Updated assessment of the distribution, status and impacts of marine non-indigenous and other newcomer species in the Maltese waters.

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Declaration of Authority

I, the undersigned, declare that this dissertation is my own original work, except as acknowledged in the text, and that it was carried out under the supervision of Dr Julian Evans. I have clearly indicated where I have used the published or unpublished work of others and I have provided the source of such work. I have acknowledged all main sources of help, and where the work was done jointly with others, I have specified what I have contributed and what has been contributed by others. Any conclusions, suggestions or assumptions are mine unless otherwise stated or attributed.

Signature

JAAP H. J. SCHRIKS

DATE:_____

I declare that I have abided by the University's Research Ethics Review Procedures.

Signature

JAAP H. J. SCHRIKS

DATE:_____

The undersigned confirm that this dissertation has been undertaken under their supervision and that they approve of its submission for final assessment by the Board of Examiners.

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DR JULIAN EVANS

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Abstract

The latest inventory on all newcomer species in Maltese waters dates back from 2015. Several new or additional records of alien and range-expanding species have been reported since, necessitating an update to this work, while no comprehensive assessment of the distribution patterns and impacts of non-indigenous species (NIS) in Maltese waters has been published to date. This project will update and re-evaluate the inventory and compare it to the previous one. The coordinates from the records will be used to look at spatial patterns, and to identify hotspots. Through literature studies the environmental impacts will be assessed.

The inventory has increased to 106 species, of which most are still considered casual newcomer species, but the amount of invasive species has increased by two. The amount of unknown pathways has decreased and shipping is the most prominent mode of entry into the Maltese waters. The spatial pattern of the records, show that the harbours are hotspots of NIS, which is also explained by the shipping pathway. Another spatial pattern was the records being in the vicinity of popular diving spots.

There is a huge bias in the known literature, since absence of an NIS is not recorded often, and the locations cover the same areas and don't cover hard to reach coastlines, like the Dingli cliffs. The records of invasive species are not a perfect tool to track the dispersal, since they are often discovered after reaching the establishment phase. The inventory needs to be kept updated, to track the status of the Maltese waters and more information should be collected on ecological impact of the newcomer species.

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Contents

List of figures

List of Tables

Introduction

The occurrence of marine non-native species in a region is the result of invasion direct or indirect human-mediated introduction. These species are often referred to as alien, exotic, or non-indigenous species (Robinson et al., 2016). Another category of newcomer species is the range extender, which in contrast to the alien species does not attribute its introduction to human activity, but as a consequence of changing environmental conditions (Occhipinti-Ambrogi et al., 2011). A big problem of alien species, is their ability to become an invasive alien species (IAS), by completing the invasion process, which consists of multiple steps, as seen in Figure 1.

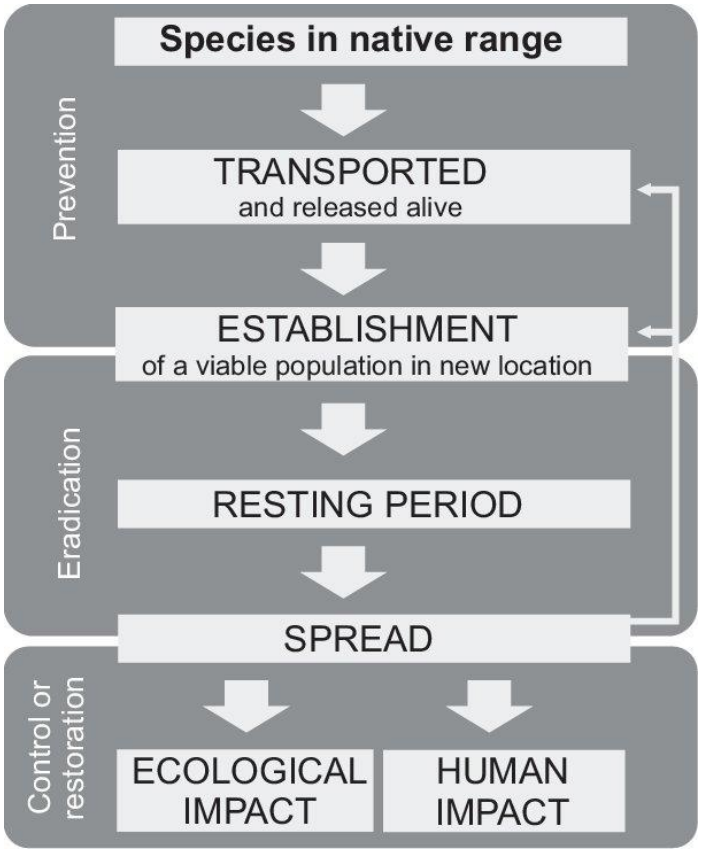

Figure 1: A schematic overview of the invasion process and the measures that can be taken at each stage to control this (source: Darrigran & Damborenea, 2015)

The displacement and introduction of marine alien species is the first step in the invasion process. This introduction is often an accidental release, which is facilitated by vectors. Vectors are often also referred to as pathways or modes of entry. Increased globalisation has led to an increase in biotic introductions, through global trade, travel and transport, which can all aid alien species in their displacement

(Meyerson & Mooney, 2007). The main vector associated with these activities is shipping, and it is the most prominent vector, being responsible for half of the alien introductions in European marine waters (Katsanevakis, Zenetos, Belchior, & Cardoso, 2013). The alien species can be transported in ballast water tanks, or as a fouling assemblage on the hulls (Hewitt, Gollasch, & Minchin, 2009). The lowest number of alien introductions in Europe are attributed to the aquarium trade, however it is the vector showing the highest rate of increase over time. Such introductions occur as a result of escapees, or due to deliberate release. Aquaculture is the only mode of entry that is decreasing in rate of introductions in recent years, which can be attributed to newly implemented measures (Katsanevakis et al., 2013). Alien species can either be the cultivated species that manage to escape or else the contaminants (Katsanevakis et al., 2013).

Another important mode of entry is manmade canals, which is the second-largest contributor to biotic introductions in Europe (Katsanevakis et al., 2013). The most notorious is the Suez Canal, which facilitates migration from the Red Sea to the Mediterranean. A big factor in this Lessepsian migration is the expansion of the Suez Canal. Its modifications include deepening of the canal and the recent instalment of a second branch, which facilitate migration of Lessepsian species. . This is very evident in the Mediterranean, where after these modifications the number of alien introductions has increased (Galil, Marchini, Occhipinti-Ambrogi, & Ojaveer, 2017).

The second step of the process is the establishment of the marine newcomer species. The establishment of a species is dependent of numerous factors. Firstly, the species has to survive the displacement and the frequency and amount of specimens influence the chance of accomplishing established populations (Keller, Geist, Jeschke, & Kühn, 2011). If this stage is not reached, the alien species is referred to as a casual alien , which can always become established at a later point. Other factors include the habitat present in the recipient area; novel physical habitats, like piers, jetties and ports and biological and environmental alteration like pollution can aid in the establishment of alien species (Bax et al., 2001; Keller et al., 2011). There are also certain characteristics that make exotic species more successful in establishing a population. The majority of alien species tend to be generalists that can tolerate a wide array of salinity and water temperature. They also tend to have a higher reproductive rate and their larval stages are better suited to survive the pathway of introduction. When aquaculture is the vector, the chance of establishment increases, since the species was selected to survive in the

environment (Keller et al., 2011). Another factor that can influence establishment of alien species within the Mediterranean is climate change, which can render the conditions present in this sea more suitable for thermophilic alien biota (Lejeusne, Chevaldonné, Pergent-Martini, Boudouresque, & Pérez, 2010; Marbà, Jorda, Agusti, Girard, & Duarte, 2015).

The resting period makes it hard to predict which of the alien species may become invasive, or when. This resting period is described in Figure 1 as only occurring after the establishment phase, but a lag phase can also occur after introduction (Crooks, 2005). The last stage is reached when the alien species migrates from that point of introduction and becomes abundant in surrounding areas, which defines an invasive species (Kolar & Lodge, 2001). However, the term invasive species is now also often used for a species that adversely impacts the environment (Richardson et al., 2000).

In the EU there are between 1200 and 1800 invasive species present that cause economic damage of at least 12.5 billion euros annually, of which 9.6 billion can be attributed to the damages caused by the AIS, and 2.9 billion to the mitigations placed to lessen the impacts of the IAS. These figures are only the documented costs, which indicates the problem might be more costly, costing the EU approximately 20 billion euros annually, which is most likely an underestimation (Kettunen et al., 2009). The EU has recognised the problem and multiple measures have been implemented to combat the issue. The newest regulation is Regulation (EU) 1143/2014 on invasive alien species, also known as the IAS Regulation (European Union, 2014). This regulation is focused on establishing inventories and lists to aid in the mitigations of alien species, to identify their presence earlier, and to prioritise management actions.

These implementations require information on the alien species present, their pathways, distribution and impacts, which are all essential to prioritise mitigation measures and to determine the right course of action. In recent years there have been multiple inventories made for various regions of the Mediterranean, including Malta. The last inventory was compiled in 2015 and included 73 marine species (Evans, Barbara, & Schembri, 2015a). Several new or additional records of alien and range-expanding species have been reported since, necessitating an update to this work, while no comprehensive assessment of the distribution patterns and impacts of non-indigenous species (NIS) in Maltese marine waters has been published to date.

The present project will therefore aim to assess the current situation in the Maltese marine waters, and try to understand where the most susceptible areas are and what causes these hotspots of newcomer species. It will do so through the following objectives:

- update and re-evaluate the inventory of newcomer species in the Maltese waters based on on a critical evaluation of recently published literature;
- compare the present inventory to the previous inventory and look at the temporal patterns of arrival of newcomer species in Malta
- extract geographic locations for all published occurrences of each newcomer species, and use these to produce distribution maps;
- assess the establishment status and modes of introduction for newcomer species;
- undertake spatial analysis to identify any links between specific areas of interest (e.g. marine traffic hotspots, marine protected areas) and the occurrence of newcomer species;
- analyse the movement of invasive species in Maltese waters
- assess the potential ecological impacts of these species in Maltese waters

Materials and methods

Inventory list

The previous inventory by Evans et al. (2015a) was the basis for this updated inventory. The names of the species were adjusted to the newest nomenclature, as was listed in the Word Register of Marine Species (Hooper et al., 2019). New records were found by using the query 'first record Malta' in two different search engines, Google Scholar and Open Access Repository at University of Malta (OAR@UM) to find new species and the species name combined with Malta was used to get more records of already listed species. The geographical data was extracted from the papers, which could be GPS coordinates or by utilizing the provided maps. When no coordinates were present, the name of the area was used to assess a logical close value using Google Maps. In a few cases the name of the area was not precise enough to estimate the location of the records. When these records mentioned the depth at which the recording took place, the EMODNET bathymetry map (EMODnet Bathymetry Consortium, 2018) was used to determine the location more precisely by matching the description of the location and the depth of the sea. Coordinates in minutes were converted to decimal degrees, to facilitate input into Geographic Information System (GIS) software. When there was no mention of an area, the coordinates of a centre point on the island Malta was used.

The data of the species was extracted from the previous inventory, the records that were obtained, a dataset by Galil, Marchini, and Occhipinti-Ambrogi (2018) on alien species and the European Alien Species International Network database (EASIN). The data that was extracted contained their native range, which was obtained from the previous inventory, the records and the following sites; SeaLifeBase, FishBase, AlgaeBase and MolluscaBase (Froese & Pauly, 2019; Guiry, 2019; MolluscaBase, 2019; Palomares & Pauly, 2019). The datasets of EASIN and Galil et al. (2018) also contained information on the first Mediterranean entry, like country and year for alien species.

The newcomer species have different origins, which was first split between alien and range-expanding species. The legal definition of alien species stated in the Regulation (EU) 1143/2014 (European Union, 2014) is as follows: " *'alien species' means any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce.*" Most definitions

of alien species incorporate a human activity as the cause of introduction, which is also used in this paper. This allows for a distinction between human-mediated introductions and autonomous introductions caused by environmental changes. Therefore, an alien species requires human activity for its introduction, whilst a range expander does not and is driven by environmental changes (Occhipinti-Ambrogi et al., 2011). The origins are not always clear, so a subcategory was made. The term cryptogenic was used to indicate the uncertainty. The reason for the uncertainty of the origin was listed in the notes of the factsheets and inventory. The data for the origin was usually obtained from the records, or the previous inventory. In some cases the origin was stated by EASIN, or to be searched for using Google Scholar.

The pathways of the species was divided into mode of entry into the Mediterranean and mode of entry into Malta. The pathways of the Mediterranean were obtained from the dataset by Galil et al. (2018) and EASIN. These did not cover all species and the first record of the Mediterranean had to be found and any mention of the pathway had to be extracted. When this was not mentioned in the first Mediterranean record or in the datasets it was noted as unknown. The pathways of the datasets were listed into six categories: shipping, canals (Lessepsian immigrant), aquarium trade, aquaculture, natural range expansion and unknown. A species could have multiple pathways into the Mediterranean.

The mode of entry into the Maltese waters was obtained from the previous inventory and from the records. A critical assessment was made to fill in gaps and to re-assess the possibilities. The species could be associated with a maximum of two different pathways, before it was registered as unknown pathway. When the literature did not state any pathways the mode of entry was listed as unknown in the 2015 inventory, however during the current project these gaps were filled based on the place of the first record and the history of the species as a non-native species.

The phase of the invasion process of the species was also listed in the inventory and the factsheets, according to the terminology of Evans et al. (2015a). There are four classes ‘Questionable’, ‘Casual’, ‘Established’ and ‘Invasive’.

‘Questionable’ status was reserved for species of which the records were sparse and doubtful. These records were mostly of species that are hard to distinguish from native species and were not verified by the needed experts (Evans et al., 2015a).

‘Casual’ species have records that are verified. The records of these species do not mention any large numbers or widespread distributions within the Maltese waters.

There is also no evidence of reproduction. A ‘casual’ species is not established and is only recorded once or twice, or is relying on repeated introductions. ‘Casual?’ is used for species that are easily overlooked, or are hard to extinguish from native species and are therefore not recorded as often. This species might be established, however records do not underline this (Evans et al., 2015a).

‘Established’ species have formed reproducing populations in the Maltese waters and do not rely on human intervention to sustain the populations. ‘Established?’ is for species that have older records that have confirmed the established stage in the past, but are missing more recent records that show this is still true. These species are often overlooked or hard to identify (Evans et al., 2015a).

‘Invasive’ species have gone beyond the established stage and are growing and expanding their range. These species threaten the native biota and may destabilize ecosystems. Their presence can also impact economic activities and/or human health (Evans et al., 2015a).

Analysis

The updated inventory was first compared to the previous inventory. Bar charts were made to describe the differences in proportion of species belonging to the different status and pathway categories. The number of first and total records were plotted against time to note temporal trends.

Spatial analysis was undertaken using GIS software (ESRI ArcGIS v10.6.1). For spatial analysis, the shape files of the Maltese Spatial Data Infrastructure (MSDI) were used. The MSDI is a platform on which spatial data, which should be available to the public, can be shared by organisations (Malta Information Technology Agency, 2019). One shapefile contained a polygon of the islands of Malta, whilst another contained the nine distinct divisions in the Maltese coastal waters. The classification of the coastal waters was performed as part of the Water Framework Directive and was based on the characteristics of the area, as well as the human influences on it. Of the nine divisions, seven were considered to be natural. The other two divisions were heavily modified. The Marsamxett and Grand Harbour around Valletta were one division, whilst the other one covered the Marsaxlokk harbour (Malta Environment and Planning Authority, 2011)

Through the use of the ‘select by location’ feature in GIS, the entries in the harbours could be coloured differently to obtain a map showing alien species records made within and outside the harbour areas. A margin of 100m was added for point data

that just fell within the shorelines. One point that was in the Natural areas was selected because of this margin, and this was manually deselected before creating a subset to be coloured.

To note whether records of alien species tend to be clustered in areas popular with divers, the website maltadives.com was used to identify the highly popular dive sites around the Maltese Islands. Then a print screen of the map showing these sites was made and aligned with the Malta shapefile. New point data were made to align with the diving spots. Then the alien species records were selected by location in a radius of 1 km around the dive sites. A new shapefile was made with the selected dots and coloured.

The alien species records point data were divided into subsets according to the decade in which each record made, starting with ‘up to 1970’, because before 1960 only one record existed with a specific location. The decade 1980-1989 was skipped due to the lack of records: only one record exists from that decade and would not have influence the point density maps. These point density maps were made based on the amount of records. The closer the records were to one another, and the more abundant, the higher the relative density. This also means, that one record has a higher impact on the density map in the earlier decades, due to a lower amount of total records.

