]*Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, Canada *(Josephine.Iacarella@dfo-mpo.gc.ca); [2]University of Victoria, School of Environmental Studies, Victoria, Canada; [3]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, Canada*

actions (Mačić *et al.* 2018). Eradication of NNS in marine systems is uncommon, but invasions may be managed by limiting known vectors of spread (eg boats, aquaculture gear), planning for rapid response, and incorporating NNS monitoring and mitigation into the MPA design process (Simberloff 2000).

Much uncertainty surrounds the issue of NNS in MPAs, including the degree to which managers and researchers engage in this problem worldwide. We conducted a global survey via a questionnaire targeting MPA managers and scientists to determine the prevalence, abundance, and impacts of NNS in MPAs, their priority as a management issue, and whether or how they are being prevented, monitored, managed, and researched. Our results exemplify the present state of knowledge and perceptions of NNS in MPAs by managers and researchers, and highlight the need for explicit consideration of NNS and how they may affect conservation goals associated with protecting marine biodiversity and resources.

Methods

We distributed an opt-in, online survey globally, targeting professionals with ≥2 years of experience working in or conducting research on MPAs (WebPanel 1). The survey was disseminated via social media, listservs, organization email lists and outreach, and online newsletters. We contacted conservation-focused (not NNS-focused) groups so as to gain a broad picture of the knowledge and perception of the issue without introducing a bias toward those who manage or conduct research on NNS. The survey contained close-ended questions, including "yes/no/don't know" (one selection allowed), ranked-response (one selection), and "check-all-that-apply" options, as well as comment boxes for "other" answers and additional information. For a survey to be successfully submitted, a respondent was required to answer all questions (except for selected comment boxes); if a "yes" was selected, then responses to prompts for further details were also required, with one exception: respondents could answer "yes" to NNS presence without identifying specific taxa (eight cases). Those who identified NNS as present were required to answer all associated ranked-response (impact and abundance levels) and check-all-that-apply (impact type, invasion pathway, and management actions) questions (WebPanel 1, Q7). We did not define ranked-response levels because doing so would require standardized quantitative measures, and we expected that the studies required for quantitative responses have not been undertaken in most MPAs. As such, the qualitative rankings are based on the respondents' general understanding and observations of NNS. The survey was presented in English, Spanish, and French, and responses were received over a period of 3 months in 2018. We ended the survey when we stopped receiving responses after two rounds of outreach. Ethics clearance was received from the Human Research Ethics Board of the University of Victoria.

We compared multiple completed questionnaires for individual MPAs (17 of 116 MPAs) and NNS within MPAs (10 of 133 taxa across MPAs and respondents) to assess consistency across responses. We identified disagreement as different answers, excluding "don't know" and "unknown" responses. In a few cases where some respondents reported presence or absence of NNS for a MPA and others reported "don't know" for the same MPA, we did not count the "don't know" responses. To identify the overall state of knowledge and perception of NNS in MPAs by respondents, we counted answers from different respondents separately for the same MPA and NNS (totals of "taxa across respondents" include a taxon as counted each time it was reported; for example, if species A were reported by two different respondents, then species A would be counted as two "taxa across respondents"). We identified unique NNS taxa based on matches in the taxonomic rank reported (eg genus, species), maintaining that an NNS identified to species may be different than one identified to the same genus, and determined the lowest taxonomic rank possible for reported common names. We grouped taxa into categories of plants and algae, sessile invertebrates (eg corals, bivalve mollusks; tunicates included), mobile invertebrates (eg crabs, nudibranchs), and fishes.

We compared distributions of responses across taxonomic categories and across paired question combinations on NNS (presence, concern, and priority ranking) and management actions using Fisher's exact test with Monte-Carlo simulations (2000 replicates) in R (R Development Core Team 2012). We excluded one survey response on a freshwater protected area from all analyses, and several non-marine NNS (eg rats, minks) in NNS-specific analyses; all other surveys and NNS reported were included in the analyses.

