Austral Ecology

Ecological Society of Australia

RESEARCH ARTICLE

The Expansion of *Perna viridis* Towards South Brazil: Bridging the Gap With Traditional Scientific Surveys and Citizen Science

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Received: 12 July 2024 | **Revised:** 3 April 2025 | **Accepted:** 11 April 2025

Funding: This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico, 140476/2023-7.

Keywords: biological invasion | distribution | green mussel | iNaturalist

ABSTRACT

In a world of constant change, biodiversity monitoring proves essential for the conservation of native species. Many of these changes are linked to the introduction of non-indigenous species (NIS), which alter ecosystem structure and community dynamics and directly impact native species. New records of NIS are often obtained through traditional scientific surveys. However, citizen science has provided significant insights into species distributions through volunteer observations by individuals outside of academia. Successful platforms for citizen science, such as iNaturalist, have revolutionised spatial and temporal understanding of biodiversity. Recently, the Green Mussel (*Perna viridis*), a NIS, was recorded in the states of Paraná, Rio de Janeiro and Ceará, Brazil. Nevertheless, there were no official records for other states along the Brazilian coast. This study aimed to use traditional scientific methods in conjunction with citizen science to update the distribution status of this species. Using traditional scientific surveys, one record of *P. viridis* was documented in the municipality of São Vicente, São Paulo state, while 42 records were obtained through iNaturalist, spanning the states of Rio de Janeiro, São Paulo, Paraná and Santa Catarina. As a result, our study filled the distribution gap for this NIS along the southern Brazilian coast, highlighting the importance of citizen science in monitoring such species. Early detection of NIS is crucial for successful management, emphasising the utility of using non-traditional methods in biological invasion studies.

RESUMO

Em um mundo em constante mudança, o monitoramento da biodiversidade se mostra fundamental para a conservação de espécies nativas. Muitas dessas mudanças estão associadas a espécies invasoras, capazes de alterar a estrutura dos ecossistemas e as comunidades locais, com impactos negativos diretos sobre as espécies nativas. Novos registros de espécies invasoras são frequentemente obtidos por meio de métodos científicos tradicionais. No entanto, a ciência cidadã tem proporcionado importantes informações sobre a distribuição de espécies, através da observação voluntária por indivíduos fora do ambiente acadêmico. Plataformas como o iNaturalist têm revolucionado o entendimento espacial e temporal da biodiversidade. Recentemente, a espécie invasora Mexilhão-verde (*Perna viridis*) foi registrada nos estados do Rio de Janeiro e Ceará, Brasil. Entretanto, não havia

[Correction added on 18 February 2026, after first online publication: The copyright line was changed.]

registros oficiais para os demais estados ao longo da costa brasileira. Este estudo teve como objetivo utilizar métodos científicos tradicionais em conjunto com a ciência cidadã para atualizar o status de distribuição dessa espécie. Utilizando o método científico tradicional, um registro de *P. viridis* foi documentado no município de São Vicente, no estado de São Paulo, enquanto 42 registros foram obtidos pelo iNaturalist, distribuídos nos estados do Rio de Janeiro, São Paulo, Paraná e Santa Catarina. Dessa forma, nosso estudo preencheu lacunas na distribuição da espécie invasora ao longo da costa brasileira, demonstrando a importância da ciência cidadã no monitoramento dessas espécies. A detecção precoce de espécies invasoras é fundamental para um manejo eficaz, evidenciando a importância da utilização de métodos não tradicionais em estudos de invasão biológica.

1 | Introduction

In a world where human modification is increasingly causing habitat loss and unsustainable use, biodiversity data are crucial for the detection and understanding of local to global biodiversity changes (Stephenson and Stengel 2020). Changes made by anthropogenic pressures range from habitat modification and global warming to biological invasion. Biological invasion occurs when a non-native species is transported and introduced to a region outside its natural range, successfully establishing a population (Simberloff 1986; Blackburn et al. 2011). This transport can occur either unintentionally or intentionally through human activities (Vitousek et al. 1996).

Once well-established, these non-indigenous species (NIS) often cause numerous negative impacts on the ecosystems, such as seascape modification (Capel et al. 2020) and changes to community structure (David et al. 2017; Bradley et al. 2019) that may result in significant financial losses (Zenni et al. 2021). Due to the significance of these impacts on ecosystems, there is a need for reliable reference data for studies of current and future biodiversity distribution. Furthermore, it is important to understand the relationship between society and nature to place people as the main drivers of biodiversity changes (Dirzo et al. 2014; Mace et al. 2012).

