Monitoring and Mapping of Invasive Aquatic Species Transported with Shipping as Vector

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Monitoring and Mapping of Invasive Aquatic Species Transported with Shipping as Vector

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Abstract

Shipping facilitates the transfer of aquatic organisms between different sea areas and enables invasive species to cross their natural dispersion limits. In this work we illustrate possible ways to trace and predict species invasions using ship traffic data. First, we exemplify with two sea squirts (growing attached to surfaces and ship hulls), by tracing back the traffic pattern at the time of their introduction. Secondly, the motile blue crab is used as an example to identify the data and information needed to predict possible locations for coming invasions. The cases are based on i) historical ship traffic data from Automated Information System (AIS) ii) recent or expected invaders for a certain location and iii) ports in the Northeast Atlantic with high risk for receiving invasive species. Within the growing and dynamic shipping industry both routes and number of ships for specific routes will change over time which also is illustrated in this work. In the end we summarize parameters that needs to be considered for work with ship traffic-based predictions of invasive species.

1. Introduction

Generally, global shipping increases in frequency and connectivity as well as liner size, *Hoffmann et al. (2017).* Biofouling on ships is shown to be responsible for a large share (56 – 69 %) of coastal transfers of Non Indigenous Species worldwide, *Galil et al. (2019)*. The relatively short transfer time of ships can transport marine organisms fast enough to survive and still be viable upon arrival in new areas. Highly connected ports are frequented by vessels from different geographical regions, and therefore possibly receive both a high number and variety of potential invaders. Ports, as the arrival place of potential invasives, are globally characterized with hard substrate, sheltered environmental conditions and high pollution. Hence, increasing shipping connectivity leads to more introductions of potential pest species in ecosystems that are already weakened due to heavy human alteration and climate change. The establishment of non-native species is favored by an impacted ecosystem, where declining biodiversity make the systems more vulnerable. The species present in the departure port are likely to survive and be successful in an arrival port with similar salinity and temperature range, *Gollasch and Leppäkoski (2007).* From there secondary spread, either by stepping stones like jetties or other artificial structures, or as biofouling on ships in local traffic and leisure boats is possible.

The marine species can be transferred to new areas via shipping in three ways, either in ballast water, as attached to the hull or associated with specific hull structures, *Schimanski et al. (2017).* Within ships ballast water species are transferred in their small larval stages as free-swimming plankton. The IMO Ballast Water Management Convention (valid for existing ships from September 2024) aim to minimize the transfer of these planktonic stages. Regarding measures to control biofouling, the IMO Biofouling guidelines were updated 2023, except the part regarding In Water Hull Cleaning (where work is ongoing in 2024). In addition to biofouling on the flat hull surfaces, special structures or areas, so-called niche areas of ships are considered hotspots for transfer of aquatic organisms, however not yet much studied, *Davidson et al. (2009), Coutts et al. (2010).*

Financially speaking, species invasions have different cost points:

1. Cost for loss of Ecosystem services, such as limiting protection of the coastline by for example seagrass meadows, which also act as nurseries for fish, that later contribute to fishery, predation on commercial fish etc.
2. Cleaning costs, such as in water hull cleaning to ensure performance of ship in terms of speed and maneuverability or cleaning of cooling water intakes used by various industries.
3. Eradication and management costs (ie restoration of habitats, harvesting)

To avoid cost and damage to the marine ecosystems, fast detection, and early measures to hinder further spread of the species is key. Efforts after establishment, if even possible, will be both time consuming and costly. To visually detect new species in the marine environment is however a challenge and much more difficult to follow compared to an introduction on land.

Today monitoring of marine environments is conducted on a national basis where programs vary between countries both in number of sampling stations, frequency and methods used. Various tools that enhance reporting of new species as regional/or national platforms severely benefit an efficient management of invasive species. Citizen reporting of invasive species has proven successful in several countries, *Lehtiniemi et al. (2020).* Within these systems citizen observers report the sighting of species (place and date), which is validated by taxonomic experts and reported into national databases. Databases for species distribution spanning over larger geographical areas can be used to find so called “door knocking species” to specific countries or regions (ie species that are not present yet but likely to arrive in a near future). Examples of species distribution databases are WORMS (mainly used in this study) AquaNIS and gbif (links provided in references).