Results

We received 151 surveys from respondents in 47 countries and territories and associated with 116 MPAs (Figure 1a). The top respondents by country were from the US and three of its territories (38), Canada (36), New Zealand (22), Australia (14), Brazil (7), and Chile (7); between two and six completed surveys were received from individual respondents in 15 countries, and one completed survey was received from a single respondent in each of the remaining 23 countries. Responses were primarily in English (141), with several in Spanish (9) and one in French. Respondents' work capacity in the MPAs included researcher/academic (62), monitoring (5), or both (27), manager (10), or enforcement in addition to other capacities (7); the remainder (40) identified a variety of work combinations. Work experience was evenly distributed across 10 years (43), 5–10 years (34), 3–5 years (34), and 2–3 years (40).

Respondents reported NNS to be present, absent, or unknown in 73, 21, and 22 of the 116 MPAs, respectively (Figures 1b and 2). Fifty-six percent of respondents (84/151) identified NNS that posed a future concern for invading the

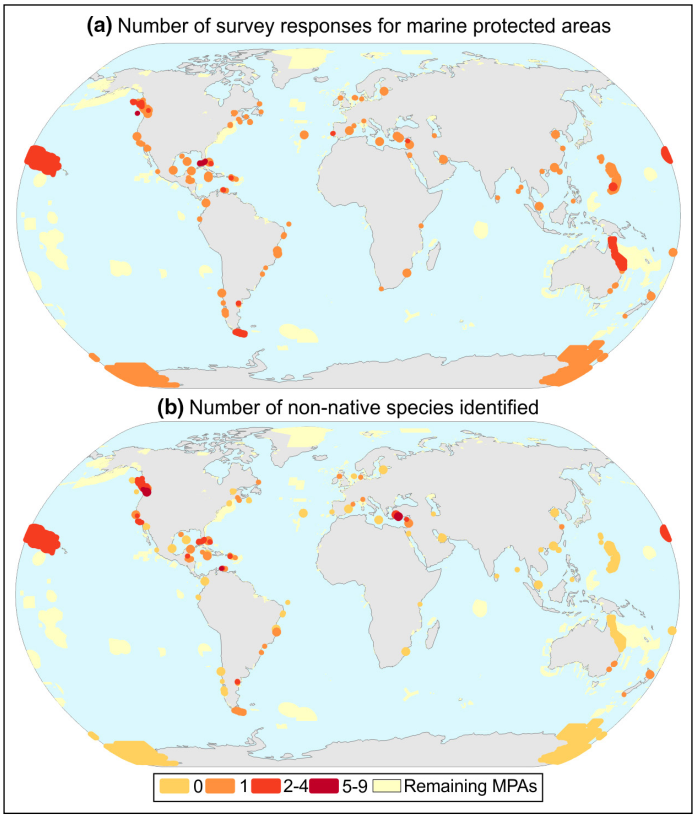

Figure 1. Global survey responses on NNS in MPAs with (a) a total of 151 responses across 116 MPAs, and (b) 58 taxonomic groups of NNS identified within those MPAs. Counts of both the number of survey responses from each MPA and the number of NNS identified for each MPA are depicted in the key at the bottom, which also shows the remaining MPAs (those that did not opt-in to the survey) in pale yellow (www.protectedplanet.net).