Tipically, new records of non-indigenous species are gathered through traditional scientific surveys (de Paula and Creed 2004; Messano et al. 2019; Hidenburgo et al. 2022). However, citizen science can provide an important source of species distribution data (Lodi and Tardin 2018; Hiller and Haelewaters 2019; Encarnação et al. 2021). Citizen science provides an engagement opportunity that encourages people to participate in the conservation of natural resources by involving volunteers in the monitoring of biodiversity (Bonney et al. 2009), which can be accomplished with citizen science research projects (Cohn 2008; Dickinson and Bonney 2012). This voluntary participation of non-scientists in science comprises the inclusion of the non-academic community in science and helps land managers and conservationists understand patterns of species occurrence, biological invasion, erosion control, habitat restoration and changes over time (Schläppy et al. 2017; Kelly et al. 2020; Wehn et al. 2025).

One of the most globally successful platforms of citizen science is iNaturalist (www.inaturalist.org), a multitaxa platform and joint initiative for the California Academy of Sciences and the National Geographic Society. Today, iNaturalist is revolutionising our understanding of biodiversity at multiple spatial and temporal scales across diverse segments of society (Callaghan et al. 2022; Stephenson and Stengel 2020). All data uploaded on this platform are identified and verified to the highest possible taxonomic resolution by the iNaturalist community, in conjunction with the rapidly improving computer vision technologies (Callaghan et al. 2022; Stephenson and Stengel 2020). However, sometimes due to the lack of specialists, the quality of the record and the rarity of the species, identification can sometimes be made only to broad taxonomic groups. The iNaturalist community—as of May 2024—includes 7.6 million users, with 475 thousand species observed and approximately 190 million observations made to date.

Thus, the present study aims to couple new records with citizen science to bridge the gap in the invasion of the green mussel, *Perna viridis* (Linnaeus, 1758), along the Brazilian coast. This species is native to sub-tropical and tropical waters of the Indo-Pacific (Rajagopal et al. 2006) and has been previously reported on the Brazilian coast in the states of Paraná and Rio de Janeiro (Messano et al. 2019; Santos et al. 2023; Beltrão et al. 2024), and it is considered a marine high-risk invader worldwide (Dias et al. 2018). In 2022, a specimen was recorded in Ceará State, on the northeastern Brazilian coast (Soares et al. 2022); however, upon recent reanalysis, this record was confirmed to be misidentified and to belong to the *Mytella* genus (Arruda et al. 2024). This species has reached the North Atlantic in the last few decades (Rajagopal et al. 2006; Dias et al. 2018) causing economic losses due to its fouling capabilities (Rajagopal et al. 1995, 2006). Therefore, this manuscript aims to provide more comprehensive records regarding the expansion of *P. viridis* towards South Brazil.

2 | Material and Methods

Regarding open science platforms, we only used iNaturalist as a source of *P. viridis* records in the present study because other databases (e.g., OBIS and GBIF) either repeat the records from iNaturalist or lack data for Brazil. Thus, we considered iNaturalist as the most comprehensive platform for the data used herein. The data from citizen science were obtained through the iNaturalist platform on October/2024.

The research protocol used to gather citizen science records followed these steps: (1) a search was conducted for "*Perna viridis*" or "*Mexilhão verde*" (Brazilian Portuguese for green mussel); (2) the coverage area was delimited to Brazil using the filter section; and (3) the "Verifiable" and "Research level" boxes were selected, as shown in the workflow in the Supporting Information. The data were exported, and the registration locations and confirmations made by members of the platform were evaluated by the research group (Supporting Information 1). We confirmed the identification based on unique characteristics of the external shell described by Arruda et al. (2024): outline mytiliform with anterior side pointed and downturned, umbo terminal, thick

hinge plate with one large tooth in each valve, anterior margin short and sharp rounded, long and broadly rounded posterior margin and straight ventral margin. All these characteristics combined are unique to *P. viridis* and most of the time more than one can be seen in the records uploaded on iNaturalist, which guarantee its correct identification. In cases when more than one characteristic is not possible to visualise, guaranteeing its correct identification, the record was discarded from the present study.