Lastly, records of a few of the species considered to be invasive were mapped to assess the expansion and dispersal of these species in the Maltese waters. This was achieved by adding a column to categorize the dates of the records. Then the point data were coloured according to this category. The drawing of the points were selected to have the oldest as the topmost layer, and the newest as the bottom layer.

Results

Inventory list

The updated inventory contains 106 newcomer species, as of July 2019. The full updated inventory is given in Appendix A. Detailed factsheets summarising all the available information for each of the newcomer species in Maltese waters are given in Appendix B There were numerous changes made to the inventory of 2015 by Evans et al. (2015a). Firstly, there were four nomenclatural changes and one newly described species, as seen in Table 1.

Table 1: Species that have been given a different name, compared to the 2015 inventory

New species name	Formerly known as	Note
***Biuve fulvipunctata* (Baba, 1938)**	*Chelidonura fulvipunctata* Baba, 1938	Nomenclatural change
***Naria turdus* (Lamarck, 1810)**	*Erosaria turdus* (Lamarck, 1810)	Nomenclatural change
***Magallana gigas* (Thunberg, 1793)**	*Crassostrea gigas* (Thunberg, 1793)	Nomenclatural change
***Ondina michaelae* Cachia & Mifsud, 2015**	*Leucotina eva* Thiele, 1925	Specimen belongs to newly described species (Cachia & Mifsud, 2015)
***Steromphala cineraria* (Linnaeus, 1758)**	*Gibbula cineraria* (Linnaeus, 1758)	Nomenclatural change
***Weinkauffia macandrewii* (E. A. Smith, 1872)**	*Atys macandrewi* E. A. Smith, 1872	Nomenclatural change

New records have led to the revision of the status of five species. The new records of three species indicated a more prominent status, whilst two species were supported in their status, which led to the loss of the question mark, as seen in Table 2.

Table 2: The species that have another status compared to the 2015 inventory.

Species	Former status	Present status	Note	Reference
***Abudefduf* cf. *saxatilis* (Linnaeus, 1758)**	Established?	Established	Recent records indicate an established status	Vella *et al.*, 2016a
***Amphistegina lobifera* Larsen, 1976**	Established	Invasive	Species has expanded its range to numerous localities and higher	Guastella *et al.*, 2019

			abundances have been reported	
***Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procacini, 2013**	Established	Invasive	Species has expanded its range to numerous localities and higher abundances have been reported	Ellul *et al.*, 2019
***Cephalopholis taeniops* (Valenciennes, 1828)**	Established?	Established	Recent records indicate an established status	Evans & Schembri, 2017; Vella *et al.,* 2016d
***Lutjanus fulviflamma* (Forsskål, 1775)**	Questionable	Casual	New authenticated record	Vella *et al.,* 2015

Several new records were made of species that were not mentioned in the 2015 inventory due to them not being present yet, or because they had yet to be reported. The updated inventory contains 37 new species, which are listed in Table 3.

Table 3: List of additions to the list of 2015 of marine newcomer species from Maltese waters

Species	Natural Range	First Maltese Record	Status	Reported By
***Abudefduf* cf. *vaigiensis* (Quoy & Gaimard, 1825)**	Indo-Pacific	2013	Established	Vella *et al.,* 2016a
***Abudefduf hoefleri* (Steindachner, 1881)**	Eastern Atlantic	2014	Established	Vella *et al.,* 2016b
***Acanthurus chirurgus* (Bloch, 1787)**	Western Atlantic, Senegal	2016	Casual	Evans *et al.,* 2017
***Acanthurus coeruleus* Bloch & Schneider, 1801**	Western Atlantic	2013	Casual	Evans *et al.,* 2015b
***Acanthurus monroviae* Steindachner, 1876**	Eastern Atlantic	2013	Established	Evans *et al.,* 2017
***Achelia sawayai sensu lato* Marcus, 1940**	Western Atlantic, Pacific	2016	Casual	Ulman *et al.,* 2017
***Amathia verticillata* (delle Chiaje, 1822)**	Caribbean Sea	2016	Casual?	Ulman *et al.,* 2017
***Amphisorus hemprichii* Ehrenberg, 1839**	Indo-Pacific	2017	Established	Guastella *et al.,* 2019
***Amphistegina lessonii* d'Orbigny in Guérin-Méneville, 1832**	Indo-Pacific, Western Central Atlantic	2017	Established	Guastella *et al.,* 2019

***Celleporaria brunnea* (Hincks, 1884)**	Northeast Pacific	2016	Casual	Ulman *et al.,* 2017
***Cephalopholis hemistiktos* (Rüppell, 1830)**	Red Sea, Western Indian Ocean	2009	Casual	Deidun *et al.,* 2011
***Cephalopholis nigri* (Günther, 1859)**	Eastern Tropical Atlantic	2016	Casual	Vella *et al*., 2016d
***Chrysiptera hemicyanea* (Weber, 1913)**	Indo-West Pacific	2017	Casual	Deidun *et al.,* 2018
***Coscinospira hemprichii* Ehrenberg, 1839**	Western Central Pacific	2017	Casual	Guastella *et al.,* 2019
***Dendostrea* c.f. *folium* (Linnaeus, 1758)**	Indo-Pacific	2016	Casual	Ulman *et al.,* 2017
***Enchelycore anatina* (Lowe, 1838)**	Eastern Atlantic	2013	Casual	Deidun *et al.,* 2015b
Erugosquilla massavensis (Kossmann, 1880)	Red Sea, Persian Gulf	2019	Casual	Deidun & Zava, 2019
***Heniochus intermedius* Steindachner, 1893**	Red Sea, Western Indian Ocean	2014	Casual	Evans *et al.,* 2015b
***Holacanthus africanus* Cadenat, 1951**	Tropical Eastern Atlantic	2017	Casual	Deidun *et al.,* 2017a
***Holocentrus adscensionis* (Osbeck, 1765)**	Western Atlantic	2016	Casual	Vella *et al.,* 2016c
***Hydroides dirampha* Mörch, 1863**	Tropical Western Atlantic	2016	Casual	Ulman *et al.,* 2017
***Hydroides elegans* (Haswell, 1883) [nomen protectum]**	Australia, Indian Ocean	1955	Casual	Zibrowius, 1971
***Kyphosus vaigiensis* (Quoy & Gaimard, 1825)**	Indo-Pacific	2015	Established	Vella *et al.,* 2016e
***Lagocephalus sceleratus* (Gmelin, 1789)**	Indo-West Pacific	2014	Casual	Deidun *et al.,* 2015a
***Maritigrella fuscopunctata* (Prudhoe, 1978)**	Indo-Pacific	2015	Established	Portelli *et al.,* 2015
***Mesanthura* cf *romulea* Poore & Lew Ton, 1986**	(Sub-) Tropical Southern Seas	2016	Casual	Ulman *et al.,* 2017
Paracerceis sculpta (Holmes, 1904)	California, Pacific Coast Mexico	2016	Casual	Ulman *et al.,* 2017
***Paranthura japonica* Richardson, 1909**	Northwest Pacific Ocean	2016	Casual	Ulman *et al.,* 2017
Peneroplis arietinus (Batsch, 1791)	Western Indian Ocean, Western Central Atlantic	2017	Established	Guastella *et al.,* 2019

***Phyllorhiza punctata* Lendenfeld, 1884**	Indo-Pacific	2016	Established	Deidun *et al.,* 2017b
***Pomacanthus maculosus* (Forsskål, 1775)**	Northwest Indian Ocean, Red Sea	2012	Casual	Evans *et al.,* 2016
***Sargocentron* sp.**	Indo-Pacific (*S. rubrum*),Iberian Peninsula (*S. hastatum*)	2015	Casual	Deidun *et al.,* 2016
***Sorites orbiculus* (Forsskål in Niebuhr, 1775)**	Indo-Pacific	2017	Casual	Guastella *et al.,* 2019
***Stenothoe georgiana* Bynum & Fox, 1977**	Western Atlantic	2016	Casual	Ulman *et al.,* 2017
***Styela plicata* (Lesueur, 1823)**	Cosmopolitan	1975-1976	Casual	Agius *et al.,* 1977
***Watersipora arcuata* Banta, 1969**	Tropical Eastern Pacific	2016	Casual	Ulman *et al.,* 2017

Some records of the previous inventory have now been proven to be based on misidentifications, or are suspected to be. These and other records have been omitted because they did not occur in the wild in Maltese waters. There are nine species that were omitted, as seen in Table 4.

Table 4: Species that were omitted from further analysis for various reasons.

Species	Reason for removal	Reference
***Branchiomma boholense* (Grube, 1878)**	Misidentification of *B. bairdi*	Arias *et al.,* 2013
***Callinectes sapidus* Rathbun, 1896**	Misidentification of *Portunus segnis*	Evans & Schembri, 2015
***Etrumeus golanii* DiBattista, Randall & Bowen, 2012**	Not recorded in Malta	Evans *et al.,* 2015a
***Littorina saxatilis* (Olivi, 1792)**	Not recorded in the wild	Mifsud & Cachia, 2011
***Naria turdus* (Lamarck, 1810)**	Removed: only in ballast tanks	Mifsud & Cachia, 2011
***Prionocidaris baculosa* (Lamarck, 1816)**	Not recorded in the wild	Schembri, 1978
***Seriola carpenteri* Mather, 1971**	Not recorded in Malta	Evans *et al.,* 2015a
***Stenothoe gallensis* Walker, 1904**	Misidentification of *S. cattai*	Krapp-Schickel, 2013

Analysing trends and patterns

When compared to the 2015 inventory, the number of species having a ‘Casual’, ‘Established’ or ‘Invasive’ status has increased. Most of the additions received the ‘Casual’ status. Only the questionable status went down. The amount of invasive species has increased by one species, as can be seen in Figure 2.

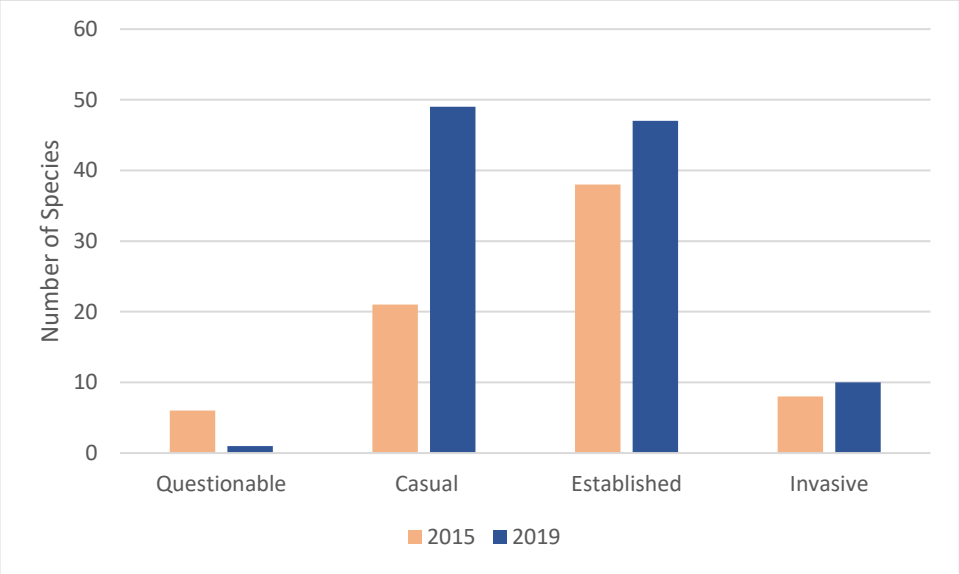

Figure 2: Number of species recorded from the Maltese waters grouped per establishment phase, with uncertainties counted to their expected phase.

The pathways of the newcomer species is now less obscure, as there are less unknown pathways mentioned. The amount of species exceeds the 106 previously mentioned, as a given species could have up to two potential pathways. The biggest increase is in shipping as a pathway, but aquarium trade has also seen a huge increase. The natural range expansion is the only pathway that remained stable, as seen in Figure 3.

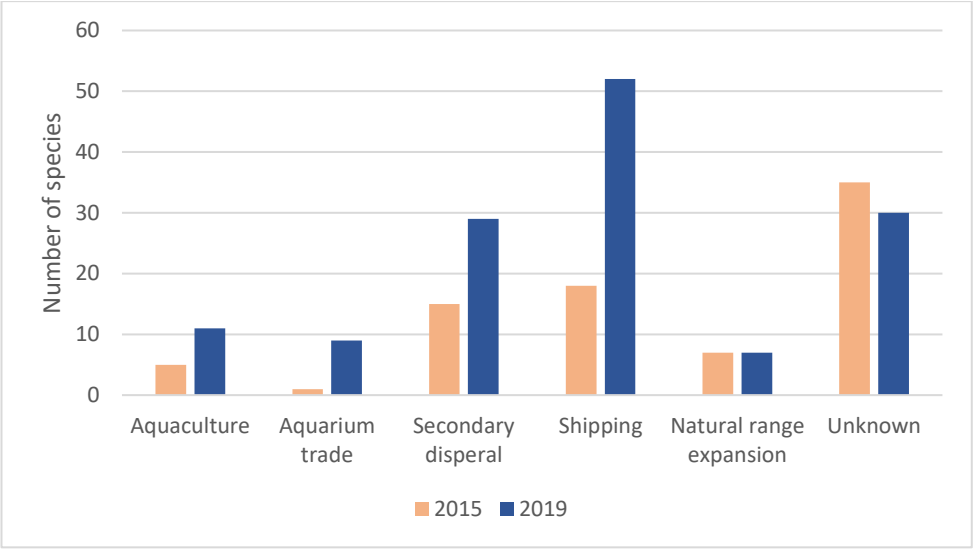

Figure 3: Number of species grouped by their mode of entry into the Maltese waters.

The amount of first records have increased over the last decades, with the amount of first records after 2010 accounting for 44% of the total amount of first records. Also the decade 1980-1989 is noteworthy for lacking any first records, as seen in Figure 4.

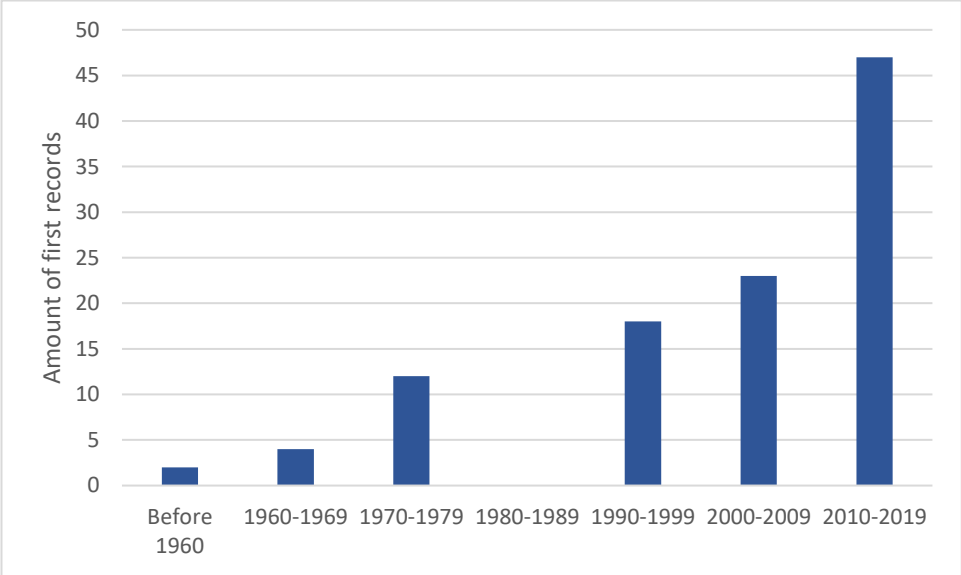

Figure 4: Amount of first records of newcomer species in Malta, per decade.

The trend in total number of records show mostly the same trend as that for first records. During the last decade a substantial amount of records have been reported, which account for 62% of all records that have been made in the Maltese waters. Again the years 1980-1989 show a lack of records, as seen in Figure 5.