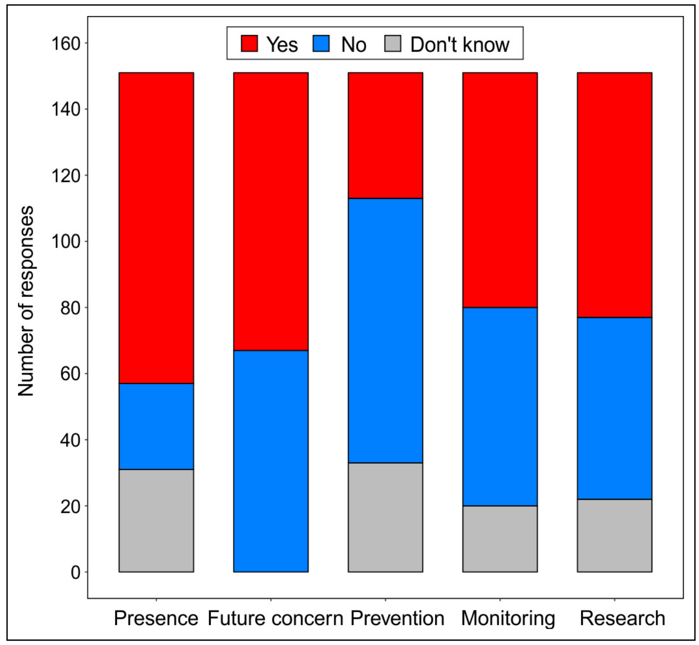

Figure 2. Number of "yes", "no", and "don't know" responses to the following questions (from left to right) in the survey: are there any known NNS in the MPA? (presence), are there any NNS that you are concerned about entering the MPA in the future? (future concern), are there any measures in place to prevent the introduction of NNS into the MPA? (prevention), are NNS populations monitored in the MPA? (monitoring), and is there ongoing research on NNS in the MPA or on potential invasion into the MPA? (research). Note that only "yes" or "no" options were provided for the second question regarding future concern. For all five questions, only one option could be selected by the respondent.

MPA, and 62% of respondents (93/151) ranked NNS as the "most" or a "somewhat" important management issue relative to other issues. Of the 17 MPAs for which multiple surveys were received, respondents agreed most about NNS presence (17/17) and least about whether there were NNS of future concern (8/17) (WebFigure 1).

Respondents identified 58 taxa as NNS that were currently present and 68 taxa that were a cause of concern for future invasion (in addition, a single report [Debrot *et al.* 2011] identified 77 species as NNS within one Dutch Caribbean MPA; WebTable 1), with even representation across taxonomic categories, with the exception of fewer mobile invertebrates (present, of future concern: plants and algae [13, 14]; sessile invertebrates [22, 23]; mobile invertebrates [5, 12]; and fishes [18, 19]) (Figure 3). With respect to NNS that were identified as present, impact levels of high/severe or medium were reported most often for mobile invertebrates (six of 10 taxa across respondents) and minimal impacts were reported most often for sessile invertebrates (15 of 31 taxa; $P < 0.001$) (WebFigure 2a). NNS were reported to most often have negative effects on native species (81 of 190 check-all-that-apply responses), especially fishes (51 of 60 taxa across respondents), followed by altering habitat structure or complexity (48 of 190); positive effects were reported in only eight of the 190 responses (Figure 4a; WebFigure 2b). Respondents identified the current abundance of NNS (high, medium, or low) at similar frequencies across taxa ($P > 0.05$), but reported more often that plants and algae were increasing in abundance (21 of 32 taxa across respondents, $P < 0.05$) as compared with invertebrates and vertebrates (WebFigure 2, c and e). The most commonly reported pathways used by NNS to invade MPAs either were secondary spread from known introduction sites outside of the MPAs (66 of 192 check-all-that-apply responses) or were unknown (35 of 192). Hull fouling and ballast water were also frequently attributed as vectors for plants and algae (six and five of 32, respectively) and sessile invertebrates (12 and nine of 31, respectively; $P < 0.001$) (WebFigure 2d). Across all taxa combined, among the six choices for management action taken in response to NNS, targeted capture and removal (48 of 185 check-all-that-apply responses), monitoring (48), and no action (52) were cited most frequently. For individual taxa, no action was most common for plants and algae (21 of 32), whereas targeted capture and removal was most common for fishes (31 of 60; $P < 0.05$) (Figure 4b; WebFigure 2f). For NNS identified within the same MPA by multiple respondents, the degree of agreement among responses was greatest for impact