The records taken on artificial structures, such as floatsam bottles, or empty shells have been included as they could be an indication of the species reaching new areas and potentially establishing itself, which aligns with our goal. Since the photographic records on citizen science platforms do not provide any size scale, it was not possible to infer the age or developmental stage of the green mussel.

Traditional scientific surveys of new records were conducted during low tide using a spatula apparatus on rocky shores at Gonzaguinha Beach (23.972 S, 46.384 W; Figure 1) located in the municipality of São Vicente, SP, Brazil in April/2024. The collected individuals were frozen at −20°C to ensure preservation and were later fixed and stored in 70% ethanol. Subsequently, the specimens were deposited in the IEAPM Scientific Collection. The present record, along with citizen science data, was confirmed using morphological characteristics based on literature (Micklem et al. 2016; Arruda et al. 2024).

3 | Results

3.1 | New Records and Citizen Science

Four specimens of *P. viridis* were sampled in São Vicente and deposited in the IEAPM Scientific Collection (IEAPM #4740). The data from iNaturalist revealed the occurrence of this species along the Brazilian coast in the following states: Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR) and Santa Catarina (SC), with the data from SP and SC representing new records for *P. viridis*. We found 47 records from 37 distinct observers who had uploaded their data to the platform; however, only 42 of these records are valid identifications (Supporting Information 2). The selected figures show examples of identification of *P. viridis* on the Brazilian coast, recorded and uploaded to iNaturalist by volunteer citizen scientists (Figure 2).

4 | Discussion

Since its first report in Brazil in 2018 (Messano et al. 2019), the green mussel has considerably expanded its range further in the Southwest Atlantic. The rapid expansion of *Perna viridis* along the Brazilian coast has been underreported by traditional scientific surveys. However, with the inclusion of citizen data, this study presents new records for the states of São Paulo and Santa Catarina, filling the gaps in the distribution of this species in southern Brazil. São Paulo borders Rio de Janeiro, where the first record was made. The introduction of *P. viridis* in Brazil is suggested to have occurred either through ballast water or as fouling on ships' hulls (Messano et al. 2019).

The expansion further south in Brazil may have occurred through fouling. Local marine transport has been found to facilitate the local spread of NIS (Ashton et al. 2014; Lacoursière-Roussel et al. 2016; Minchin et al. 2009), with more marine species reported due to the intensification of maritime traffic in recent decades. Thus, *P. viridis* may have spread towards southern Brazil as fouling on local ships' hulls. In fact, in the past few months, we have observed *P. viridis* attached to artificial structures such as buoys in both Arraial do Cabo—Rio de Janeiro (da Silva personal observation) and São Vicente—São Paulo (Cirillo personal observation), although it is found in low population densities.

The present new records, whether through traditional scientific surveys or citizen science, are close to ports and harbours. São Vicente is a city close to Santos, which is home to the largest port in South America (Port of Santos); in Paraná, the records were primarily collected in Paranaguá, which has the state's largest