According to EU-Marine Strategy Framework Directive (MSFD) each member state in EU has to consider Non-Indigenous Species (NIS) in their management strategies. The Non-Indigenous Species treated under Descriptor D2 includes one primary criterion (D2C1: new NIS introductions) and within six-year cycles each member state are obliged to reports the status (i.e. if Good Environmental Status is reached) for each water basin. In regard to shipping and to provide a globally consistent approach to manage biofouling on ship hulls the above-mentioned IMO Biofouling guidelines (2023) are available, as a guidance. This can be compared to the IMO Ballast Water Management Convention, in force from September 2024, which strictly require that all ships in international trade treat the ballast water before discharge. The global IMO regulations are developed to “protect” different countries from new introductions of invasive species. In our examples, we follow the current administrative setup of invasive species mitigation, taking on national (in this case Norwegian and Swedish) perspectives. However, as marine organisms do not sense or detect any borders, the current national approaches could be improved by instead or in addition using regional areas or water basins, considering geographic and oceanographic parameters.

2. Tracing back invasive species - possibilities to mitigate species invasions using shipping data

The examples presented are selected based on i) species known to have shipping as vector for transfer ii) port of first arrival for the specific invader is located in a prior uninfected geographic area.

The aim for the first two examples was to investigate if changes in shipping patterns can be used for predictions of new NIS arrivals and serve as basis for future rapid mitigation of NIS invasions. The two well-known invasive tunicates *Didemnum vexillium* (sea carpet) and *Styela clava* (club tunicate) were from their respective time of invasion traced back by analyzing historical AIS data.

In the example with the crab *Callinectes sapidus* (blue crab) we instead reason on how to use shipping routes and patterns as a measure to predict future plausible or “risky” ports for arrival.

2.1. Example sea carpet tunicate *Didemnum vexillium* to Engøysundet, Stavanger, Norway

Didemnum vexillium originally native to Japan, recently has been recorded as established over the west coast of Scandinavia, where it first arrived in Engøysundet in Stavanger (Norway) in 2020, Fig.1. *D.*

vexillium is growing and spread as (carpet like) colonies and shown to be transported over 100 km *Fletcher et al. (2013). D. vexillum* rapidly overgrows rocks, shellfish, and other organisms (e.g. sponges, hydroids, tunicates, algae) and has the potential to cause economic damage to fisheries and aquaculture. It can also have negative ecological impacts and in some areas its rapid expansion has reduced the abundance of previously established benthic species like for example the blue mussel *Mytilus edulis, Auker (2010). D. vexillium* is preliminarily associated with pontoons, platforms, and ships and boats with long inactive times in ports, *Manson and Brown (2011),* therefore it is hypothesized to travel with slow moving big structures such as towed jetties, as well as leisure boats.

Transactions from 55 ports, Fig.1, within the distribution area of *D. vexillium* were used for the analysis of potential shipping vector of invasion to Norway. Shipping data (Sea-Web database) from 2018-2020 including transits from British Isles to Engøysundet, Stavanger, were analyzed to identify changes in patterns or intensity that could be associated with the invasion event in 2020.

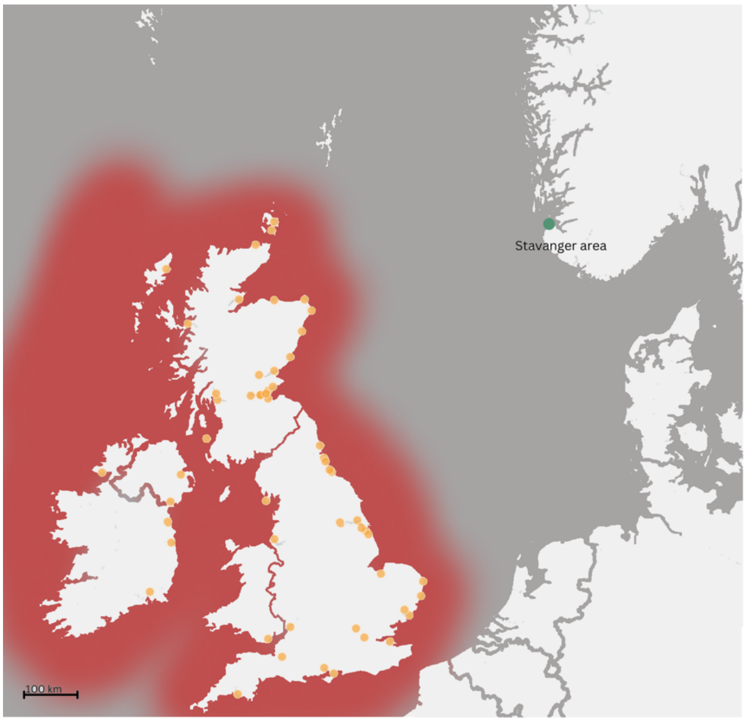

Fig.1: Shipping as potential vector for *Didemnum vexillium* invasion to Norway: *D. vexillium* was first observed in Stavanger area, transactions from ports (marked in orange) to Stavanger area, within the distribution range (marked red) in the years 2018-2020 were analyzed to identify changes in patterns or intensity that could be associated with the invasion event in 2020.