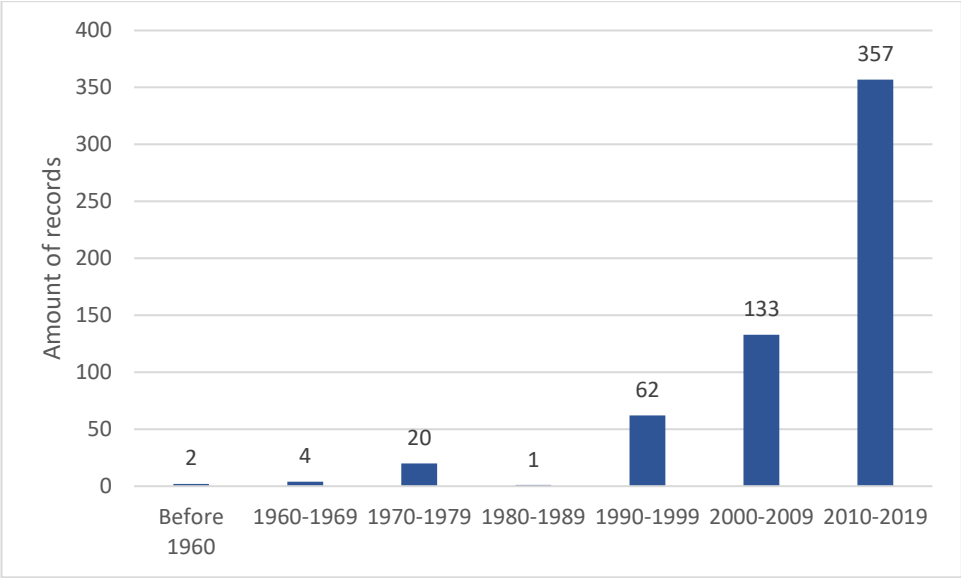

Figure 5: The amount of records made of newcomer species in Malta per decade.

There is a lack of known and potential impacts that are mentioned in the records. Only 14% of the species have any information on the impact that they can or could cause, as seen in Figure 6. Of these 15 species, 7 have information from impacts caused in Maltese waters, whilst the potential impact covered 11 species and mentioned the impact of the species elsewhere in the Mediterranean, or mentioned the impact of the genus, which could also be caused by the NIS. The potential and known impacts exceed the combined, since some species had known and potential impacts listed.

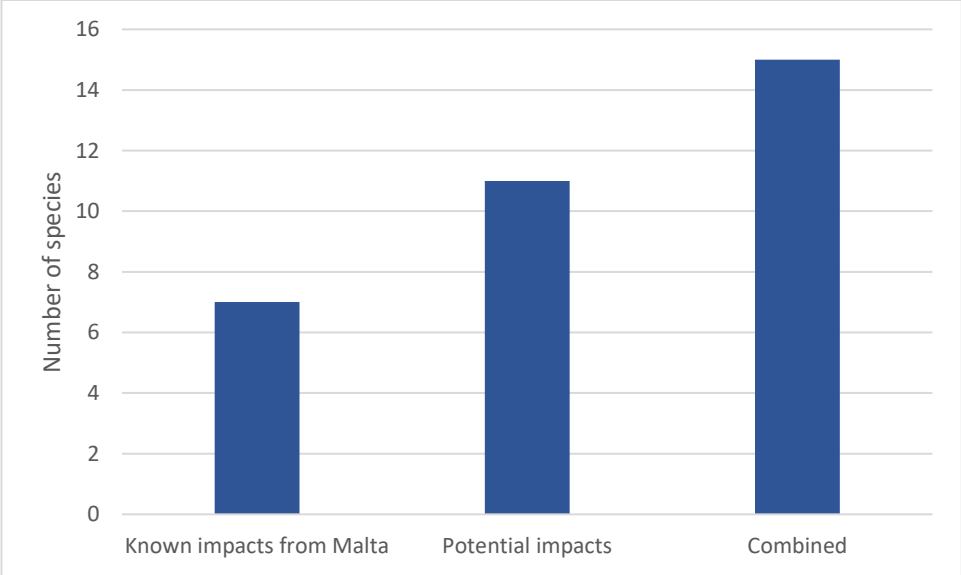

Figure 6: Number of newcomer species with existing data on environmental impact, divided into known impacts in Malta, and potential impacts based on studies made elsewhere in the Mediterranean.

Spatial analysis

A large portion of the first records were made from the harbours of Malta. The Heavily Modified Areas align with the Valletta/Marsamxett Harbour and the Freeport of Birzebbuga. Of the 106 recorded NIS, 68 were initially recorded from the harbours, which accounts for 64% of all newcomer species.

There were a total of 579 recorded locations, of which 179, marked in red, were located in the Heavily Modified Areas, otherwise known as the harbours. 400 records were located in the other seven divisions that are considered natural. This means that 31% of the records are located in the harbours, as seen in Figure 7.

There is also a trend in the amount of all records and diving activity in the vicinity. Of all 106 NIS, 47 newcomer species were recorded within a 1 km radius from the dive sites, which accounts for 44% of all recorded newcomer species. Of all 579 records, 193 records, marked in magenta, were located within a 1 km radius of the most popular dive sites. This accounts for 33% percent of the records, as seen in Figure 8.

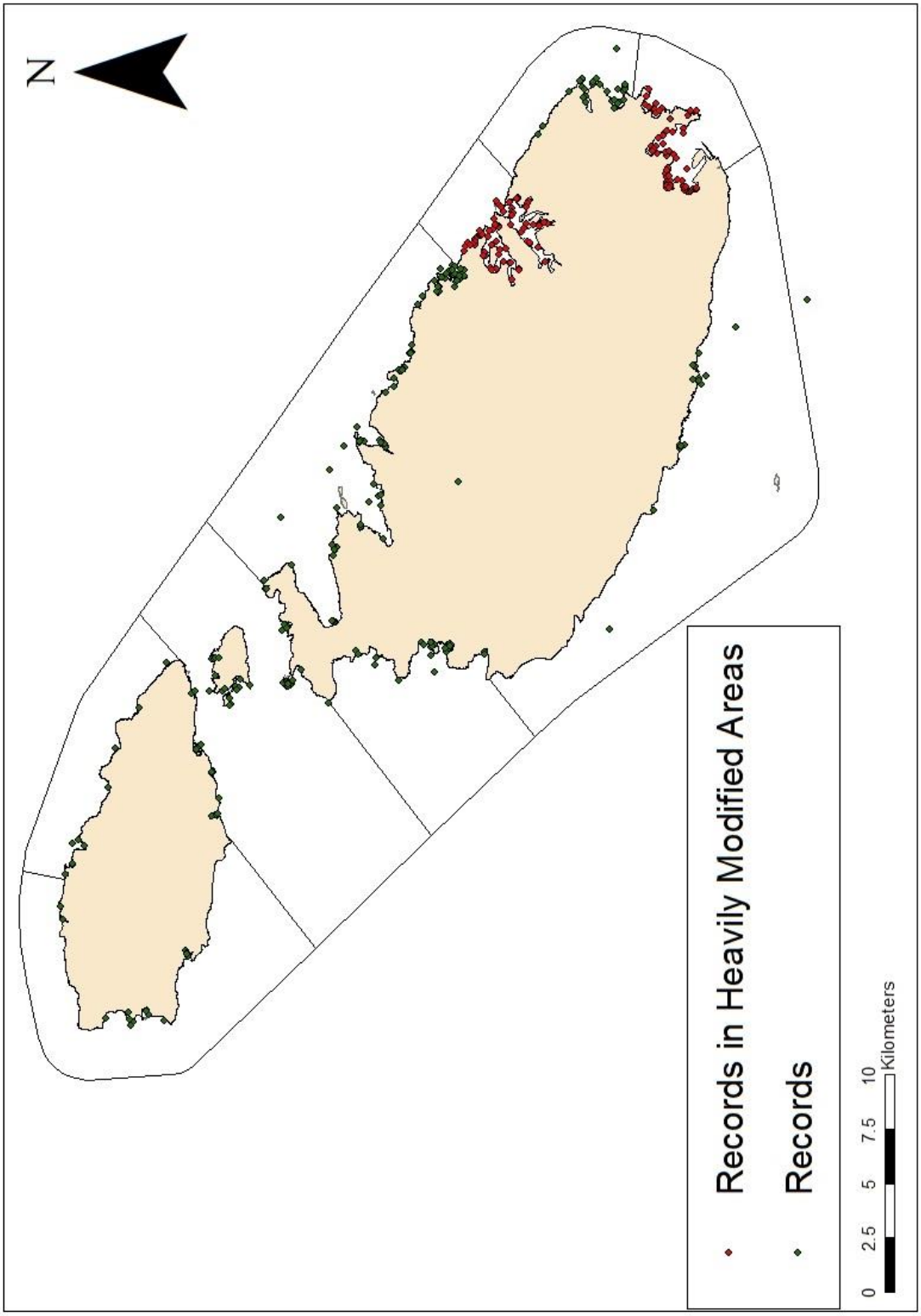

Figure 7: Map of Malta showing the locations of all records, divided in their occurrence in the Heavily Modified and Natural Areas as specified in the MSDI - Waterbodies.

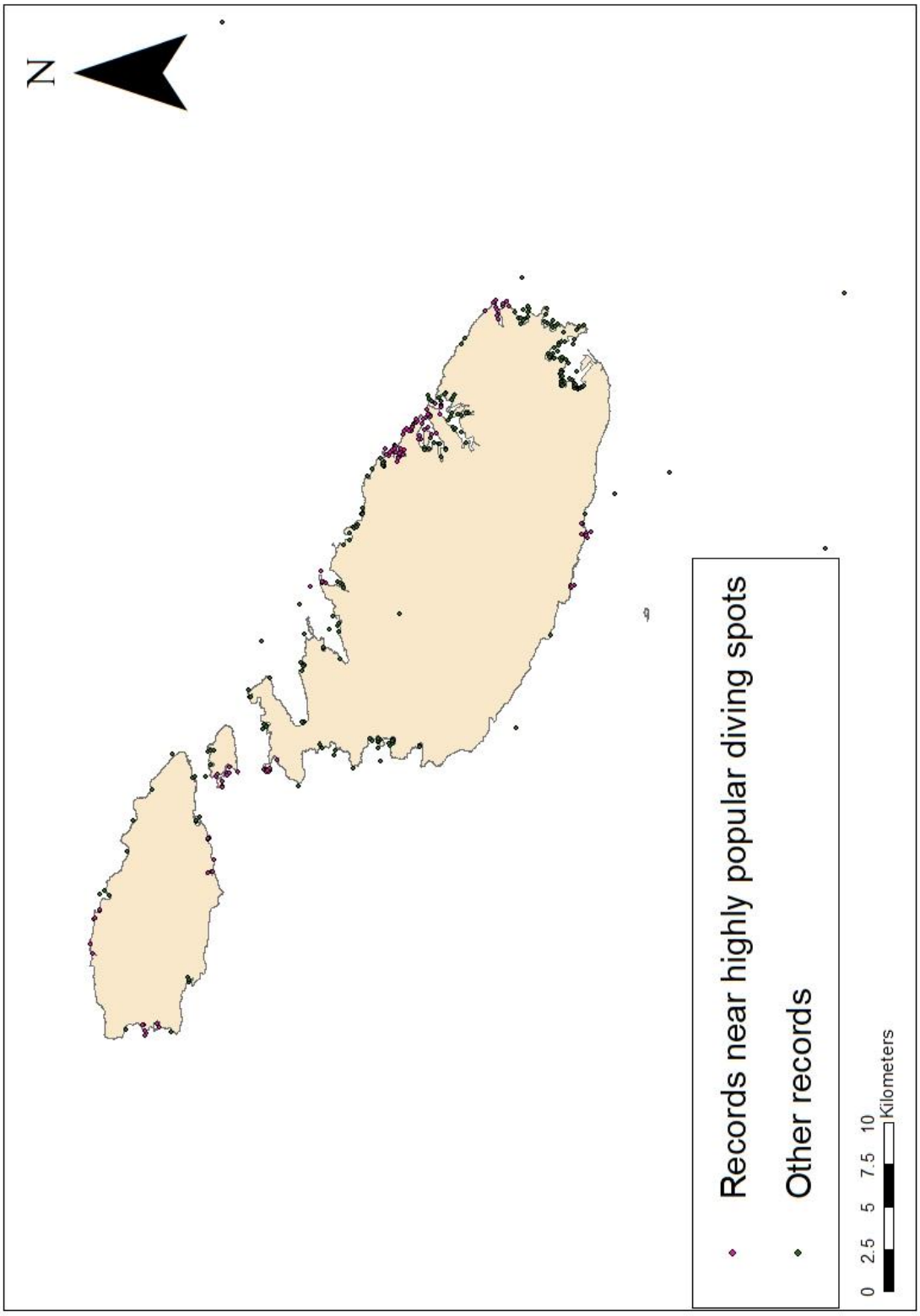

Figure 8: Map of Malta showing all records in a 1 km radius of the most popular diving spots.

Temporal patterns

The density maps of all records around Malta have shown, that up to 1970, the only areas with records are the Marsamxett Harbour and Marsaxlokk, as evident by only having two categories as seen in Figure 9.

The records, first and sequential, up to 1980 still show the same high density at Marsaxlokk, however the hotspot at Valletta has shifted to the other side the Grand Harbour. There is also another spot of low density that occurs at Xemxija Bay, as seen in Figure 10.

Later records, up to 2000, have led to more density areas at Blue Grotto and Marsaxlokk Bay in the south, more records are present along the coast between Xemxija Bay and Marsamxett. The north of Malta now has a few density areas, as well as Comino and the south and west of Gozo, as seen in Figure 11.

When looking at the hotspots up to 2010, the shift of the hotspot at Birzebbuga, near the Freeport is noticeable. The relative densities of Gozo have lessened, as well as the other spots in the north, whilst a new spot is present around at Cirkewwa. Higher densities are seen at St Julians and Marsamxett, as seen in Figure 12.

The most recent density map, containing all records up to 2019, shows the same pattern as the one before, however there are a few changes. The Grand Harbour is more prevalent and the point around Delimara connects with Zonqor Point. Also Gozo has a new point in the east. Overall the densities around Malta seem to be decreasing, due to them being relative towards the total amount. Only the area from St Julians to Valletta reaches the highest category, and there is also a high density at Birzebbuga, as seen in Figure 13.

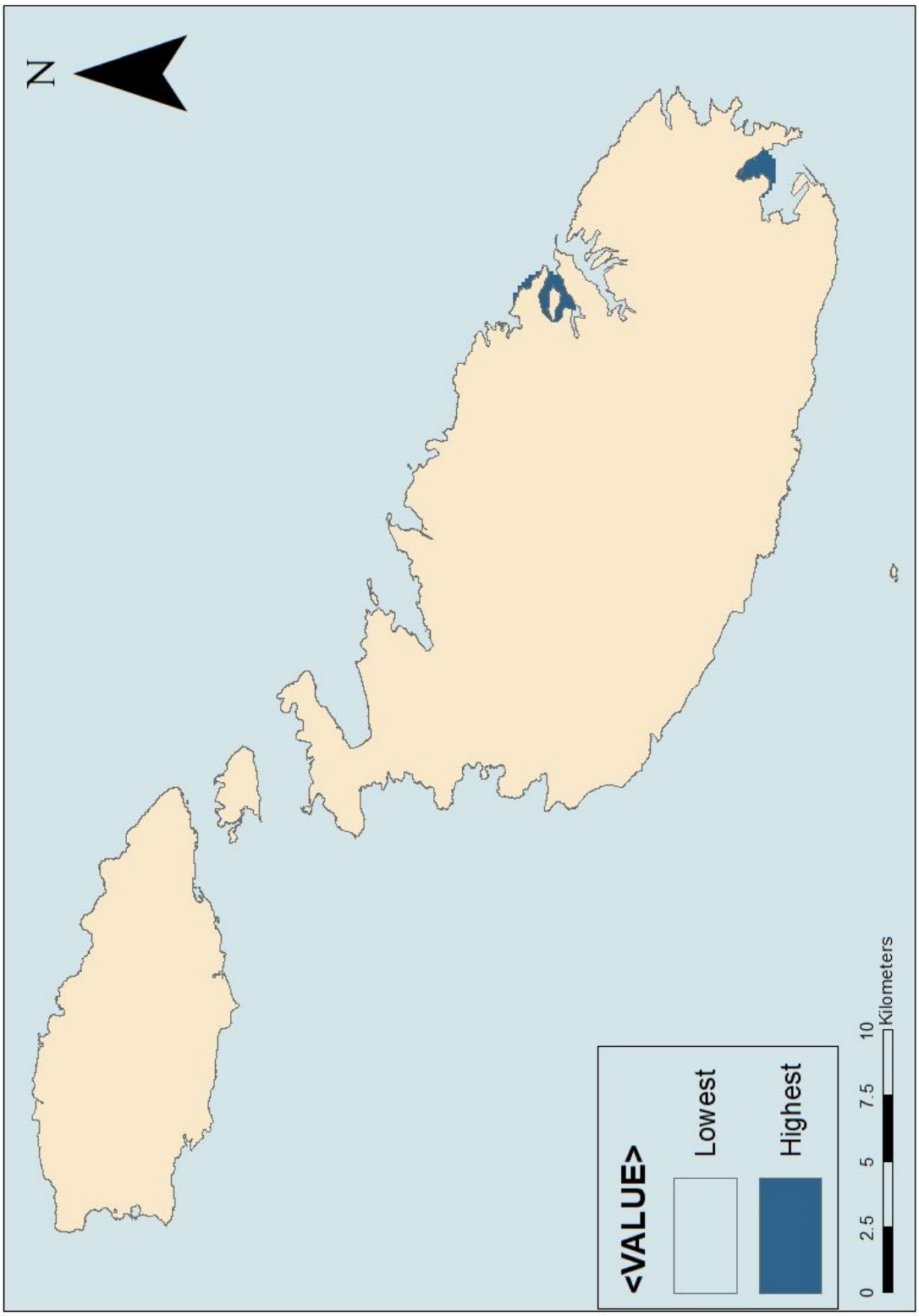

Figure 9: Density map of all records up to 1970.