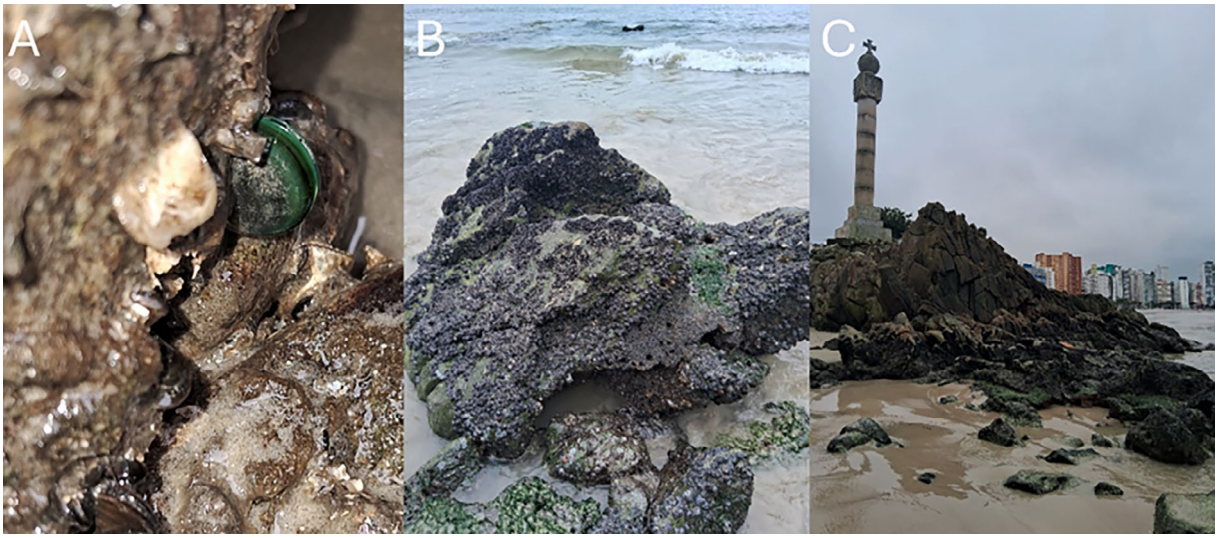

FIGURE 1 | Photos of one of the green mussels *Perna viridis* found at São Vicente, SP. (A) Solitary individual of *Perna viridis* found at intertidal region, (B) rock where the individual was found and (C) urban rocky shore where the four individuals used in traditional scientific survey were found.

port (Port of Paranaguá) and in Matinhos, a touristic destination with marinas that is also close to Paranguá (~36 km); finally, the records from Santa Catarina were taken in Bombinhas and São Francisco do Sul, in which the first is a famous touristic destination in Brazil, featuring several marinas, while the second is situated near a port complex in Babitonga Bay, with the highest cargo movement in the state (Knie et al. 2003; São Francisco Port https://www.portosaofrancisco.com.br/). The southward distribution of *P. viridis* in Brazil extends from Rio de Janeiro state to Santa Catarina state, a continuous coastal strip that serves as a corridor for commercial, leisure and fishery vessels, highlighting the probability and importance of these boats as dispersion vectors due to the fouling behaviour of the green mussel. Most records from citizen science were taken close to ports and highly populated areas, and it may be promoting more effort in those areas than in the least visited areas. Additionally, the southward expansion of *P. viridis* matches the environmental suitability models proposed for this species along the Brazilian coast (see Figure 2 in Messano et al. 2024).

The data gathered through iNaturalist suggest that the expansion of green mussel has probably occurred over the past 2 years (Figure 3). The first observation of green mussels registered on iNaturalist occurred in September 2022 in Rio de Janeiro, and the southernmost observation was made in June/2023 in Bombinhas, Santa Catarina. This indicates that *P. viridis* has spread approximately 1.000 km south in a timespan of roughly 5 years. Although these records were made in 2022 and 2023, this species may have arrived earlier, as citizen science data platforms have only recently gained popularity and widespread use (Callaghan et al. 2019). The timespan of sights through the iNaturalist platform has gathered more data than traditional scientific surveys; this highlights the importance of citizen science as a rapid tool for monitoring biodiversity in real time,

FIGURE 2 | Selection of *Perna viridis* records from iNaturalist. (A) *Perna viridis* by Áthila Bertoncini (@athilapeixe, record #199024440, CC-BY-NC-SA); (B, C) *Perna viridis* in Matinhos, PR, by Helena Ody Neves (@lenaody, records #195840590 and #196195923, CC-BY-NC); (D) *Perna viridis* in Peruíbe, SP, by Mongue (@mongue, record #203267493, CC-BY-NC).