In a selected smaller set of data, including only the most likely vessel type to carry *D. vexillium,* pontoon-like structures, the transactions from the infected coastline of the British Isles increased gradually from three in 2017, six in 2018 to nine in 2019, Fig.2. The total number of transits are in total 14, where pipelayer crane ship was the most abundant. Establishment of new species has shown to occur even with an initial low concentration of invasive individuals, *Clarke and Therriault (n.d.), Lange and Marshall (2016).* With these few ships, it could potentially be interesting to investigate the cleaning records of the distinct vessels both in regard to find traces of *D. vexillium* and (if cleaning not was performed) advice on that for the future.

Additionally, there was seen to be a variation in number of ships in traffic to Stavanger between the years for the different ports in the British Isles (Figure 3), with some ports having departure during all three years, some two of the years and others only a single year. The insecurity due to a lack of high-resolution distribution data of *D. vexillium* in the actual ports, could, in combination with the varying spatial departure pattern, make it difficult to predict invasion risk.

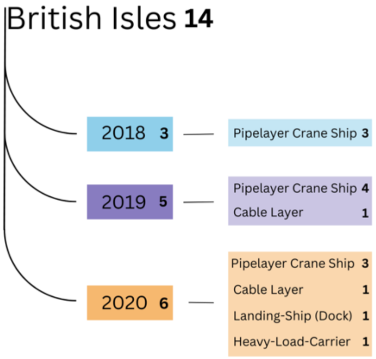

Fig.2: Changes in shipping intensity of potential high-risk ships and structures for D. *vexillium* invasion: including all ships that inhabit pontoon/platform like structures, the 14 transactions from the area of *D. vexillium* distribution around the British Isles are divided by year and ship type. 2018 (three): three pipelayer crane ships, 2019 (six) four pipelayer crane ships, and one cable layer, 2020 (nine): three pipelayer crane ships, one cable layer, one Dock, and one Heavy Load Carrier.

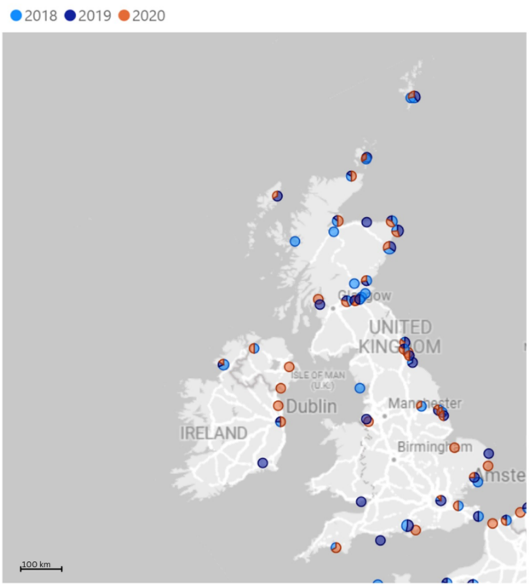

Fig.3: Variation in departures to Stavanger between the years for the different British Isles ports: Ports of origin to Stavanger Area, over the Years 2018 (light blue), 2019 (dark blue), 2020 (orange).

2.2. Example club tunicate *Styela clava* to Brofjorden, Lysekil, Swedish Westcoast

With *Styela Clava* being present at the British Isles, as well as in more temperate regions like the west coast of Spain, Portugal and Marocco (WORMS), Fig.4, its spread towards other places with matching habitats is inevitable. *S. clava* grows rapidly and can quickly reach high densities, i.e. compete with present communities for food and space. While there is some knowledge about the settlement preferences of S. *clava* and other tunicates on antifouling paints, *Locke et al. (2009),* species specific preferences concerning vessel types are unknown.