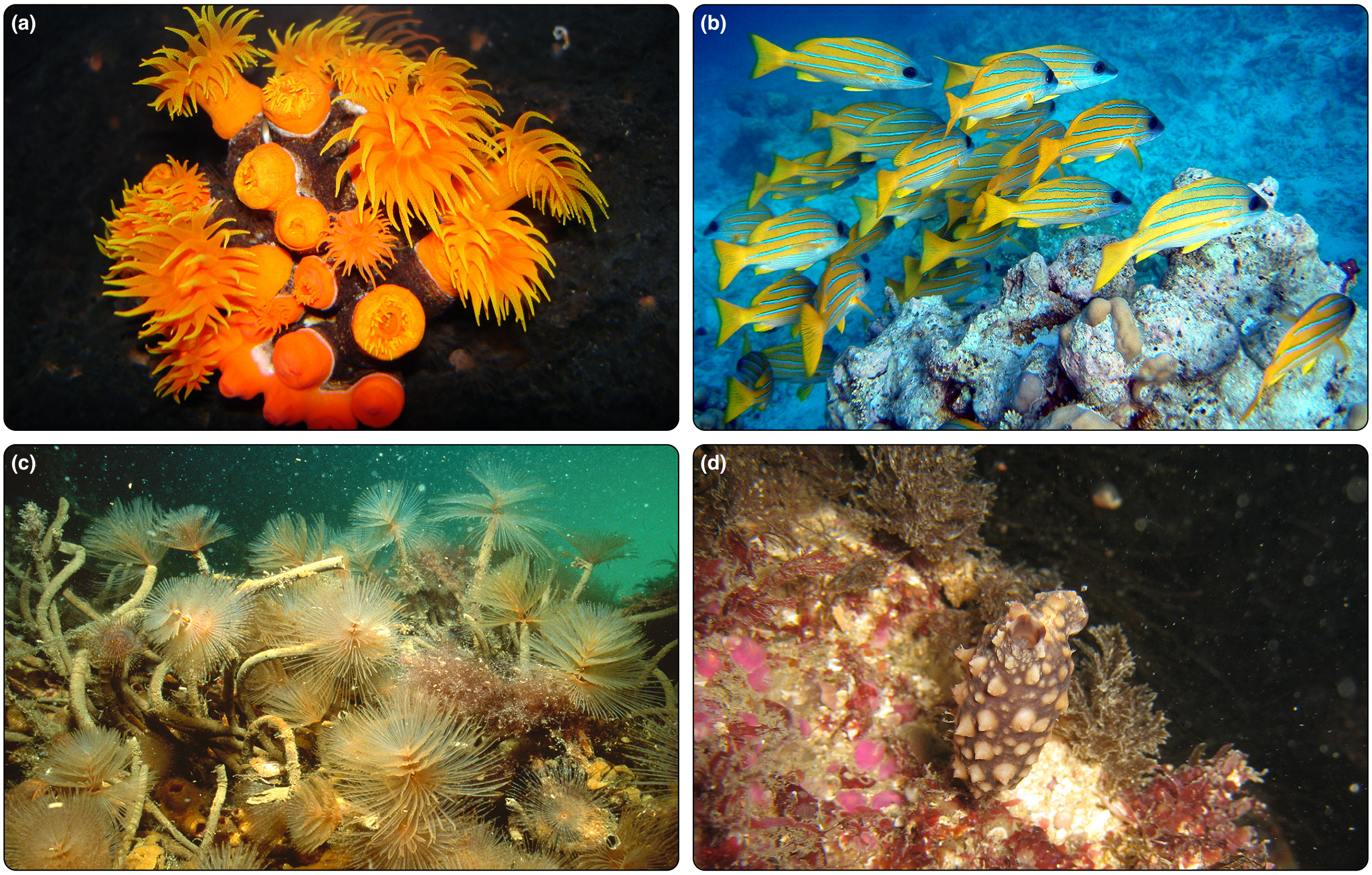

Figure 3. Examples of NNS reported to be present within MPAs include (a) orange cup coral (*Tubastraea coccinea*), (b) bluestripe snapper (*Lutjanus kasmira*), (c) European fan worm (*Sabella spallanzanii*), and (d) clubbed tunicate (*Styela clava*).

level (nine of 10 cases) and impact type (eight), and least for management actions (one); for check-all-that-apply questions (impact type, invasion pathway, and management action), inconsistencies often stemmed from respondents agreeing in some, but not all, selections (WebTable 2).