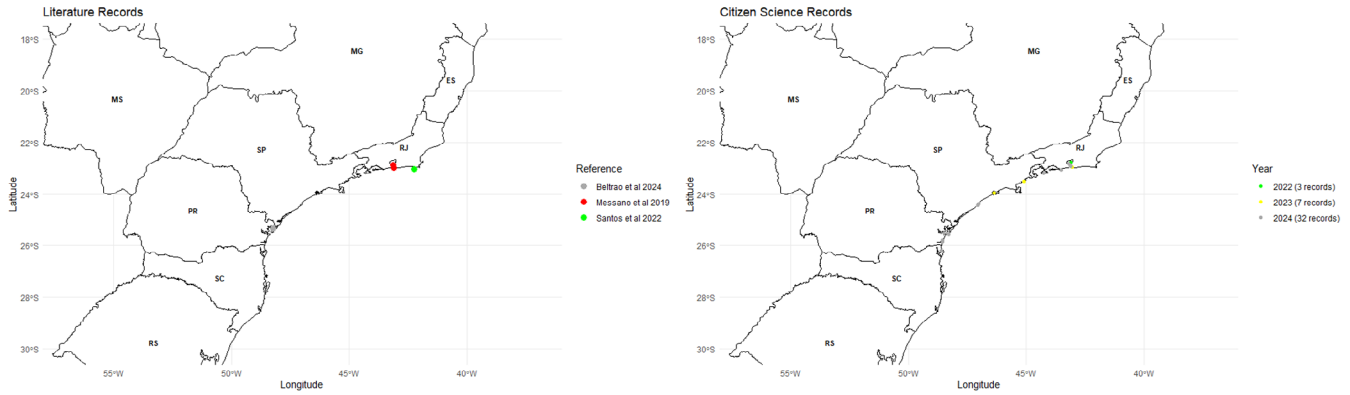

FIGURE 3 | Distribution records of the green mussel Perna viridis according to (A) Year when the literature data from traditional scientific methods were published and (B) citizen science data from the iNaturalist platform for the years 2022, 2023 and 2024, these years represent when the data were logged.

with the early detection of NIS being a crucial stage for management efforts, especially when populations are at low densities (Blackburn et al. 2011).

Recently—October 2024—a new record of *P. viridis* was added to iNaturalist at the Jureia-Itatins Ecological Station (#ID 246316350), located in the municipality of Peruibe/SP. This may be the first record, outside Rio de Janeiro state, for this NIS in Brazilian protected areas, being in one of the best-preserved and most biodiverse remnants of Atlantic rainforest along the São Paulo state coast. The presence of NIS in protected areas may impact native fauna at population, community and ecosystem scales (Carneiro et al. 2024), threatening the balance of ecosystems and vulnerable species in biodiverse hotspots (Bellard et al. 2014) by range displacement and changes in community structure and composition (Ziller et al. 2020). This record emphasises the importance of the iNaturalist observations of NIS for providing real-time data on a broader scale record than traditional scientific surveys.

Several projects that used citizen science to gather biodiversity records in recent years, mainly in Europe and North America, have yielded interesting and satisfactory results (van der Wal et al. 2015; Lodi and Tardin 2018; Hiller and Haelewaters 2019; Encarnação et al. 2021). However, some taxa are still underrepresented in those programs and platforms (Marchante et al. 2024). These types of projects can be a vital tool for monitoring species like *Perna viridis*, helping to understand, prevent and manage these rapidly spreading organisms. The green mussel is considered highly invasive (Rajagopal et al. 2006), presenting reproductive and feeding competitive advantages over commercially important species (e.g., brown mussel *Perna perna*) and native species, with the ability to displace them (Rajagopal et al. 2006; Garcia and Rangel-Buitrago 2020). Improved monitoring programmes based on citizen science can provide useful information for biodiversity research in marine environments, significantly reducing financial costs and time in the field. Such programmes contribute to biological knowledge, community awareness and environmental education.

In the study published by Beltrão et al. (2024), the sampling of *P. viridis* was conducted on 15 February 2023 in Paraná State, South Brazil, and it was published in July 2024. However, the first record published on open citizen science databases such as iNaturalist was made earlier, with the collection occurring on 2 September and the inclusion in the open database on 7 September 2023. Most of the records made through specialised literature and citizen science were made on areas of rocky substrate or artificial substrate. This supports the idea that citizen science databases help with the rapid response to the identification of areas threatened by NIS, since the publication and validation of the record can be done instantaneously after the data are collected, in this case with only a few days between the collection and the inclusion and availability of the data. It is important to highlight that in these platforms the records are published with no delay compared to the editorial process of traditional scientific publications; however, experts, taxonomists and scientists from related fields should be attracted to these platforms to ensure correct identification in order to avoid scientific bias.

Thus, citizen science is increasingly taking on the responsibility of bridging the complex interactions between research, society and policymaking in areas such as sustainability (Sauermann et al. 2020). As the open science movement continues to grow and strengthen, scientific research is tasked with fostering partnerships and sharing information, new knowledge and discoveries to address the rising complexity of scientific challenges and socio-environmental issues (Albagli et al. 2014). Therefore, citizen science data could be an important tool for biodiversity monitoring, providing a low-cost, efficient and real-time solution for the early detection of NIS species to Brazilian authorities and scientific centres, enhancing the effectiveness of managing these species.

Author Contributions

Marcos Akira-Umeno: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing. **Leonardo Cirillo:** conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing. **Alexandre Ribeiro da Silva:** conceptualization, data curation, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing.