Transactions were analyzed using AIS data from 2016 to 2024 from potentially infested ports in the North East Atlantic Area including British Isles, France, Portugal, and the west coast of Spain to Brofjorden area, where S. *clava* was first recorded in Sweden 2022 (Rappen). In 2017, 181 vessels to Brofjorden area were recorded, the transactions then decreased gradually to 64 vessels in 2023. Transaction based on the total fleet were not found as indicator for this invasion event and information of *S. clava* preferences for ship types are lacking, why further processing not was possible. However (as also written above) a small number of infected vessels, even down to one, can cause the establishment of an invasive species. The countries bordering to Sweden (Denmark and Norway) were not included as potential donor areas in this analysis as natural spread (ocean currents) and secondary spread (local shipping and leisure boating) also are considered as possible vectors.

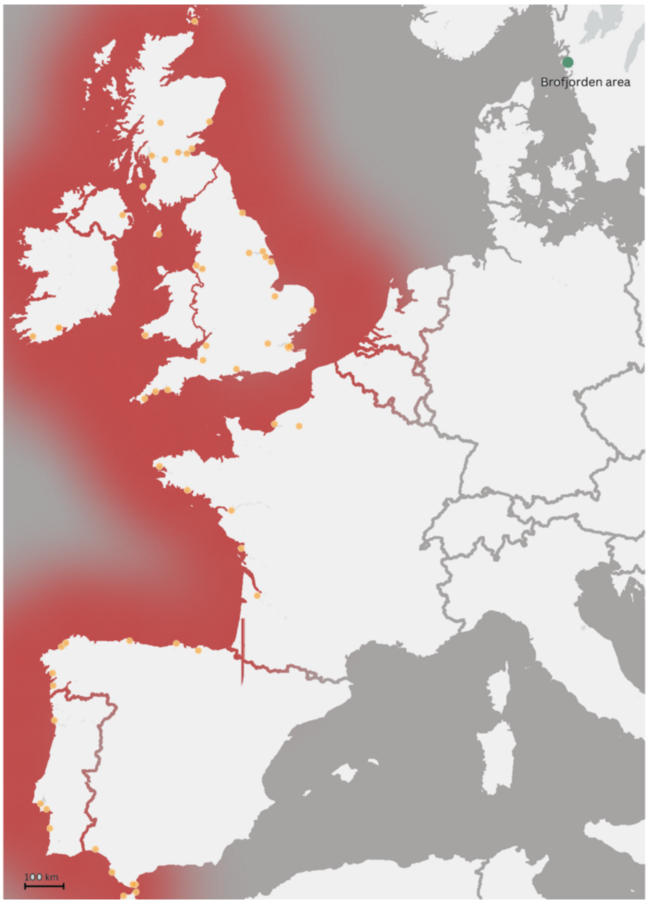

Fig.4: Ports of origin (orange dots) used for the analysis of potential shipping vector for Styela clava invasion to Sweden: S. clava was first observed in Brofjorden area (marked in green), transactions from ports (marked in orange) to Brofjorden area, within the distribution range (marked red) of the Years 2017-2023 were analyzed to identify changes in patterns or intensity that could be associated with the invasion event in 2022.

2.3. Example Predict *Callinectes sapidus* first arrival to Sweden

The blue crab is here used as an example of how to use shipping patterns as a management tool in predicting invasions. First present in Europe in 1901, the blue crab is now present in seven of the nine south European marine ecoregions (the Mediterranean Sea), after a rapid extension of the species from 2010, *Clavero et al. (2022).* Mating and nursing of *C. sapidus* is done in low salinity environments and survival and reproduction are impacted in temperatures below 10°, *Serc et al. (2007).* Global warming with rising temperatures in the Baltic Sea and Kattegat-Skagerrak Area (Swedish coasts) could therefor lead to increase in favorable conditions for *C. sapidus*. Adult individuals of the blue crab can potentially travel in niche areas, and on heavily fouled hulls, *Nehring et al. (2011)*, while larvae have been found in high concentrations in cooling and ballast water, *Galil et al. (2006), Nehring et al. (2011)*. *C. sapidus* can function as a so-called keystone species in the invaded ecosystems, leading to that native species like the green crab reduce drastically in abundance, and the ecosystem is instead shaped by the new species, *Clavero et al. (2022).* The potential invasion to Swedish waters and especially the Baltic Sea therefore could lead to severe impacts on ecosystems, ecosystem functions and fishery resources. Since *C. sapidus* is an impactful invader in the Mediterranean, management plans of mitigation and eradication are tested and known, *Marchessaux et al. (2023),* such as preventive catching pots close to high-risk ports, *Cerri et al. (2020),* specific hull-cleaning methods on high-risk transfers and an increase in fishing pressure on the blue crab in already infected areas. Knowledge about the connectivity of invasive species populations is key (see above) in management actions, *Hulme (2006),* and for *C. sapidus* until now mostly unknown. Wider screenings and specification of potential vectors of invasion, such as vessel type, may lead to higher success probabilities in mitigation of establishment of *C. sapidus* in Swedish waters and the Baltic Sea, *Mancinelli et al. (2017). C. sapidus* stands as an example of a species whose invasion to Swedish waters can potentially be mitigated, if specific monitoring and preventive low impact measures are implemented. Research that provides detailed information on biological traits, in combination with shipping analysis and suggestions of action plans to authorities are needed.