Although 53% of responses (80/151) indicated that there were no existing measures in place to prevent NNS invasion, 47% and 49% of responses (71/151 and 74/151) revealed the presence of activities devoted to NNS monitoring and research, respectively (Figure 2). These findings corresponded with more frequent identification of the current presence of and future concern about NNS (of those who answered "yes" to NNS presence, 36% [54/151] answered "no" to prevention, 43% [65/151] answered "yes" to monitoring, and 44% [67/151] answered "yes" to research; similarly, of those who answered "yes" to NNS of future concern, 33% [50/151] answered "no" to prevention, 31% [47/151] answered "yes" to monitoring, and 36% [54/151] answered "yes" to research; $P \leq 0.05$) (WebFigure 3, a–c). The presence of monitoring and research also coincided with more frequent ranking of NNS as "somewhat" of a priority management issue above "not very" and "least" ("yes" to monitoring, "yes" to research: both 53 of 151; $P < 0.001$). For the 31 MPAs where prevention measures were in place, respondents most commonly cited ballast water control and legislation (in nine and seven of 31 MPAs, respectively). Likewise, in the 45 MPAs where monitoring occurred, common methods included visual surveys and specimen collections (in 28 and seven of 45 MPAs, respectively). Fifty-one percent of responses (77/151) indicated that it was unknown whether there was a section on NNS included in the MPA's management plan, and the occurrence of such a section did not coincide with responses on presence, concern, or priority of NNS ($P > 0.05$) (WebFigure 3d).

Discussion

Responses to the survey from MPA practitioners and scientists worldwide showed that NNS are a prevalent issue and a priority management concern for many MPAs. NNS in MPAs were diverse, and had a range of impacts that often included negative effects on native species and alterations to habitat. As such, NNS will likely prevent the achievement of conservation goals for affected or at-risk MPAs. Efforts to prevent invasions were uncommon, with NNS often spreading into MPAs from sites of primary introduction outside MPA boundaries. Monitoring and research on NNS, noted by half of the respondents, were associated with the identification of NNS both already present and of future invasion concern. Our results provide important insight into the current state of – and exemplify the need for proactive and focused actions to help monitor, study, and counteract – NNS in MPAs.

The opt-in survey responses were knowledge- or perception-based, and most came from developed countries. The high number of responses from North America is likely due in part to the authors' network of colleagues. Numerous responses were also received from New Zealand and Australia, which may reflect the high level of biosecurity awareness and policies in those countries. MPAs are also not distributed evenly across the globe; 80% of the global MPA extent lies within the US, France, the UK, Cook Islands, New Zealand, Mexico, and associated territories (www.protectedplanet.net/marine#national). Many MPAs lack adequate resources for management, with minimal staff or scientific monitoring capacity (Gill *et al.* 2017), and may be less likely to be represented in surveys. Our survey method allowed us to obtain information on NNS in MPAs that was otherwise unavailable in the literature, while also representing the prevalence and understanding of this issue among experts involved with MPAs. For example, although "don't know" responses did not provide any genuine information on NNS, those responses illuminated the level of detail known about NNS, which can be a substantial challenge in marine systems. Cases where there were inconsistent responses regarding either the same MPAs or the same NNS within an MPA also highlight existing knowledge gaps and differences in perceptions of NNS as a management issue.