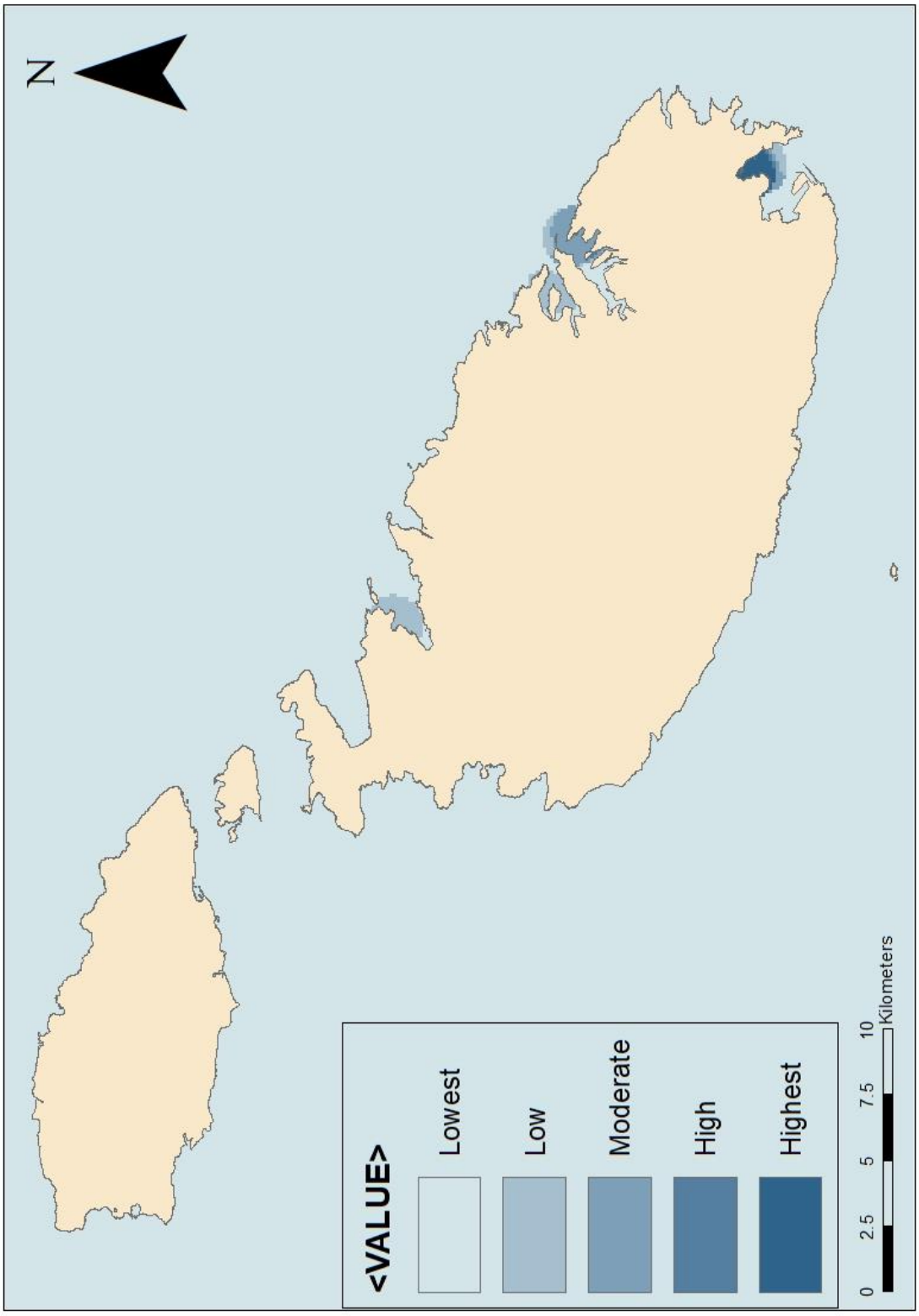

Figure 10: Density map of all records up to 1980.

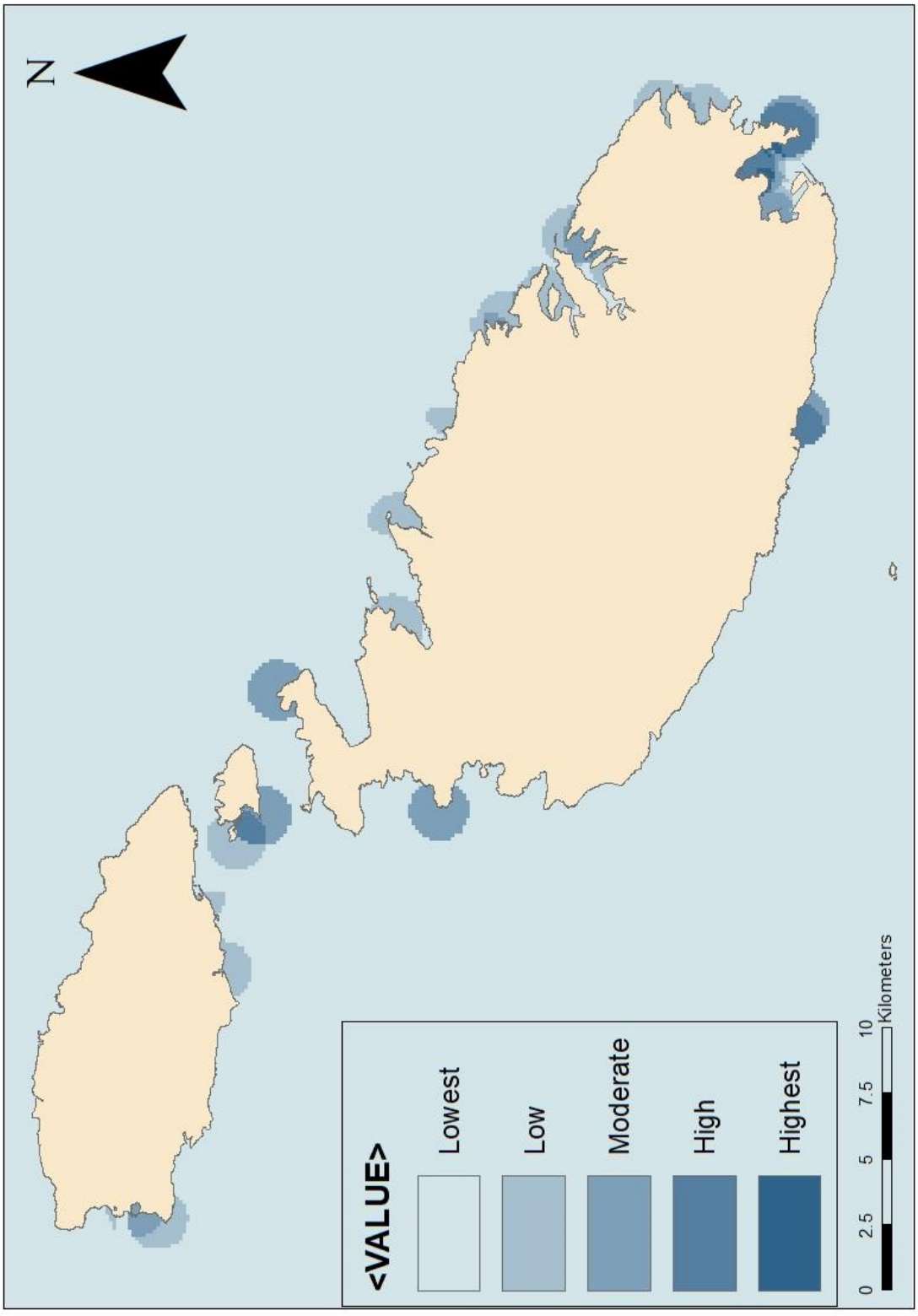

Figure 11: Density map of allrecords up to 2000.

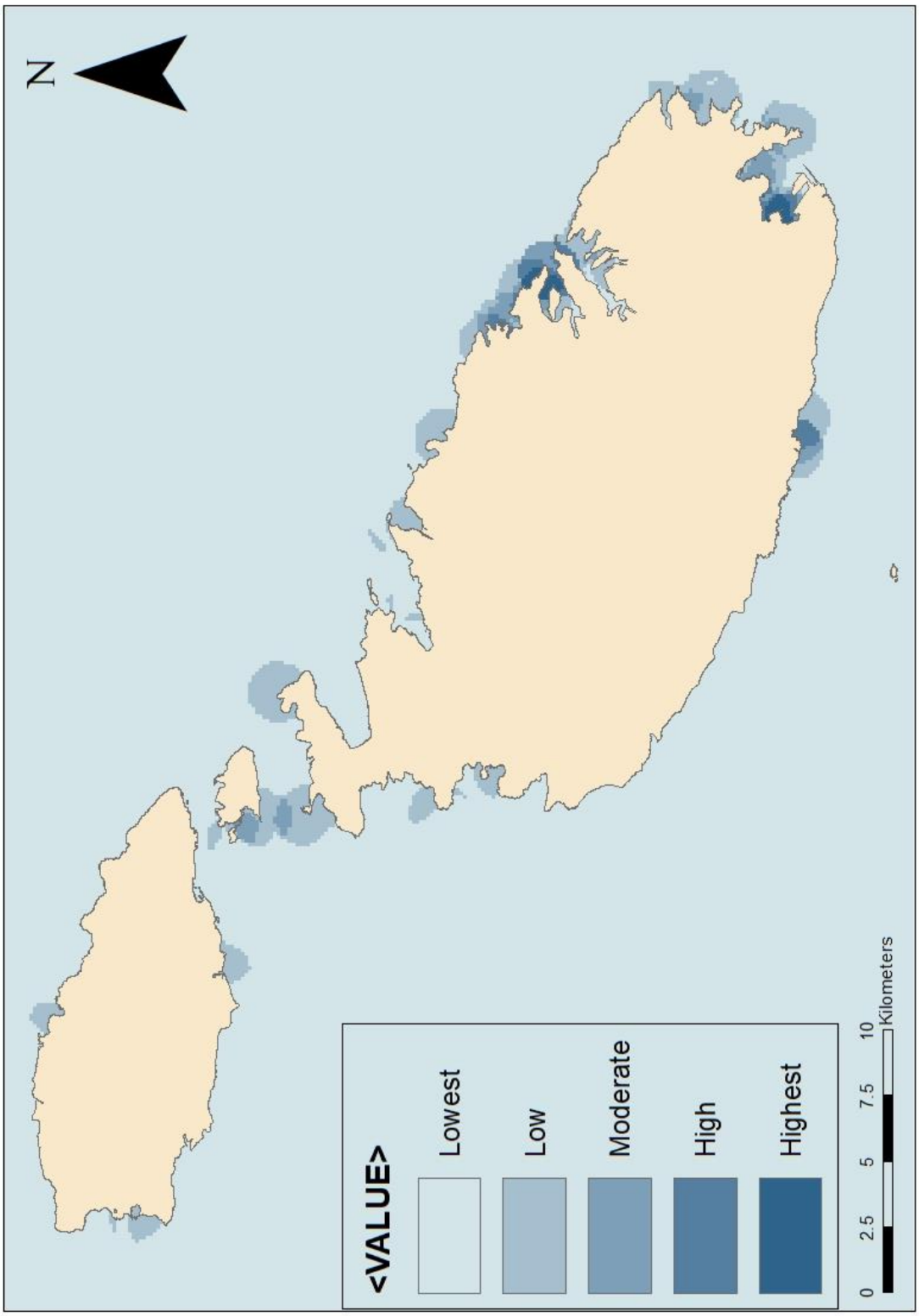

Figure 12: Density map of all records, up to 2010

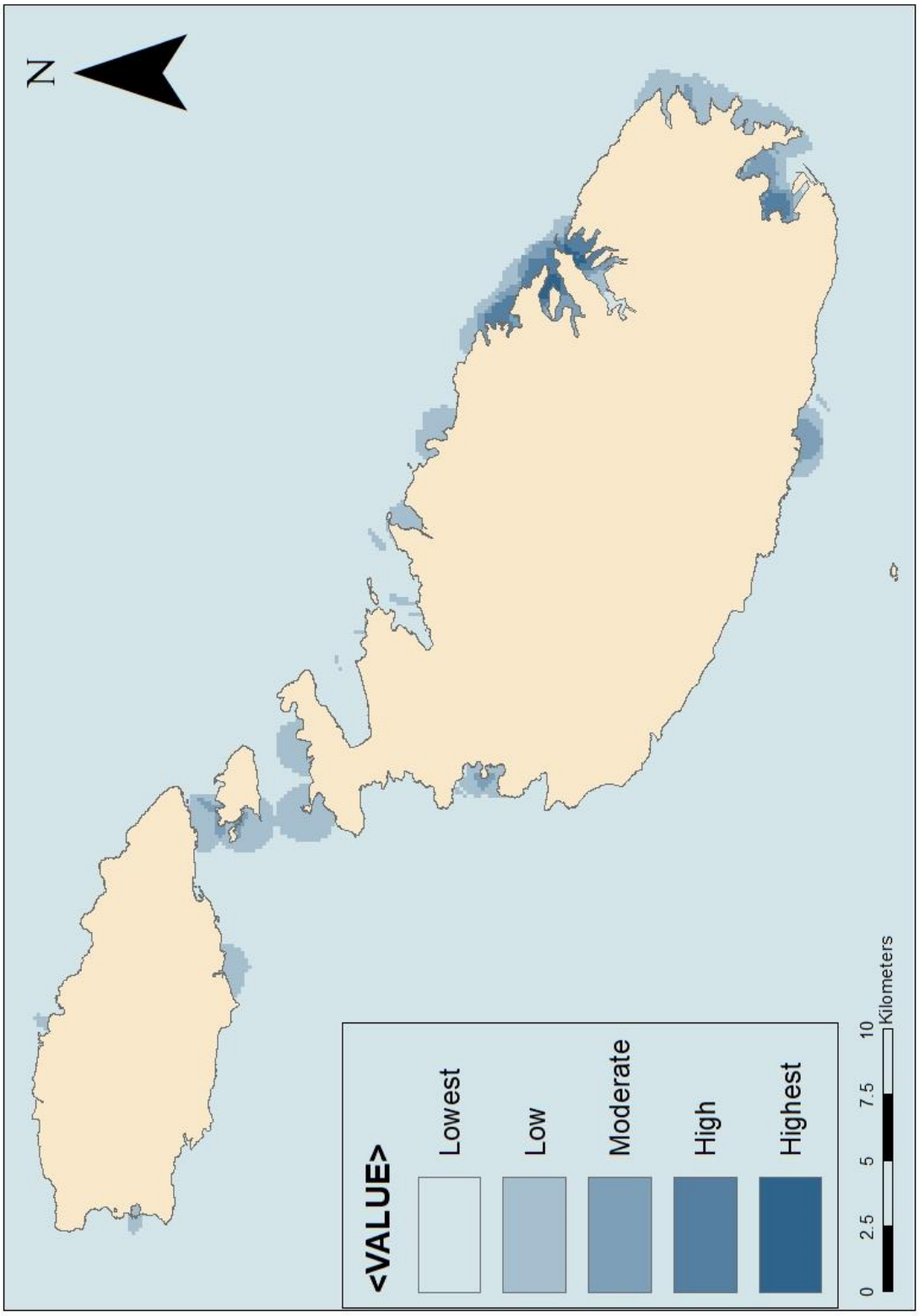

Figure 13: Density map of all records as of 2019

Invasive species

Amphistegina lobifera was first reported in 2006, from various points around the Maltese Islands. It was recorded from Dwejra, Gozo, Comino, Sliema and Gnejna Bay. The 2017 records show an almost connected range between these points, however no records were made in the south, as seen in Figure 14.