2.4. Result summary

For the sea carpet an increase in traffic from the infested area coincided in time with the first finding of the species at the Norwegian west coast. The analysis was based on specific ship types considered to facilitate transfer of the sea carpet. For the club tunicate, instead the total number of vessels arriving from the identified risk area was used and it was shown to decrease during the time period of interest. Data on what ship types most likely to transfer the specific species is crucial for the analyses.

For the blue crab and other so called "door knocking species" (not yet in area of interest but detected in nearby areas) frequent monitoring and updated, comprehensive and accessible distribution data is key to prevent future invasions.

3. Discussion and conclusion

To enable tracing back of invasion events will require thorough knowledge about the specific species of interest as well as the shipping vector. Data needed for species are in addition to the distribution range and first recordings also the so-called biological traits like temperature and salinity limits, reproduction and spread, habitat preferences etc. To identify high-risk vessels, ports and pathways, the vessel characteristics and shipping patterns are needed. Predicting invasions using AIS data of ship traffic is therefore possible if enough data about both species of interest, transfer and port att risk is present.

Adding known invaders like the blue crab to EU monitoring and making the data available in a comprehensive and accessible way, is key to prevent future invasions. Port monitoring with traditional identification methods are time-consuming and costly, and in addition is the taxonomic expertise getting more difficult to reach. The use of molecular techniques in monitoring is therefore timely, and with eDNA can for example water samples be used to identify the species present.

While this study only focused on importance of shipping as vector also other ways of introduction like aquaculture should optimally be included for a more complete picture of invasions. Also, secondary spread with local traffic and leisure boating needs to be described as well as the importance of natural spread with ocean currents setting the dispersal limits for specific species.

In conclusion, to identify high-risk vessels, ports, and pathways, preventing future invasions, following information should be investigated:

i. The potential invasive species habitat requirements and tolerance in transport
ii. The potential invasive species preferred invasion vector
iii. The species distribution (updated data)
iv. Ecological habitats of connected ports
v. Vessel characteristics, such as presence of niche areas, hull cleaning protocols, etc
vi. Shipping patterns between ports in infected areas and non-infected areas

Acknowledgement

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References

AUKER, L.A. (2010) *The effects of Didemnum vexillum overgrowth on Mytilus edulis biology and ecology*, PhD thesis, University of New Hampshire

CERRI, J.; CHIESA, S.; BOLOGNINI, L.; MANCINELLI, G.; GRATI, F.; DRAGIČEVIĆ, B.; DULČIC, J.; AZZURRO, E. (2020), *Using online questionnaires to assess marine bio-invasions: A demonstration with recreational fishers and the Atlantic blue crab Callinectes sapidus (Rathbun, 1986) along three Mediterranean countries*, Marine Pollution Bulletin 156, https://doi.org/10.1016/j.marpolbul.2020.111209

CLARKE, C.L.; THERRIAULT, T.W. *(n.d.), Biological Synopsis of the Invasive Tunicate Styela clava (Herdman 1881),* Canadian Manuscript Report of Fisheries and Aquatic Sciences 2807

CLAVERO, M.; FRANCH, N.; BERNARDO-MADRID, R.; LÓPEZ, V.; ABELLÓ, P.; QUERAL, J.M.; MANCINELLI, G. (2022), *Severe, rapid and widespread impacts of an Atlantic blue crab invasion*, Marine Pollution Bulletin 176, https://doi.org/10.1016/j.marpolbul.2022.113479

COUTTS, A.D.M.; PIOLA, R.F.; TAYLOR, M.D.; HEWITT, C.L.; GARDNER, J.P.A. (2010), *The effect of vessel speed on the survivorship of biofouling organisms at different hull locations*, Biofouling 26(5), pp.539–553

DAVENPORT, J.; DAVENPORT, J.L. (2006), *Ecology of Transportation: Managing Mobility for the Environment*, Springer