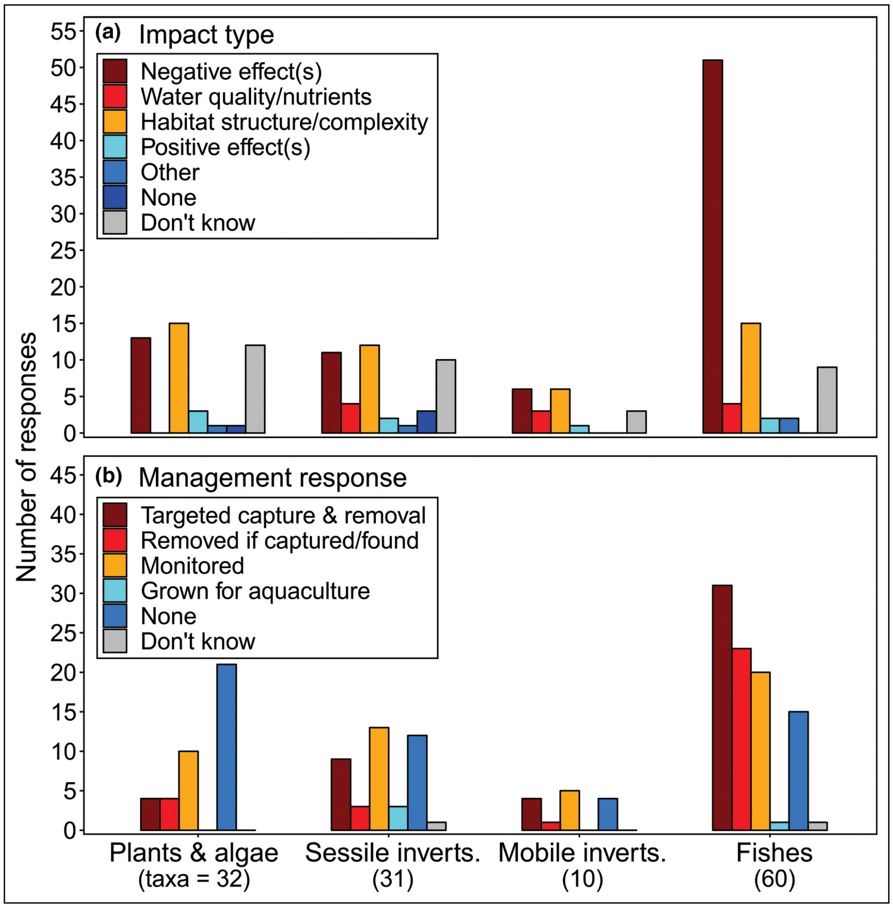

Figure 4. Number of responses provided for NNS identified within MPAs sorted by (a) impact type and (b) management actions within the MPA. NNS are categorized as plants and algae, sessile invertebrates ("inverts"), mobile invertebrates, and fishes (total "taxa across respondents" are provided, where a taxon was counted each time it was reported). Respondents could select multiple options for each NNS.

Over half of marine NNS with reported impacts have been found to disrupt multiple species or wider ecosystems (Molnar *et al.* 2008). In our survey, an average of 17% of respondents reported that NNS have high or severe impacts in an MPA, and all but two of these cases coincided with negative effects on native species. High-impact NNS reported in the survey included macroalgae (wakame [*Undaria pinnatifida*], devil weed [*Sargassum horneri*]), green algae (*Caulerpa cylindracea*, sea lettuce [*Ulva* spp]), crabs (green crab [*Carcinus maenas*]), and fishes (eg lionfish [*Pterois* spp], rabbitfish [*Siganus* spp]). The number of NNS in MPAs is certainly much higher than reported in our survey – 125 non-native fishes have been recorded in the Eastern Mediterranean alone (Arndt *et al.* 2018) – and conspicuous species were likely identified more often by survey respondents. However, a substantial number of reported NNS had unknown levels of impact. Estimating the impacts of marine NNS is particularly challenging compared to those of freshwater or terrestrial NNS because of the scale, connectivity, and relatively unobstructed nature of seascapes. Arndt *et al.* (2018) stressed that the current understanding of the impacts of marine non-native fishes, in particular, is lagging behind the rise in invading fish species.