Brachidontes pharaonis were first recorded from the harbours and there are records from Qawra, and the eastern tip. Later it has been recorded from below the Dingli Cliffs in the 1990s. After the turn of the century more records confirm its presence in the harbours, but after 2010, most of the records show a presence covering the whole island. However, the west side of Malta, starting at Birzebbuga and ending at Cirkewwa only contains a few records, as seen in Figure 15.

Caulerpa cylindracea was first recorded in the late 1990s, with records in Gozo, Qawra, Blue Grotto and the southeast of Malta. It has been recorded later at more locations, with the most of the records being from St Julians, as seen in Figure 16.

Cylindracea taxifolia var. distichophylla were first recorded around 2013, ranging from Sliema to Qawra. Later records show an expansion to Comino and Gozo, but at Valletta and the southeast the species was recorded as well. In 2017 and 2018 the species was recorded from Birzebugga and the bays in the west, as seen in Figure 17.

The first record of *Fistularia commersonii* is north of Gozo in 2005. It seemed to have expanded to Comino and south of Gozo between 2006 and 2010, whilst more specimens were recorded in the southeast. Between 2011 and 2015 the species was recorded from Blue Grotto, Cirkewwa and within the harbours, as seen in Figure 18.

Percnon gibbesi was first recorded around Sliema. Between 2002 and 2003 the species was recorded in St Julians, and in the south and north of Gozo. Later it was recorded from numerous locations around Malta and Gozo, as seen in Figure 19.

The first record of *Siganus luridus* has no real detail about the location. It was then recorded from the Blue Grotto and west of Cirkewwa. Later the species was recorded in the harbours and in the north and south of Gozo, as seen in Figure 20.

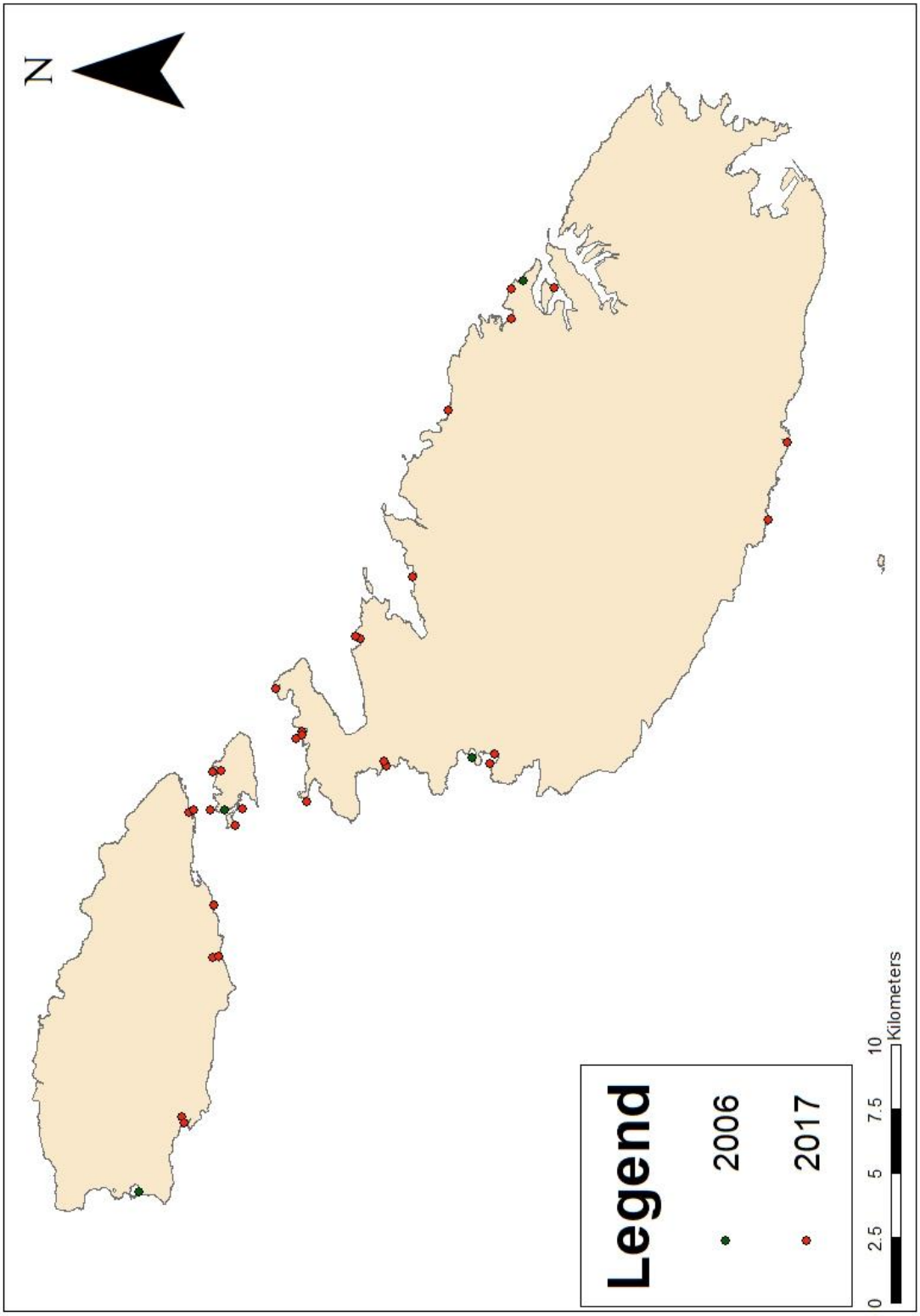

Figure 14: All records of the invasive *Amphistegina lobifera* around Malta, coloured according to the record date.

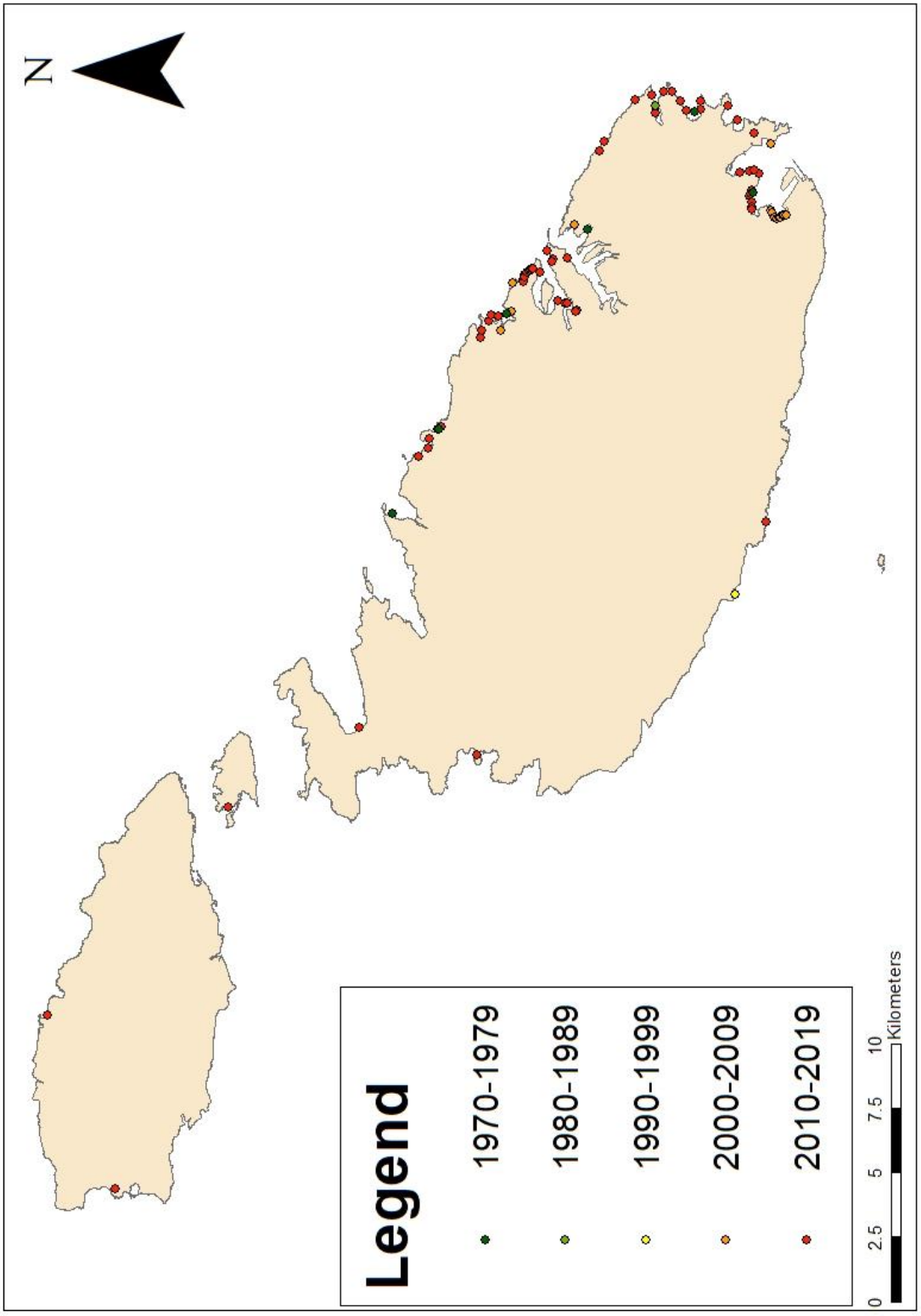

Figure 15: All records of the invasive *Brachidontes pharaonis* around Malta, coloured according to the record date.

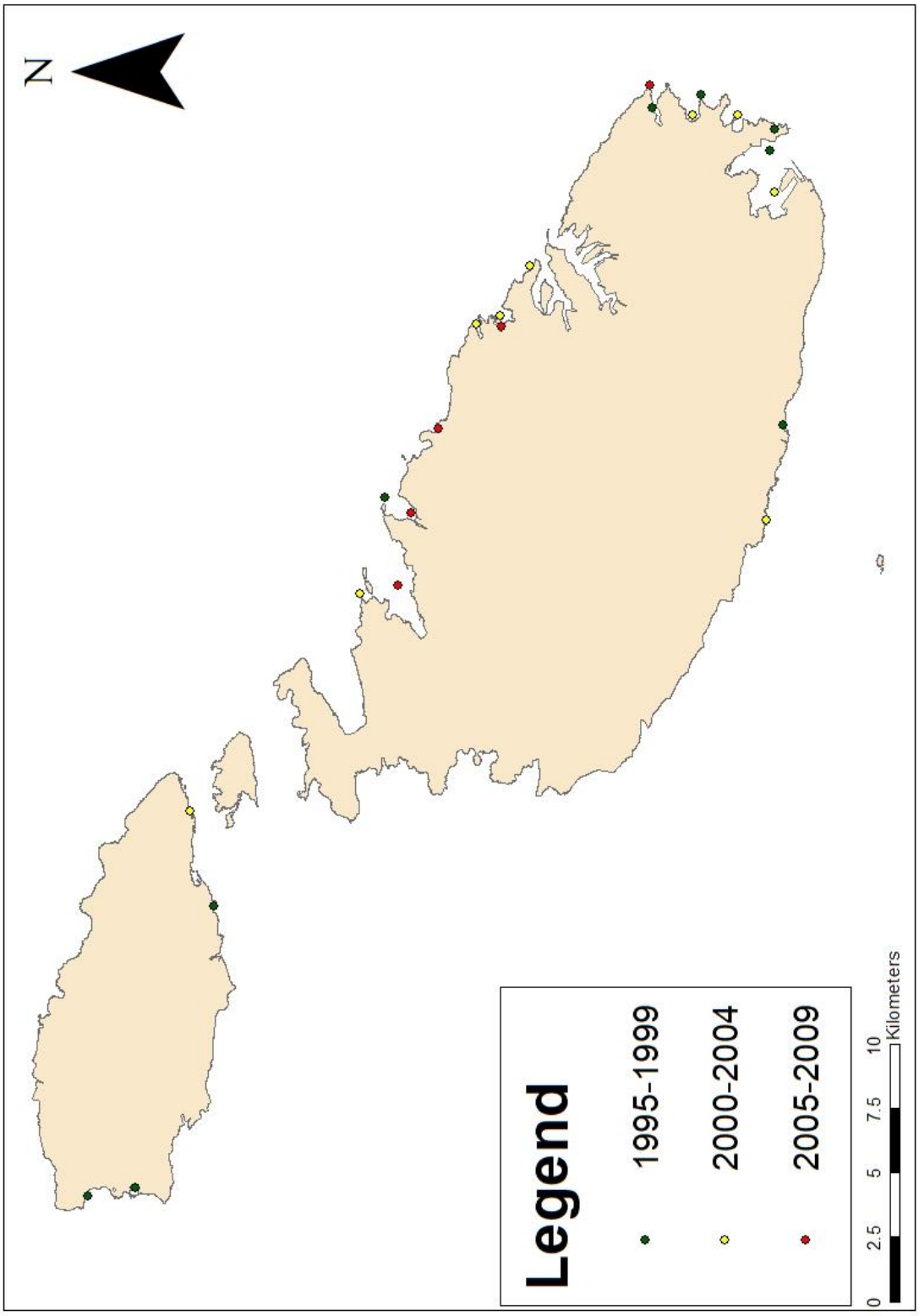

Figure 16: All records of the invasive *Caulerpa cylindracea* around Malta, coloured according to the record date.

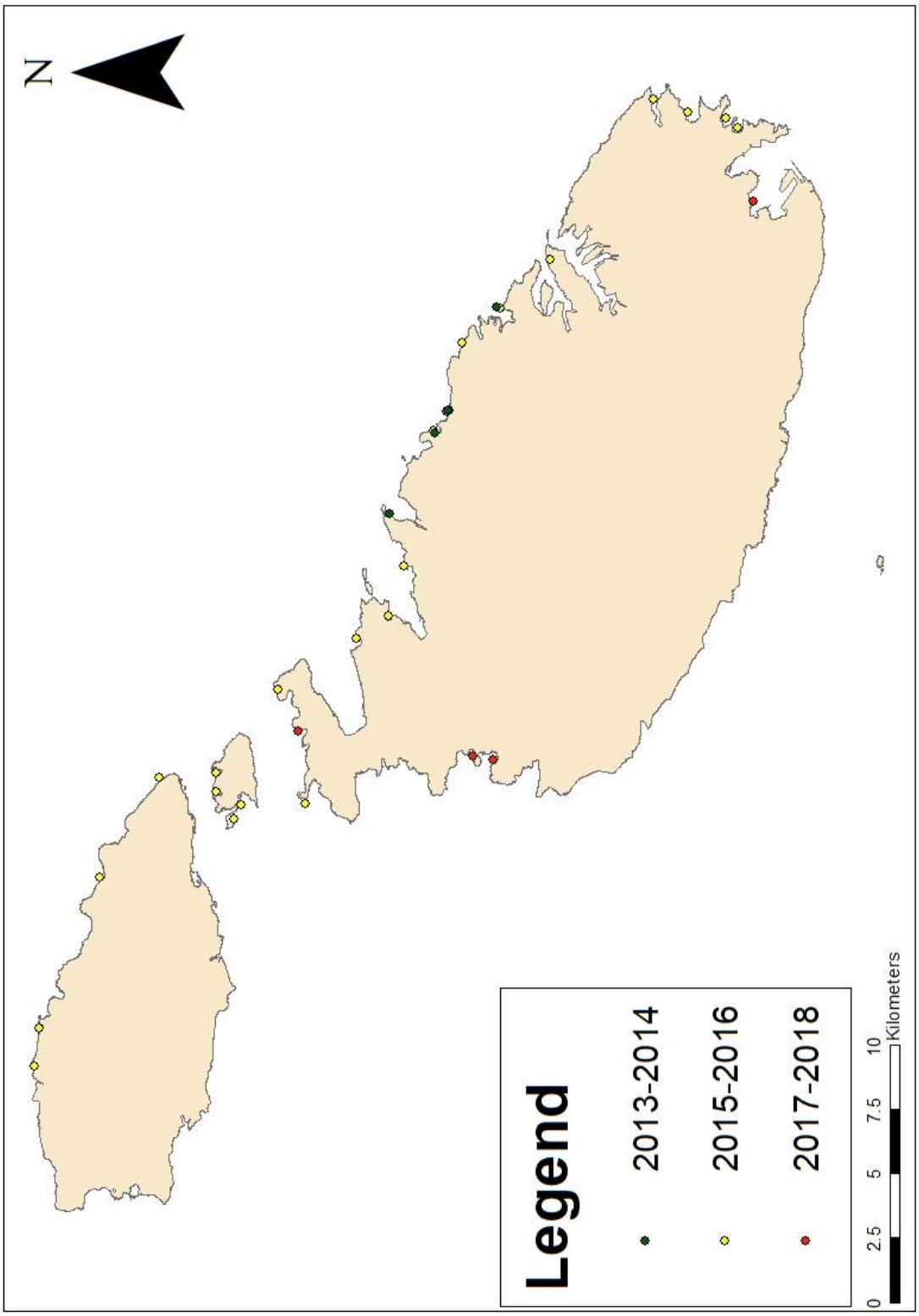

Figure 17: All records of the invasive *Caulerpa taxifolia var. distichophylla* around Malta, coloured according to the record date.