Acknowledgements

Thanks to the iNaturalist platform and all its citizen scientists for their efforts and dedication to collaborating in the monitoring and conservation of biodiversity. The authors thank Dr. Leonardo Sousa for the discussions on *P. viridis* in Brazil. The Article Processing Charge (APC) for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES (ROR identifier: 00x0ma614). For the purpose of open access, the authors have assigned a Creative Commons CC BY license to any accepted version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data from citizen science are open source and available through iNaturalist platform. Also, we attached as Supporting Information the data gathered.

References

Albagli, S., A. Clinio, and S. Raychtock. 2014. "Open Science: Interpretive Trends and Types of Action." *Liin Cem Revista* 10, no. 2: 424–450. https://doi.org/10.18617/liinc.v10i2.749.

Arruda, E. P., L. B. Regis, M. Oliveira, et al. 2024. "An Erroneous Record of *Perna viridis* (Linnaeus, 1758) (Bivalvia, Mytilidae) for the Northeastern Coast of Brazil, Southwestern Atlantic." *Ocean and Coastal Management* 72: e24064.

Ashton, G., I. Davidson, and G. Ruiz. 2014. "Transient Small Boats as a Long-Distance Coastal Vector for Dispersal of Biofouling Organisms." *Estuaries and Coasts* 37: 1572–1581. https://doi.org/10.1007/s12237-014-9782-9.

Bellard, C., C. Leclerc, B. Leroy, et al. 2014. "Vulnerability of Biodiversity Hotspots to Global Change." *Global Ecology and Biogeography* 23, no. 12: 1376–1386. https://doi.org/10.1111/geb.12228.

Beltrão, M. C., N. J. R. da Cunha, Y. O. Laaf, et al. 2024. "Molecular Methods Confirm the First Report of the Non-Indigenous *Perna viridis* Linnaeus, 1758 (Mytilida, Mytilidae) in Southern Brazil." *Check List* 20, no. 4: 859–867. https://doi.org/10.15560/20.4.859.

Blackburn, T. M., P. Pysek, S. Bacher, et al. 2011. "A Proposed Unified Framework for Biological Invasions." *Trends in Ecology & Evolution* 26, no. 7: 333–339.

Bonney, R., C. B. Cooper, J. Dickinson, et al. 2009. "Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy." *Bioscience* 59: 977–984. https://doi.org/10.1525/bio.2009.59.11.9.

Bradley, B. A., B. B. Laginhas, R. Whitlock, et al. 2019. "Disentangling the Abundance–Impact Relationship for Invasive Species." *Proceedings of the National Academy of Sciences of the United States of America* 116, no. 20: 9919–9924.

Callaghan, C. T., A. G. B. Poore, R. E. Major, J. J. L. Rowley, and W. K. Cornwell. 2019. "Optimizing Future Biodiversity Sampling by Citizen Scientists." *Proceedings of the Royal Society B* 286: 20191487. https://doi.org/10.1098/rspb.2019.1487.

Callaghan, C. T., T. Mesaglio, J. S. Ascher, et al. 2022. "The Benefits of Contributing to the Citizen Science Platform iNaturalist as an Identifier." *PLoS Biology* 20: e3001843. https://doi.org/10.1371/journal.pbio.3001843.

Capel, K. C. C., M. V. Kitahara, J. C. Creed, and C. Zilberberg. 2020. "Invasive Corals Trigger Seascape Changes in the Southwestern Atlantic." *Bulletin of Marine Science* 85, no. 1: 217–218.

Carneiro, L., N. O. R. Miiler, R. N. Cuthbert, and J. R. S. Vitule. 2024. "Biological Invasions Negatively Impact Global Protected Areas." *Science of the Total Environment* 948: 174823. https://doi.org/10.1016/j.scitotenv.2024.174823.

Cohn, J. P. 2008. "Citizen Science: Can Volunteers Do Real Research?" *Bioscience* 58, no. 3: 192–197. https://doi.org/10.1641/B580303.

David, P., E. Thebault, O. Anneville, et al. 2017. "Impacts of Invasive Species on Food Webs: A Review of Empirical Data." *Advances in Ecological Research* 56: 1–60.

de Paula, A. F., and J. C. Creed. 2004. "Two Species of the Coral *Tubastraea* (Cnidaria, Scleractinia) in Brazil: A Case of Accidental Introduction." *Bulletin of Marine Science* 9: 175–183.