Managers can customize prevention strategies to reduce the spread or introduction of NNS into MPAs. Respondents to our survey commonly reported an absence or unawareness of existing prevention measures for their MPA, although several identified such options as biosecurity regulations, bans on particular aquarium species, cleaning of gear and vessels, and public education. There is a multitude of marine invasion vectors, the relative importance of which varies by region (Bax *et al.* 2003). As such, all modes of introduction into an MPA should be identified and consideration given to methods for reducing their vector potential (eg through complete restriction or mandated cleaning practices). Shipping is the most common marine invasion vector, with NNS transfer via hull fouling or dumping of ballast water (Molnar *et al.* 2008). Given the survey's findings regarding the prevalence of NNS that moved into MPAs from other areas, and/or were introduced by large-scale vectors such as shipping, regional-scale initiatives will be necessary to effectively reduce invasion potential.

Our survey found that several MPA practitioners are actively monitoring and managing NNS already present within the MPAs. Respondents noted a variety of monitoring methods, as well as targeted removal of green crab and lionfish; creative management actions included public competitions for capturing lionfish and marketing them for human consumption. Despite increasing public awareness and assistance with early detection and rapid response, marketing NNS for consumption is complicated by having to capture an adequate number of individuals at the appropriate life stage to reduce populations while avoiding the development of a dependent market (Nuñez *et al.* 2012). Plans for the prevention and early detection of – and rapid response to – invasions, though not impervious to new invasions and impacts, can have promising results (Simberloff 2000). However, many countries currently lack the research capacity, financial resources, and public engagement required for effective responses to invasions (Early *et al.* 2016).

Proactively incorporating the locations of high NNS richness and introduction hubs into the MPA design process – currently an uncommon practice (Giakoumi *et al.* 2016; Mačić *et al.* 2018) – will likely facilitate future NNS management. In degraded areas where NNS are dominant (eg the Eastern Mediterranean), these species may deliver ecosystem services that are no longer provided by their native counterparts; in this case, conservation goals for MPAs may instead focus on overall ecosystem functioning in management of NNS and native species. However, the effective functional replacement of native species by NNS is unknown and will require extensive research (Rilov *et al.* 2017).

Policy makers, practitioners, and scientists worldwide have recognized the importance of NNS research with respect to future NNS management (Dehnen-Schmutz *et al.* 2018), and research also featured strongly in our survey as a link to identifying NNS already present and those of invasion concern. Research on NNS may be conducted in response to detection of NNS or vice versa; studies currently conducted by MPA practitioners were geared toward specific evaluations of the impacts of a known invader or were assessments of general biodiversity with subsequent documentation of the presence of NNS. Examinations of the relationship between invasions and MPAs have been minimal to date (see reviews by Burfeind *et al.* [2013] and Giakoumi and Pey [2017]), and information about the impacts of many marine NNS is lacking (Arndt *et al.* 2018). Filling these knowledge gaps will enable MPA managers to better evaluate risks and distribute resources more effectively.

Acknowledgements

We thank those who participated in and who helped disseminate the survey, J Ojeda Villarroel for Spanish translation, I Maurice for French translation, and the Ban lab for ideas and feedback. Funding was provided by the Strategic Program for Ecosystem-based Research and Advice of Fisheries and Oceans Canada (JCI, AD) and a Discovery Grant from the Natural Sciences and Engineering Research Council (NCB).

References

Arndt E, Marchetti MP, and Schembri PJ. 2018. Ecological impact of alien marine fishes: insights from freshwater systems based on a comparative review. *Hydrobiologia* **817**: 457–74.

Bax N, Williamson A, Aguero M, *et al.* 2003. Marine invasive alien species: a threat to global biodiversity. *Mar Policy* **27**: 313–23.

Burfeind DD, Pitt KA, Connolly RM, *et al.* 2013. Performance of non-native species within marine reserves. *Biol Invasions* **15**: 17–28.

Buschbaum C, Lackschewitz D, and Reise K. 2012. Nonnative macrobenthos in the Wadden Sea ecosystem. *Ocean Coast Manage* **68**: 89–101.

Caselle JE, Davis K, and Marks LM. 2018. Marine management affects the invasion success of a non-native species in a temperate reef system in California, USA. *Ecol Lett* **21**: 43–53.

Coma R, Serrano E, Linares C, *et al.* 2011. Sea urchins predation facilitates coral invasion in a marine reserve. *PLoS ONE* **6**: e22017.