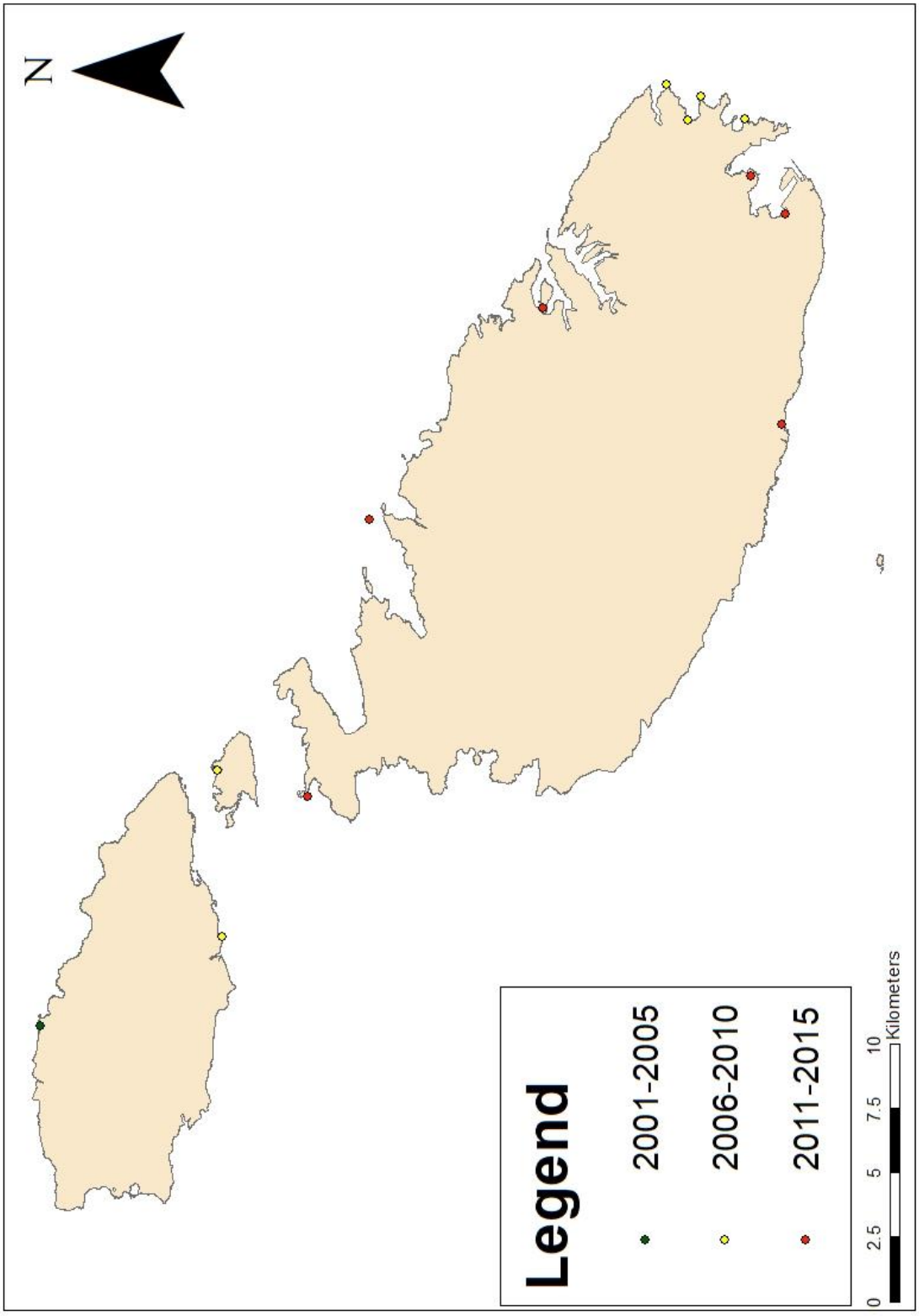

Figure 18: All records of the invasive *Fistularia commersonii* around Malta, coloured according to the record date.

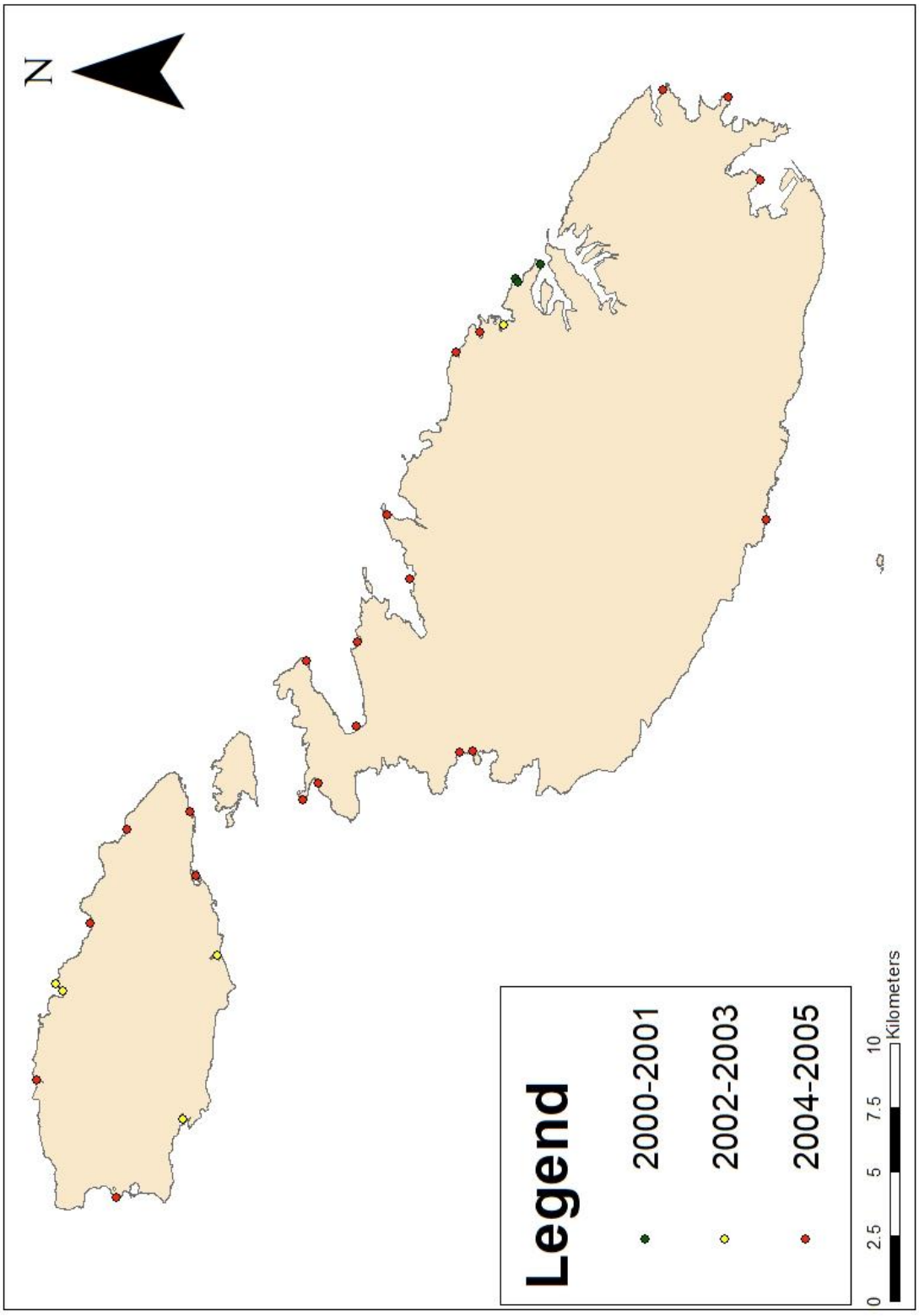

Figure19: All records of the invasive *Percnon gibbesi* around Malta, coloured according to the record date.

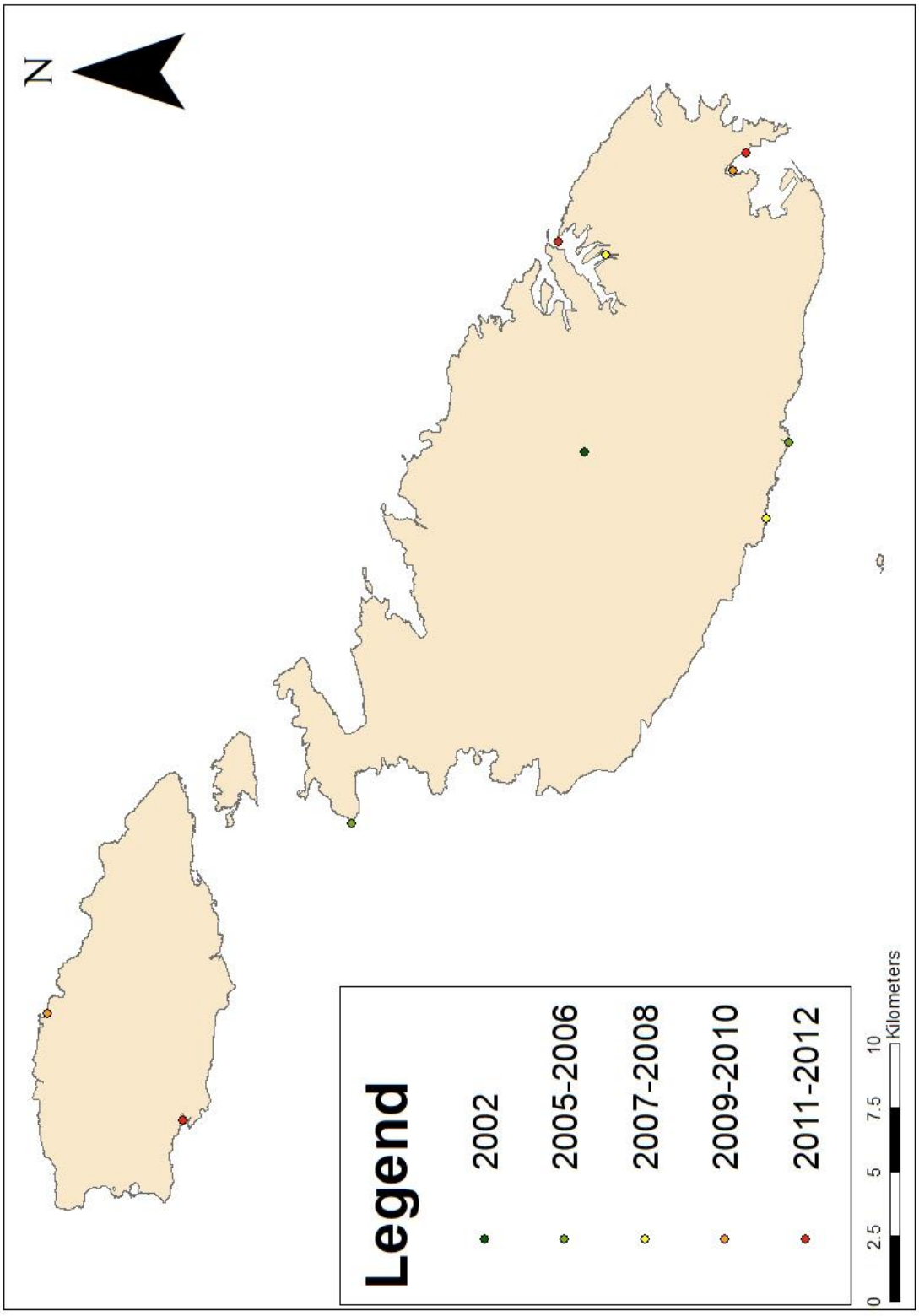

Figure 2: All records of the invasive *Siganus luridus* around Malta, coloured according to the record date

Discussion

The inventory list has seen some changes in the nomenclature of the species, but there have also been rectifications of records that were listed in older inventories. Misidentifications have been made in the past, which were only recently discovered, however sometimes native species were described after attributing the specimen to an alien species. This shows that the records of new additions may change in the future. Other changes were made to the status of the species, which could be derived from new information. There were two species whose establishment status was previously unsure, but new records have clarified this issue. The most noteworthy change is *Amphistegina lobifera* which has been assigned an invasive status.

The last decade has seen a large increase of records and first records of new species, which can be seen by the 62% and 44% increase respectively. Most of this increase is caused by casual newcomers, which is the first stage of a biotic invasion. This means that newcomers are detected fairly early in the invasion process. It also implies that keeping the inventory updated might prove to be a useful tool to monitor the status of alien species in Maltese waters. This is not consistent with all the data of the Mediterranean, as Galil et al. (2018) state that 2000-2010 had the highest increase in the Mediterranean. In this paper Malta has one of the lowest reported NIS and may therefore be less well-studied in the same decade. Also the central location of Malta could be the reason that the NIS reach Malta later, in the 2010-2019 era.

However, two big contributors to the first records were Ulman et al. (2017) and Guastella et al. (2019). Guastella et al. (2019) covered specifically foraminifera, which have never been studied in detail in the Maltese waters, whilst Ulman et al. (2017) focused on faunal groups like polychaetes, bryozoans and sponges that have not been covered well in Malta. Therefore, these two studies show that the other decades may have been underrepresented in these taxa. If these two papers were set aside, there would still be an increase in first records, but not as much.

The increase of the records can be attributed to both an increased interest in alien species and an increase in the amount of alien species present. Globalization, increased marine traffic and climate change are big drivers of biotic invasions in the Mediterranean Sea and the Maltese waters. There could also be another reason, as the EU regulation on invasive alien species, went into effect on January 1st, 2015. This regulation is set in place to prevent and mitigate biotic invasions, and could

have increased public awareness on alien species; a citizen science project has also been put in place (Gatt, Deidun, Galea, & Gauci, 2018). Other projects that are not directly linked with monitoring biotic invasions have shown to contribute to the inventory, like various genetic studies in hard to distinguish alien species, which main goal is to help discern them.

Most of the species introductions are as a result of shipping and secondary dispersal, however a large portion remains unknown. These species have too many possible modes of introduction to be assigned to one or two pathways. Almost half of all the species are attributed to shipping, making it the biggest contributor to the biotic invasions. This is further supported by the fact that, most of the records occur in the heavily modified areas, which are the two main harbour areas of the island. In fact, 31% of the records are in these areas, despite that these area occupy a much smaller fraction of Maltese waters. These two areas have always been a hotspot for biotic invasions over the last century. A very noteworthy change in these hotspots is the occurrence of a hotspot near the Freeport. Before the opening of the Freeport (1988), there was no hotspot. However, ten years later the area has one of the largest densities of records. This may be due to an increase of introductions, as ports and marinas were identified as the hotspots in a study performed in Sicily and Sardinia. It also showed that recreational vessels can also contribute heavily to dispersing the NIS to other areas from the marinas and harbours (Ferrario, Caronni, Occhipinti-Ambrogi, & Marchini, 2017).

Another interesting aspect of the records is their proximity to diving sites, and absence from some harder to reach coastlines, like the Dingli cliffs. The most popular diving sites were selected, and these alone account 33% of the newcomer records in a radius of 1 km from the dive spots. This indicates that diving might increase the chance of sighting a newcomer. Another explanation that transport of boat divers to the dive sites may facilitate spread of NIS, especially when the embarkation point is within a harbour. Also the presence of more people in dive sites might disturb the area and make it more vulnerable to introductions.

The most notable aspect of the point density maps of the decades is the spread of the hotspots. This means that species are expanding their distribution ranges, however Gozo seems to be less affected than the main island Malta. The hotspots of the records are the Valletta Harbours, Sliema-St Julians coastline, Marsaxlokk Bay, Blue Grotto and Comino. The first three hotspots are the most modified areas in Malta, whilst the other two are known for their water activities, as mentioned

before recreational vessels can be the cause. But, the diving activity also increases the detection of NIS in the area.