Dias, P. J., M. R. Gilg, S. S. Lukehurst, et al. 2018. "Genetic Diversity of a Hitchhiker and Prized Food Source in the Anthropocene: The Asian Green Mussel *Perna viridis* (Mollusca, Mytilidae)." *Biological Invasions* 20, no. 7: 1749–1770. https://doi.org/10.1007/s10530-018-1659-6.

Dickinson, J., and R. Bonney. 2012. *Why Citizen Science? Citizen Science: Public Participation in Environmental Research*, 1–14. *Cornell University Press*.

Dirzo, R., H. S. Young, M. Galetti, G. Ceballos, N. J. B. Isaac, and B. Collen. 2014. "Defaunation in the Anthropocene." *Science* 345: 401–406. https://doi.org/10.1126/science.1251817.

Encarnação, J., M. A. Teodósio, and P. Morais. 2021. "Citizen Science and Biological Invasions: A Review." *Frontiers in Environmental Science* 8: 602980. https://doi.org/10.3389/fenvs.2020.602980.

Garcia, A. C., and N. Rangel-Buitrago. 2020. "The Invasive Species *Perna viridis* (Linnaeus, 1758—Bivalvia: Mytilidae) on Artificial Substrates: A Baseline Assessment for the Colombian Caribbean Sea." *Marine Pollution Bulletin* 152: 110926. https://doi.org/10.1016/j.marpolbul.2020.110926.

Hidenburgo, I., D. E. G. Martins, A. G. C. Klautau, et al. 2022. "The Bioinvasion of Lionfish *Pterois volitans* (Linnaeus, 1758) in Brazilian Waters: An Urgent Necessity to Create Strategies to Contain the Expansion of the Species in Brazil." *Research Square*: 1–14. https://doi.org/10.21203/rs.3.rs-2203913/v1.

Hiller, T., and D. Haelewaters. 2019. "A Case of Silent Invasion: Citizen Science Confirms the Presence of *Harmonia axyridis* (Coleoptera, Coccinellidae) in Central America." *PLoS One* 14, no. 7: e0220082. https://doi.org/10.1371/journal.pone.0220082.

Kelly, R., A. Fleming, G. T. Pecl, et al. 2020. "Citizen Science and Marine Conservation: A Global Review: Citizen Science and Marine Conservation." *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 375: 20190461. https://doi.org/10.1098/rstb.2019.0461.

Knie, J. L. W., B. G. Catarina, and F. D. Catarina. 2003. *Atlas Ambiental da Região de Joinville: Complexo Hídrico da Baía da Babitonga*, 144. Academic Press.

Lacoursière-Roussel, A., D. G. Bock, M. E. Cristescu, F. Guichard, and C. W. McKindsey. 2016. "Effect of Shipping Traffic on Biofouling Invasion Success at Population and Community Levels." *Biological Invasions* 18, no. 12: 3681–3695. https://doi.org/10.1007/s10530-016-1258-3.

Lodi, L., and R. Tardin. 2018. "Citizen Science Contributes to the Understanding of the Occurrence and Distribution of Cetaceans in Southeastern Brazil–a Case Study." *Ocean and Coastal Management* 158: 45–55. https://doi.org/10.1016/j.ocecoaman.2018.03.029.

Mace, G. M., K. Norris, and A. H. Fitter. 2012. "Biodiversity and Ecosystem Services: A Multilayered Relationship." *Trends in Ecology & Evolution* 27: 19–26. https://doi.org/10.1016/j.tree.2011.08.006.

Marchante, E., F. A. López-Núñez, L. N. Duarte, and H. Marchante. 2024. "The Role of Citizen Science in Biodiversity Monitoring: When Invasive Species and Insects Meet." In *Biological Invasions and Global Insect Decline*, edited by E. Marchante, F. A. López-Núñez, L. N. Duarte, and H. Marchante, 291–314. Academic Press.

Messano, L. D., J. E. A. Gonçalves, H. F. Messano, et al. 2019. "First Report of the Asian Green Mussel *Perna viridis* (Linnaeus, 1758) in Rio de Janeiro, Brazil: A New Record for the Southern Atlantic Ocean." *BioInvasions Records* 8, no. 3: 653–660. https://doi.org/10.3391/bir.2019.8.3.22.