Debrot AO, van Buurt G, and Vermeij JA. 2011. Preliminary overview of exotic and invasive marine species in the Dutch Caribbean. Wageningen, The Netherlands: Institute for Marine Resources & Ecosystem Studies, Wageningen University & Research.

Dehnen-Schmutz K, Boivin T, Essl F, *et al.* 2018. Alien futures: what is on the horizon for biological invasions? *Divers Distrib* **24**: 1149–57.

Early R, Bradley BA, Dukes JS, *et al.* 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature* **7**: 12485.

Edgar GJ, Stuart-Smith RD, Willis TJ, *et al.* 2014. Global conservation outcomes depend on marine protected areas with five key features. *Nature* **506**: 216.

Gallagher MC, Culloty SC, Davenport J, *et al.* 2017. Short-term losses and long-term gains: the non-native species *Austrominius modestus* in Lough Hyne Marine Nature Reserve. *Estuar Coast Shelf S* **191**: 96–105.

Giakoumi S and Pey A. 2017. Assessing the effects of marine protected areas on biological invasions: a global review. *Front Mar Sci* **4**: 49.

Giakoumi S, Guilhaumon F, Kark S, *et al.* 2016. Space invaders: biological invasions in marine conservation planning. *Divers Distrib* **22**: 1220–31.

Gill DA, Mascia MB, Ahmadia GN, *et al.* 2017. Capacity shortfalls hinder the performance of marine protected areas globally. *Nature* **543**: 665.

Kaplan KA, Hart DR, Hopkins K, *et al.* 2018. Invasive tunicate restructures invertebrate community on fishing grounds and a large protected area on Georges Bank. *Biol Invasions* **20**: 87–103.

Lubchenco J and Grorud-Colvert K. 2015. Making waves: the science and politics of ocean protection. *Science* **350**: 382–83.

Mačić V, Albano PG, Almpanidou V, *et al.* 2018. Biological invasions in conservation planning: a global systematic review. *Front Mar Sci* **5**: 178.

Molnar JL, Gamboa RL, Revenga C, *et al.* 2008. Assessing the global threat of invasive species to marine biodiversity. *Front Ecol Environ* **6**: 485–92.

Nuñez MA, Kuebbing S, Dimarco RD, and Simberloff D. 2012. Invasive species: to eat or not to eat, that is the question. *Conserv Lett* **5**: 334–41.

R Development Core Team. 2012. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Rilov G, Peleg O, Yeruham E, *et al.* 2017. Alien turf: overfishing, overgrazing and invader domination in south-eastern Levant reef ecosystems. *Aquat Conserv* **28**: 351–69.

Roberts CM, O'Leary BC, McCauley DJ, *et al.* 2017. Marine reserves can mitigate and promote adaptation to climate change. *P Natl Acad Sci USA* **114**: 6167–75.

Simberloff D. 2000. No reserve is an island: marine reserves and non-indigenous species. *B Mar Sci* **66**: 567–80.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2100/suppinfo

FrontiersEcoPics

Fringehead cirri: for sensing or blending in?

Moss fringehead (*Neoclinus bryope*) is a cryptobenthic blenny – a fish that lives on the seafloor and usually hides itself in crevices with only its head protruding. Divers often find them in holes along the rocky shores of southern Japan. As implied by their name, fringehead blennies have fringes on their head called "cirri". Cirri in fish are normally thought to play a role in chemical and tactile sensing, but their function has never been investigated or tested in fringehead blennies. One possibility is that they act as camouflage. The cirri in moss fringeheads seem to mimic turf algae that grow off rocky shores. Among 11 species of fringehead blenny in the genus *Neoclinus*, all have different cirri structures and colors, depending on the habitat where they are found. The cirri may therefore help these fish to blend in with the turf algae, making them more elusive and protecting them from predation. This hypothesis is waiting to be explored in both functional and evolutionary contexts.

Watcharapong Hongjamrassilp
University of California–Los Angeles, Los Angeles, CA
doi:10.1002/fee.2119