The maps of the invasive alien species do not show a universal dispersal route. *Amphistegina lobifera* was first recorded by Yokes et al. (2007) in various locations. It confirmed the presence on Gozo at Dwejra, Comino at Blue Lagoon and two localities far apart on Malta. These areas are popular bathing or diving spots, and since they were not in close proximity, it is safe to assume the species were introduced a while before it was first recorded, by which time it had already spread. Later Guastella et al. (2019) confirmed their spread around the whole island.

The situation for *Caulerpa cylindracea* is similar to that of *A. lobifera*, in that the species was most likely already widespread when it was first recorded. However later studies confirmed the presence at other locations, but no real migration direction can be discerned from the data.

This is different from *Brachidontes pharaonis*, which was first recorded from the harbours and in the area spanning from Sliema to Qawra. Later it was recorded multiple times around these locations and the other site of the island at Blue Grotto. It was also discovered on the other islands later. This might be caused through recreational vessels, since shipping is one of its pathways. The first study already covered quite some locations, however it is likely that it originated from the harbours of Malta and expanded from there.

Caulerpa taxifolia var. *distichophylla* was first recorded in four instances, and was later recorded in the northern area of Malta, in Gozo, and Comino. It was also recorded in the south, after which it was recorded in Marsaxlokk and lastly the west coast of the island at Gnejna Bay. The species is also likely dispersed via recreational vessels, as Comino is a popular destination from recreational vessels leaving from Sliema. However, it could have migrated on its own or been displaced via fishing gear.

Fistularia commersonii was first recorded in the north of Gozo and later records show an expansion to the south and Comino, however around the same time the species was recorded at multiple locations between Zonqor Point and Delimara, which is unlike the other invasive species. This is because *F. commersonii* is a very motile fish and the first record predates the next one with three years. It only relies on its own dispersal capacity.

Percnon gibbesi was first recorded from Sliema and was later recorded from St Julians, which is very near, but also Gozo. It might have hitched a ride to Gozo with the recreational vessels, but it is also a species used in aquaria, so it is possible there have been separate introductions at different locations. Afterwards it was recorded all over Malta and its dispersion happened quickly.

Siganus luridus' first record did not state the location, but the next two are close to diving spots. It has dispersed along the coast to the harbours and Gozo, which indicate a more independent secondary dispersal.

The conclusion one could make from the analysis of dispersal patterns seen in these invasive species is that when the introduction occurred long before a species is first recorded, it becomes increasingly difficult to elucidate the original site of introduction or the dispersal pattern in the Maltese waters. Some species are first recorded near popular bathing/diving sites, whilst others are initially recorded in the harbours. However, the issue lies with the way of reporting alien species. In order to properly assess the dispersal in the Maltese waters, negative data (known absences) are also needed, but these are mostly absent unless the species is already well-known. When assessing the dispersal routes in the Maltese waters the early records do not indicate absence elsewhere. This publication bias makes it harder to ensure the species did not occur before its record in a location.

When collecting data there was also a noteworthy absence on ecological impact of the non-native species. This is obvious since the impact is often noted after the species has reached the invasive phase. The effects from the newcomer species may also be very subtle, indirect or else not evident until combined with other synergistic impacts. However, in some instances generalizations of the genus might be of help, or the impacts shown in other regions.

Conclusions

The amount of newcomer species is increasing, but is also most likely underrepresented. There is a lot of missing information, which is confirmed by the large amount of new recorded species by Ulman et al. (2017) and Guastella et al. (2019) that focused on less studied taxa. However, these also did not cover the whole island, so there is always a publication bias present. Data on ecological impact is only present after being witnessed in Malta, with only a few papers looking towards other areas or species in the same genus to predict the impact.

The most important pathway is shipping, which is confirmed by the large portion of alien species that are attributed to it, and the invasive species distribution maps, which can be linked to recreational vessels. The heavy modifications in the area might contribute by making the area more susceptible.

The species that were newly recorded, were often ‘Casual’, however the amount of ‘Invasive’ species is increasing. The bias of the location might give a misrepresentation of the newcomer species and some may have a larger range than currently reported.

The hotspots of the non-native species are the harbours and popular bathing and diving sites, which underline the bias in data. The most of the sightings take place in these areas due to the increased effort, but the activities are also a contributor to biotic invasions.

Updating inventories is a useful tool to assess similarities between species in an area and might be used to assess problematic areas. An inventory requires a regular update, since a large amount of records are being published, or modified, yearly.

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Appendix A: Updated inventory list

Species	Kingdom	Phylum	Natural range	Category	Origin	Maltese Mode of Entry	Status	First Maltese record
***Abudefduf* cf. *saxatilis* (Linnaeus, 1758)**	Animalia	Chordata	Atlantic Ocean	Alien	Cryptogenic	Unknown	Established	Sep-13
***Abudefduf* cf. *vaigiensis* (Quoy & Gaimard, 1825)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Aquaculture, Shipping	Established	Apr-13
***Abudefduf hoefleri* (Steindachner, 1881)**	Animalia	Chordata	Eastern Atlantic	Alien	Alien	Shipping	Casual	Jan-14
***Acanthophora nayadiformis* (Delile) Papenfuss, 1968**	Plantae	Rhodophyta	Red Sea, Indian Ocean	Alien	Cryptogenic	Secondary dispersal	Established	In 1969
***Acanthurus chirurgus* (Bloch, 1787)**	Animalia	Chordata	Western Atlantic, Senegal	Alien	Alien	Aquarium release, Shipping	Casual	Aug-16
***Acanthurus coeruleus* Bloch & Schneider, 1801**	Animalia	Chordata	Western Atlantic	Alien	Alien	Unknown	Casual	Oct-13
***Acanthurus monroviae* Steindachner, 1876**	Animalia	Chordata	Eastern Atlantic	Range-Expansion	Range-Expansion	Secondary dispersal	Established	Sep-13
***Acanthurus monroviae* Steindachner, 1876**	Animalia	Chordata	Eastern Atlantic	Range-Expansion	Range-Expansion	Secondary dispersal	Established	Nov-15

***Achelia sawayai sensu lato* Marcus, 1940**	Animalia	Arthropoda	Western Atlantic, Pacific	Alien	Alien	Shipping	Casual	Jul-16
***Acrothamnion preissii* (Sonder) E.M.Wollaston, 1968**	Plantae	Rhodophyta	Indo-Pacific	Alien	Alien	Secondary dispersal, Shipping	Established	Apr-14
***Alepes djedaba* (Forsskål, 1775)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Secondary dispersal	Established	In 1961
***Amathia verticillata* (delle Chiaje, 1822)**	Animalia	Bryozoa	Caribbean Sea	Alien	Alien	Shipping	Casual?	Jul-16
***Amphisorus hemprichii* Ehrenberg, 1839**	Chromista	Foraminifera	Indo-Pacific	Alien	Cryptogenic	Unknown	Established	Nov-17
***Amphistegina lessonii* d'Orbigny in Guérin-Méneville, 1832**	Chromista	Foraminifera	Indo-Pacific, Western Central Atlantic	Alien	Cryptogenic	Unknown	Established	Oct-17
***Amphistegina lobifera* Larsen, 1976**	Chromista	Foraminifera	Indo-Pacific, Atlantic Ocean	Alien	Alien	Secondary dispersal, Shipping	Invasive	Jun-06
***Anteaeolidiella lurana* (Ev. Marcus & Er. Marcus, 1967)**	Animalia	Mollusca	Atlantic Ocean	Alien	Cryptogenic	Unknown	Established	Jan-93
***Aplysia dactylomela* Rang, 1828**	Animalia	Mollusca	Atlantic Ocean	Alien	Cryptogenic	Secondary dispersal, Shipping	Established	May-08

***Aplysia parvula* Mörch, 1863**	Animalia	Mollusca	Circumtropical	Alien	Cryptogenic	Secondary dispersal	Casual?	Sep-67
***Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon, 1845**	Plantae	Rhodophyta	Lineage-dependent, Lineage 3: Atlantic, Lineage 2: Indo-Pacific	Alien	Cryptogenic	Secondary dispersal, Shipping	Established	Sep-94
***Aspidosiphon* (Akrikos) *mexicanus* (Murina, 1967)**	Animalia	Sipuncula	West-Atlantic, Indian Ocean	Alien	Cryptogenic	Unknown	Established	Prior to 1999
***Atactodea striata* (Gmelin, 1791)**	Animalia	Mollusca	Indo-Pacific, Red Sea	Alien	Alien	Secondary dispersal, Shipping	Casual	Aug-77
***Biuve fulvipunctata* (Baba, 1938)**	Animalia	Mollusca	Indo-Pacific	Alien	Alien	Unknown	Established	Aug-93
***Botryocladia madagascariensis* G.Feldmann, 1945**	Plantae	Rhodophyta	Indo-Atlantic tropical	Alien	Alien	Secondary dispersal, Shipping	Established?	Sep-94
***Brachidontes pharaonis* (P. Fischer, 1870) (= variabilis)**	Animalia	Mollusca	Indian Ocean, Red Sea	Alien	Alien	Secondary dispersal, Shipping	Invasive	Oct-70
***Branchiomma bairdi* (McIntosh, 1885)**	Animalia	Polychaeta	Caribbean Sea	Alien	Alien	Secondary dispersal, Shipping	Established	Mar-11
***Bursatella leachii* Blainville, 1817**	Animalia	Mollusca	Circumtropical	Alien	Alien	Secondary dispersal	Established	Apr-69
***Caprella scaura* Templeton, 1836**	Animalia	Arthropoda	Indian Ocean	Alien	Alien	Aquaculture	Established	Oct-10
***Cassiopea andromeda* (Forsskål, 1775)**	Animalia	Cnidaria	Indo-Pacific, Red Sea	Alien	Alien	Shipping	Established	Mar-09

***Caulerpa cylindracea* Sonder, 1845**	Plantae	Chlorophyta	Indian Ocean	Alien	Alien	Unknown	Invasive	Feb-97
***Caulerpa taxifolia var distichophylla* (Sonder) Verlaque, Huisman & Procacini, 2013**	Plantae	Chlorophyta	Western Australia	Alien	Alien	Shipping	Invasive	Jun-13
***Celleporaria aperta* (Hincks, 1882)**	Animalia	Bryozoa	Indo-Pacific	Alien	Alien	Aquaculture, Shipping	Established?	1975/1976
***Celleporaria brunnea* (Hincks, 1884)**	Animalia	Bryozoa	Northeast Pacific	Alien	Alien	Shipping	Casual	Jul-16
***Celleporaria pilaefera* (Canu & Bassler, 1929)**	Animalia	Bryozoa	Indo-West Pacific	Alien	Alien	Aquaculture, Shipping	Established?	1975/1976
***Cephalopholis hemistiktos* (Rüppell, 1830)**	Animalia	Chordata	Red Sea, Western Indian Ocean	Alien	Alien	Aquaculture, Aquarium release	Casual	Aug-09
***Cephalopholis nigri* (Günther, 1859)**	Animalia	Chordata	Eastern Tropical Atlantic	Alien	Alien	Aquarium release, Shipping	Casual	Jul-16
***Cephalopholis taeniops* (Valenciennes, 1828)**	Animalia	Chordata	(Sub-) Tropical Eastern Atlantic	Range-Expansion	Range-Expansion	Natural range expansion	Established	Jul-08
***Cerithium scabridum* Philippi, 1848**	Animalia	Mollusca	Indo-Pacific	Alien	Alien	Secondary dispersal, Shipping	Established	Jan-05
***Chondria pygmaea* Garbary & Vandermeulen, 1990**	Plantae	Rhodophyta	Indo-Pacific	Alien	Alien	Unknown	Established?	Sep-94

***Chrysiptera hemicyanea* (Weber, 1913)**	Animalia	Chordata	Indo-West Pacific	Alien	Alien	Aquarium release	Casual	Jun-17
***Colpomenia peregrina* Sauvageau, 1927**	Chromista	Ochrophyta	Pacific	Alien	Alien	Unknown	Casual	In 1997
***Coronaster briareus* (Verrill, 1882)**	Animalia	Echinodermata	Western Atlantic, Caribbean	Range-Expansion	Cryptogenic	Unknown	Established	Jul-15
***Coscinospira hemprichii* Ehrenberg, 1839**	Chromista	Foraminifera	Western Central Pacific	Alien	Cryptogenic	Unknown	Casual	Oct-17
***Crepidula fornicata* (Linnaeus, 1758)**	Animalia	Mollusca	Atlantic coast of North America	Alien	Alien	Aquaculture, Shipping	Casual	In 1973
***Cuvierina cancapae* A. W. Janssen, 2005**	Animalia	Mollusca	Southern Atlantic	Range-Expansion	Range-Expansion	Natural range expansion	Casual	In 2007
***Cymadusa filosa* Savigny, 1816**	Animalia	Arthropoda	Indo-Pacific	Alien	Cryptogenic	Unknown	Casual	Oct-10
***Dendostrea* c.f. *folium* (Linnaeus, 1758)**	Animalia	Mollusca	Indo-Pacific	Alien	Alien	Shipping	Casual	Jul-16
***Dosima fascicularis* (Ellis & Solander, 1786)**	Animalia	Arthropoda	Cosmopolitan	Alien	Cryptogenic	Unknown	Casual	May-04
***Enchelycore anatina* (Lowe, 1838)**	Animalia	Chordata	Eastern Atlantic	Range-Expansion	Range-Expansion	Natural range expansion	Casual	Sep-13
***Epinephelus malabaricus* (Bloch & Schneider, 1801)**	Animalia	Chordata	Indo-Pacific, Red Sea	Alien	Alien	Shipping	Casual	Jul-11

***Erugosquilla massavensis* (Kossmann, 1880)**	Animalia	Arthropoda	Red Sea, Persian Gulf	Alien	Alien	Shipping	Casual	May-19
***Eucidaris tribuloides* (Lamarck, 1816)**	Animalia	Echinodermata	Atlantic Ocean	Alien	Alien	Shipping	Established	In 1998
***Eurythoe laevisetis* Fauvel, 1914**	Animalia	Annelida	Atlantic Ocean	Alien	Alien	Unknown	Casual?	Mar-11
***Fistularia commersonii* Rüppell, 1838**	Animalia	Chordata	Indo-Pacific, Eastern Central Pacific	Alien	Alien	Secondary dispersal	Invasive	Dec-05
***Fulvia fragilis* (Forsskål in Niebuhr, 1775)**	Animalia	Mollusca	Indo-Pacific, Red Sea	Alien	Alien	Secondary dispersal, Shipping	Established?	Dec-08
***Halophila stipulacea* (Forsskål) Ascherson, 1867**	Plantae	Tracheophyta	Indo-Pacific, Red Sea	Alien	Alien	Secondary dispersal, Shipping	Established	Aug-70
***Haminoea cyanomarginata* Heller & T. E. Thompson, 1983**	Animalia	Mollusca	Indo-Pacific, Sudanese Red Sea	Alien	Alien	Secondary dispersal, Shipping	Established	Oct-Nov 2006
***Heniochus intermedius* Steindachner, 1893**	Animalia	Chordata	Red Sea, Western Indian Ocean	Alien	Alien	Unknown	Casual	Nov-14
***Herdmania momus* (Savigny, 1816)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Shipping	Established	Jun-13
***Holacanthus africanus* Cadenat, 1951**	Animalia	Chordata	Tropical Eastern Atlantic	Alien	Alien	Aquarium release, Shipping	Casual	Apr-17

***Holocentrus adscensionis* (Osbeck, 1765)**	Animalia	Chordata	Western Atlantic	Alien	Alien	Unknown	Casual	Aug-16
***Hydroides dirampha* Mörch, 1863**	Animalia	Annelida	Tropical Western Atlantic	Alien	Cryptogenic	Shipping	Casual	Jul-16
***Hydroides elegans* (Haswell, 1883) [nomen protectum]**	Animalia	Annelida	Australia, Indian Ocena	Alien	Alien	Shipping	Casual?	Nov-55
***Kyphosus vaigiensis* (Quoy & Gaimard, 1825)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Secondary dispersal, Shipping	Established	Jan-15
***Lagocephalus sceleratus* (Gmelin, 1789)**	Animalia	Chordata	Indo-West Pacific	Alien	Alien	Secondary dispersal	Casual	Aug-14
***Lophocladia lallemandii* (Montagne) F.Schmitz, 1893**	Plantae	Rhodophyta	Indo-Pacific	Alien	Alien	Unknown	Invasive	Sep-94
***Lutjanus fulviflamma* (Forsskål, 1775)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Aquarium release, Shipping	Casual	Dec-13
***Magallana gigas* (Thunberg, 1793)**	Animalia	Mollusca	Western Pacific	Alien	Alien	Aquaculture	Established	Mid-1970s
***Maritigrella fuscopunctata* (Prudhoe, 1978)**	Animalia	Platyhelminthes	Indo-Pacific	Alien	Alien	Unknown	Established	Jul-15
***Megabalanus tintinnabulum tintinnabulum* Linnaeus, 1758**	Animalia	Arthropoda	East Atlantic, south of Gibraltar	Alien	Alien	Shipping	Casual	In 1972
***Melibe viridis* (Kelaart, 1858)**	Animalia	Mollusca	Tropical Indo-West Pacific (no Red Sea)	Alien	Alien	Secondary dispersal, Shipping	Established?	Sep-08