Messano, L. V. R., J. E. A. Gonçalves, A. D. Kassuga, et al. 2024. "Updated Range Distribution of the Non-Native Asian Green Mussel *Perna viridis* (Linnaeus, 1758) at Guanabara Bay, Rio de Janeiro, Brazil." *PeerJ* 12: e18649. https://doi.org/10.7717/peerj.18649.

Micklem, J. M., C. L. Griffiths, N. Ntuli, and M. Mwale. 2016. "The Invasive Asian Green Mussel Perna Viridis in South Africa: All That is Green is Not Viridis." *African Journal of Marine Science* 38, no. 2: 207–215. https://doi.org/10.2989/1814232X.2016.1180323.

Minchin, D., S. Gollasch, A. N. Cohen, et al. 2009. "Characterizing Vectors of Marine Invasion." In *Biological Invasions in Marine Ecosystems: Ecological, Management, and Geographic Perspectives*, 109–116. Springer.

Rajagopal, S., V. P. Venugopalan, G. Van der Velde, and H. A. Jenner. 2006. "Greening of the Coasts: A Review of the *Perna viridis* Success Story." *Aquatic Ecology* 40: 273–297. https://doi.org/10.1007/s10452-006-9032-8.

Rajagopal, S., V. P. Venugopalan, K. Nair, K. V. K. Nair, and J. Azariah. 1995. "Response of Green Mussel, *Perna viridis* (L.) to Chlorine in the Context of Power Plant Biofouling Control." *Marine and Freshwater Behaviour and Physiology* 25, no. 4: 261–274. https://doi.org/10.1080/10236249509378922.

Santos, H. S., J. C. Bertollo, and J. C. Creed. 2023. "Range Extension of the Asian Green Mussel *Perna viridis* (Linnaeus, 1758) Into a Marine Extractive Reserve in Brazil." *BioInvasions Records* 12: 208–222. https://doi.org/10.3391/bir.2023.12.1.17.

Sauermann, H., K. Vohland, V. Antoniou, et al. 2020. "Citizen Science and Sustainability Transitions." *Research Policy* 49, no. 5: 103978. https://doi.org/10.1016/j.respol.2020.103978.

Schläppy, M. L., J. Loder, J. Salmond, A. Lea, A. J. Dean, and C. M. Roelfsema. 2017. "Making Waves: Marine Citizen Science for Impact." *Frontiers in Marine Science* 4: 146. https://doi.org/10.3389/fmars.2017.00146.

Simberloff, D. 1986. "The Proximate Causes of Extinction." In *Patterns and Processes in the History of Life*, 259–276. Springer.

Soares, M. O., F. R. Xavier, N. M. Dias, et al. 2022. "Alien Hotspot: Benthic Marine Species Introduced in the Brazilian Semiarid Coast." *Marine Pollution Bulletin* 174: 113250. https://doi.org/10.1016/j.marpolbul.2021.113250.

Stephenson, P. J., and C. Stengel. 2020. "An Inventory of Biodiversity Data Sources for Conservation Monitoring." *PLoS One* 10: e0242923.

van der Wal, R., H. Anderson, and A. Robinson. 2015. "Mapping Species Distributions: A Comparison of Skilled Naturalist and Lay Citizen Science Recording." *Journal of Scientific Communication* 44: 584–600. https://doi.org/10.1007/s13280-015-0709-x.

Vitousek, P. M., C. M. d'Antonio, L. L. Loope, and R. Westbrooks. 1996. "Biological Invasions as Global Environmental Change." *American Scientist* 84, no. 5: 468–478.

Wehn, U., E. A. Bilbao, L. Somerwill, et al. 2025. "Past and Present Marine Citizen Science Around the Globe: A Cumulative Inventory of Initiatives and Data Produced." *Ambio*. https://doi.org/10.1007/s13280-024-02119-z.

Zenni, R. D., F. Essl, E. García-Berthou, and S. M. McDermott. 2021. "The Economic Costs of Biological Invasions Arou Nd the World." *NeoBiota* 67: 1–9. https://doi.org/10.3897/neobiota.67.69971.

Ziller, S. R., M. S. Dechoum, S. R. A. Duarte, et al. 2020. "A Priority-Setting Scheme for the Management of Invasive Non-Native Species in Protected Areas." *NeoBiota* 62: 591–606. https://doi.org/10.3897/neobiota.62.52633.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.