DAVIDSON, I.C.; BROWN, C.W.; SYTSMA, M.D.; RUIZ, G.M. (2009), The role of containerships as transfer mechanisms of marine biofouling species, *Biofouling 25*(7), pp.645–655

FLETCHER, L.M.; FORREST, B.M.; BELL, J.J. (2013), *Natural dispersal mechanisms and dispersal potential of the invasive ascidian Didemnum vexillum,* Biological Invasions 15(3), pp.627–643

GALIL, B.S.; CLARK, P.F.; CARLTON, J.T. (2011), *In the Wrong Place-Alien Marine Crustaceans: Distribution, Biology and Impacts,* www.springer.com/series/7228

GALIL, B.S., McKENZIE, C.; BAILEY, S.; CAMPBELL, M.; DAVIDSON, I.; DRAKE, L.; HEWITT, C.; OCCHIPINTI-AMBROGI, A.; PIOLA, R. (2019), *ICES Viewpoint background document: Evaluating and mitigating introduction of marine non-native species via vessel biofouling,* ICES, https://doi.org/10.17895/ices.pub.4680

GOLLASCH, S.; LEPPÄKOSKI, E. (2007), *Risk assessment and management scenarios for ballast water mediated species introductions into the Baltic Sea*, Aquatic Invasions, 2(4), pp.313–340. https://doi.org/10.3391/ai.2007.2.4.3

HOFFMANN, J.; WILMSMEIER, G.; LUN, Y.H.V. (2017), *Connecting the world through global shipping networks*, J. Shipping and Trade, 2(1), https://doi.org/10.1186/s41072-017-0020-z

HULME, P.E. (2006), *Beyond control: Wider implications for the management of biological invasions*, J. Applied Ecology 43/5, pp.835–847, https://doi.org/10.1111/j.1365-2664.2006.01227.x

LANGE, R.; MARSHALL, D.J. (2016), *Propagule size and dispersal costs mediate establishment success of an invasive species*, Ecology 97(3), pp.569–575, https://doi.org/10.1890/15-1573

LEHTINIEMI, M. ; OUTINEN, O. ; PUNTILA-DODD, R. (2020), *Citizen science provides added value in the monitoring for coastal non-indigenous species*, J. Environmental Management 267, https://doi.org/10.1016/j.jenvman.2020.110608

LOCKE, A.; CARMAN, M.; DARBYSON, E.A.; HANSON, J.M.; WILLISON, J.H.M. (2009), *Settlement and potential for transport of clubbed tunicate (Styela clava) on boat hulls*, Aquatic Invasions 4, https://doi.org/10.3391/ai

MANCINELLI, G.; CHAINHO, P.; CILENTI, L.; FALCO, S.; KAPIRIS, K.; KATSELIS, G.; RIBEIRO, F. (2017), *The Atlantic blue crab Callinectes sapidus in southern European coastal waters: Distribution, impact and prospective invasion management strategies*, Marine Pollution Bulletin 119/1, pp.5–11, https://doi.org/10.1016/j.marpolbul.2017.02.050

MANSON, F.; BROWN, K. (2011), *Initial response to the invasive carpet sea squirt, Didemnum vexillum, in Scotland Initial response to the invasive carpet sea squirt, Didemnum vexillum, in Scotland,* Commissioned Report

MARCHESSAUX, G.; MANGANO, M.C.; BIZZARRI, S.; M'RABET, C.; PRINCIPATO, E.; LAGO, N.; VEYSSIERE, D.; GARRIDO, M.; SCYPHERS, S.B.; SARÀ, G. (2023), *Invasive blue crabs and small-scale fisheries in the Mediterranean Sea: Local ecological knowledge, impacts and future management*, Marine Policy 148. https://doi.org/10.1016/j.marpol.2022.105461

SCHIMANSKI, K.B.; GOLDSTIEN, S.J.; HOPKINS, G.A.; ATALAH, J.; FLOERL, O. (2017), *Life history stage and vessel voyage profile can influence shipping-mediated propagule pressure of non-indigenous biofouling species*, Biological Invasions 19(7), pp.2089–2099

Species Distribution Databases:

WoRMS - World Register of Marine Species: https://www.marinespecies.org/index.php

AquaNIS: http://www.corpi.ku.lt/databases/index.php/aquanis/

Gbif: https://www.gbif.org

Rappen Reporting (artfakta.se): https://rapportera.artfakta.se/eftersokta/rappen/taxa