***Mesanthura* cf *romulea* Poore & Lew Ton, 1986**	Animalia	Arthropoda	(Sub-) Tropical Southern Seas	Alien	Cryptogenic	Shipping	Casual	Jul-16
***Microcosmus squamiger* Michaelsen, 1927**	Animalia	Chordata	Pantropical	Alien	Alien	Shipping	Established	2003-2004
***Notocochlis gualtieriana* (Récluz, 1844)**	Animalia	Mollusca	Indian Ocean, Red Sea, Tropical Western Pacific	Alien	Alien	Unknown	Casual	In 1978
***Ondina michaelae* Cachia & Mifsud, 2015**	Animalia	Mollusca	Indo-Pacific	Alien	Cryptogenic	Shipping	Casual?	In 2009
***Ophioblennius atlanticus* (Valenciennes, 1836)**	Animalia	Chordata	Western and Eastern Atlantic	Range-Expansion	Range-Expansion	Natural range expansion, Shipping	Casual	Sep-14
***Oplegnathus fasciatus* (Temminck & Schlegel, 1844)**	Animalia	Chordata	Northwest and Eastern Central Pacific	Alien	Alien	Shipping	Casual	Nov-09
***Padina* cf. *boergesenii* Allender & Kraft, 1983**	Chromista	Ochrophyta	Pacific	Alien	Alien	Unknown	Questionable	In 1994
***Parablennius pilicornis* (Cuvier, 1829)**	Animalia	Chordata	Atlantic, possibly Mediterranean	Range-Expansion	Cryptogenic	Natural range expansion	Established	Aug-98
Paracerceis sculpta (Holmes, 1904)	Animalia	Arthropoda	California, Pacific Coast Mexico	Alien	Alien	Shipping	Casual	Jul-16
***Paraleucilla magna* Klautau,**	Animalia	Porifera	Brazilian Atlantic Coast	Alien	Alien	Aquaculture, Shipping	Established	July-August 2007

Monteiro & Borojevic, 2004								
***Paranthura japonica* Richardson, 1909**	Animalia	Arthropoda	Northwest Pacific Ocean	Alien	Alien	Aquaculture, Shipping	Casual	Jul-16
Peneroplis arietinus (Batsch, 1791)	Chromista	Foraminifera	Western Indian Ocean, Western Central Atlantic	Alien	Cryptogenic	Unknown	Established	Oct-17
***Percnon gibbesi* (H. Milne Edwards, 1853)**	Animalia	Arthropoda	(Sub-) Tropical Western, Eastern Atlantic and (Sub-) Tropical Eastern Pacific	Alien	Alien	Secondary dispersal	Invasive	Jun-01
***Phyllorhiza punctata* Lendenfeld, 1884**	Animalia	Cnidaria	Indo-Pacific	Alien	Alien	Secondary dispersal, Shipping	Established	Oct-16
***Pinctada imbricata radiata* (Leach, 1814)**	Animalia	Mollusca	Indo-Pacific, Red Sea	Alien	Alien	Secondary dispersal, Shipping	Established	In 1912
***Polycerella emertoni* A.E. Verrill, 1880**	Animalia	Mollusca	Tropical Atlantic	Alien	Alien	Unknown	Established?	Aug-93
***Pomacanthus maculosus* (Forsskål, 1775)**	Animalia	Chordata	Northwest Indian Ocean, Red Sea	Alien	Alien	Aquarium release, Shipping	Casual	Dec-12
Portunus segnis (Forskål, 1775)	Animalia	Arthropoda	Western Indian Ocean	Alien	Alien	Shipping	Casual	Nov-72
***Rhopilema nomadica* Galil, 1990**	Animalia	Cnidaria	East Africa, Red Sea	Alien	Alien	Secondary dispersal	Casual	Nov-04
Sargocentron sp.	Animalia	Chordata	Indo-Pacific (S. rubrum),Iberian	Alien	Cryptogenic	Secondary dispersal	Casual	Jan-15

			Peninsula (S. hastatum)					
***Scatophagus argus* (Linnaeus, 1766)**	Animalia	Chordata	Indo-Pacific (no Red Sea)	Alien	Alien	Aquarium release	Established	Mar-11
***Selene dorsalis* (Gill, 1863)**	Animalia	Chordata	(Sub-) Tropical East Atlantic	Alien	Cryptogenic	Unknown	Casual	Aug-07
***Seriola fasciata* (Bloch, 1793)**	Animalia	Chordata	Western, possibly Eastern Atlantic	Range-Expansion	Range-Expansion	Natural range expansion	Established	Oct-08
***Siganus luridus* (Rüppell, 1829)**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Secondary dispersal	Invasive?	Aug-02
***Sorites orbiculus* (Forsskål in Niebuhr, 1775)**	Chromista	Foraminifera	Indo-Pacific	Alien	Cryptogenic	Unknown	Established	Oct-17
***Sphoeroides pachygaster* (Müller & Troschel, 1848)**	Animalia	Chordata	Circumglobal, Tropical and Temperate	Range-Expansion	Range-Expansion	Unknown	Invasive	In 1994
***Sphyraena chrysotaenia* Klunzinger, 1884**	Animalia	Chordata	Indo-Pacific	Alien	Alien	Secondary dispersal	Established	In 1993
***Spinocalanus terranovae* Damkaer, 1975**	Animalia	Arthropoda	(Sub-) Antarctic	Alien	Cryptogenic	Unknown	Casual?	In 2001
***Stegastes variabilis* (Castelnau, 1855)**	Animalia	Chordata	Western Atlantic	Alien	Alien	Aquarium release, Shipping	Casual	Sep-13
***Stenothoe georgiana* Bynum & Fox, 1977**	Animalia	Arthropoda	Western Atlantic	Alien	Alien	Aquaculture, Shipping	Casual	Jul-16

***Stephanolepis diaspros* Fraser-Brunner, 1940**	Animalia	Chordata	Western Indian Ocean	Alien	Alien	Secondary dispersal	Established	In 1993
***Steromphala cineraria* (Linnaeus, 1758)**	Animalia	Mollusca	East Atlantic, Norway to Gibraltar	Alien	Alien	Aquaculture	Casual	Mar-76
Stomatella sp.	Animalia	Mollusca	Depends on the species	Alien	Alien	Unknown	Casual?	Apr-12
***Styela plicata* (Lesueur, 1823)**	Animalia	Chordata	Cosmopolitan	Alien	Alien	Shipping	Casual?	February 1975-February 1976
***Watersipora arcuata* Banta, 1969**	Animalia	Bryozoa	Tropical Eastern Pacific	Alien	Alien	Shipping	Casual	Jul-16
***Weinkauffia macandrewii* (E. A. Smith, 1872)**	Animalia	Mollusca	Atlantic, possibly Mediterranean	Alien	Cryptogenic	Unknown	Established	Aug-90
***Womersleyella setacea* (Hollenberg) R.E. Norris, 1992**	Plantae	Rhodophyta	Circumtropical	Alien	Alien	Unknown	Invasive	Sep-94

Appendix B: Factsheets of invasive species

***Amphistegina lobifera* Larsen, 1976**

Taxonomic group (Kingdom): Chromista

Taxonomic group (Phylum): Foraminifera

Natural range: Indo-Pacific and Atlantic Ocean

First Mediterranean record: 1959, Israel (Emery & Neev, 1960)

Mediterranean mode of entry: Canals (Lessepsian Immigrant) (EASIN)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 2006 (Yokes, Merİc, & Avsar, 2007)

Mode of entry into Malta: Shipping, secondary dispersal

Notes on Mode of entry: Not specified by Yokes et al. (2007), however aquaculture and aquarium trade are very unlikely.

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
June 2006	Fungus Rock, Gozo	36.045278	14.190556	18 alive	Yokes *et al.,* 2007
June 2006	Blue Lagoon, Comino	36.0152778	14.323611	32 tests in sediment	Yokes *et al.,* 2007
June 2006	Golden Bay, Malta	35.929167	14.341944	12 alive	Yokes *et al.,* 2007
June 2006	Sliema, Malta	35.91167	14.507778	26 alive	Yokes *et al.,* 2007
October 2017	Wied iz-Zurrieq, Malta	35.819528	14.451306	167 dead	Guastella *et al.,* 2019
October 2017	Ghar Lapsi, Malta	35.826444	14.424333	1 stained, 161 dead	Guastella *et al.,* 2019
October 2017	Cirkewwa, Malta	35.986694	14.326667	6 stained, 274 dead	Guastella *et al.,* 2019
October 2017	Comino (P31)	36.009139	14.324111	3 stained, 6 dead	Guastella *et al.,* 2019
October 2017	Cominotto Arch, Comino	36.011722	14.318361	221 dead	Guastella *et al.,* 2019
November 2017	Comino Channel, Comino	36.020528	14.323722	2 stained, 11 dead	Guastella *et al.,* 2019

November 2017	Anchor Bay, Malta	35.959083	14.338778	123, stained, 85 dead	Guastella *et al.,* 2019
November 2017	Manoel Island, X127	35.900722	14.505139	104 dead	Guastella *et al.,* 2019
November 2017	St. Paul's Bay, Malta	35.949889	14.404639	1 stained, 4 dead	Guastella *et al.,* 2019
November 2017	Balluta Bay, Malta	35.915833	14.494389	2 dead	Guastella *et al.,* 2019
November 2017	Anchor Bay, Malta	35.960000	14.340500	88 stained, 135 dead	Guastella *et al.,* 2019
November 2017	Bahar ic-Caghaq, Malta	35.937583	14.462750	24 stained, 245 dead	Guastella *et al.,* 2019
December 2017	Fond Ghadir, Sliema - Malta	35.915750	14.504944	43 stained, 194 dead	Guastella *et al.,* 2019
December 2017	Dahlet ix-Xmajjar, Malta	35.997472	14.365722	13 stained, 51 dead	Guastella *et al.,* 2019
December 2017	Qortin East, Malta	35.988472	14.350694	4 stained, 21 dead	Guastella *et al.,* 2019
December 2017	Qortin West, Malta	35.988417	14.349806	3 dead	Guastella *et al.,* 2019
December 2017	Qortin North, Malta	35.990472	14.348472	11 stained, 14 dead	Guastella *et al.,* 2019
December 2017	Gnejna – Inner, Malta	35.921556	14.343056	4 stained, 19 dead	Guastella *et al.,* 2019
December 2017	Gnejna – Outer, Malta	35.922944	14.339806	1 dead	Guastella *et al.,* 2019
December 2017	Mgarr ix-Xini – Inner, Gozo	36.019417	14.272250	2 dead	Guastella *et al.,* 2019
December 2017	Mgarr ix-Xini – Outer, Gozo	36.017333	14.272694	2 stained, 3 dead	Guastella *et al.,* 2019
December 2017	Xlendi – Inner, Gozo	36.030167	14.216861	1 stained, 1 dead	Guastella *et al.,* 2019
December 2017	Xlendi – Outer, Gozo	36.029472	14.214611	46 stained, 168 dead	Guastella *et al.,* 2019
December 2017	Xatt l-Ahmar, Gozo	36.019083	14.290528	74 stained, 158 dead	Guastella *et al.,* 2019
December 2017	Hondoq – Inner, Gozo	36.027667	14.322778	76 stained, 224 dead	Guastella *et al.,* 2019
December 2017	Hondoq – Outer, Gozo	36.026306	14.323472	18 stained, 96 dead	Guastella *et al.,* 2019
December 2017	Santa Maria – Inner, Comino	36.016611	14.337194	4 dead	Guastella *et al.,* 2019
December 2017	Santa Maria – Outer, Gozo	36.019694	14.336889	62 stained, 303 dead	Guastella *et al.,* 2019
December 2017	Mgiebah – Inner, Malta	35.968167	14.382944	5 dead	Guastella *et al.,* 2019
December 2017	Mgiebah – Outer, Malta	35.969972	14.384139	2 stained, 27 dead	Guastella *et al.,* 2019

Establishment status in Malta:	Invasive
Notes on Establishment status:	It has spread rapidly to every area of the Maltese islands with large numbers
Known impacts from Malta:	Unknown

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Unknown

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***Caulerpa cylindracea* Sonder, 1845**

Taxonomic group (Kingdom): Plantae

Taxonomic group (Phylum): Chlorophyta

Natural range: Indian Ocean

First Mediterranean record: 1990, Libya (Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Mediterranean mode of entry: Aquaculture (Galil et al., 2018), Shipping (EASIN; Galil et al., 2018)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 1997 (Borg, Dimeck, & Schembri, 1997)

Mode of entry into Malta: Unknown

Notes on Mode of entry: Not indicated by Borg et al. (1997) and there are multiple pathways possible.

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
February 1997	Ta Slima area	36.063034	14.189124	5-10 % cover	Borg et al., 1997
February 1997	Dwejra (Gozo)	36.046472	14.192008	5-10 % cover	Mifsud & Lanfranco, 2007
February 1997	Hurd's Bank	35.916700	14.833300	20-30 % cover	Mifsud & Lanfranco, 2007
August 1997	M'Scala (near the waterpolo pitch)	35.866526	14.568034	70 % cover	Mifsud & Lanfranco, 2007
June 1998	M'Xlokk	35.825569	14.553204	30-40 % cover	Mifsud & Lanfranco, 2007
July 1998	Kalanka it-Tawwalija-Dellimara	35.823764	14.560468	20-25 % cover	Mifsud & Lanfranco, 2007
October 1998	Wied Iz-zurrieq	35.820841	14.457577	Few fronds	Mifsud & Lanfranco, 2007
June 1999	Munxar Point	35.849696	14.572595	20-30 % cover	Mifsud & Lanfranco, 2007

August 1999	Off Qawra /Ghallis	35.959576	14.432543	20-30 % cover	Mifsud & Lanfranco, 2007
October 1999	Xatt l-Ahmar (Gozo)	36.019292	14.289985	5-10 % cover	Mifsud & Lanfranco, 2007
March 2000	Kalanka t-Tawwalija	35.823764	14.560468	5 % cover	Mifsud & Lanfranco, 2007
June 2000	Spinola Headland	35.919533	14.495498	1-2 % cover	Mifsud & Lanfranco, 2007
July 2000	St.Thomas Bay	35.852585	14.565586	5-10 % cover	Mifsud & Lanfranco, 2007
October 2001	Tigné (Sliema)	35.909157	14.513038	5 % cover	Mifsud & Lanfranco, 2007
August 2002	Off il-Hofriet	35.836661	14.565471	-	Mifsud & Lanfranco, 2007
March 2003	Birzebbuġa	35.823825	14.538713	-	Mifsud & Lanfranco, 2007
June 2003	Ħondoq ir-Rummien	36.027294	14.323036	15 % cover	Mifsud & Lanfranco, 2007
June 2003	Ghar Lapsi	35.826779	14.424519	10 % cover	Mifsud & Lanfranco, 2007
June 2003	St. George's Bay - Paceville	35.927727	14.492621	15 % cover	Mifsud & Lanfranco, 2007
October 2003	Blata l-Bajda	35.968235	14.398884	50 % cover	Mifsud & Lanfranco, 2007
2009	St Paul's Bay	35.954910	14.401752	61.6 % cover	Barbara & Borg, 2014
2009	Salina Bay	35.950467	14.426864	38.33 % cover	Barbara & Borg, 2014
2009	Bahar ic-Caghaq	35.941102	14.456202	7.67 % cover	Barbara & Borg, 2014
2009	St. George's Bay, St Julians	35.927727	14.492621	6.67 % cover	Barbara & Borg, 2014
2009	Spinola Bay	35.918843	14.492163	1.67 % cover	Barbara & Borg, 2014
2009	Zonqor Point (Marsaskala)	35.867146	14.575965	65.0 % cover	Barbara & Borg, 2014

Establishment status in Malta: Invasive

Notes on Establishment status: Widespread and in high coverage percentages

Known impacts from Malta: Can modify floristic components of its habitat (Evans, Barbara, & Schembri, 2015)

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Unknown

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***Caulerpa taxifolia var distichophylla* (Sonder) Verlaque, Huisman & Procacini, 2013**

Taxonomic group (Kingdom): Plantae

Taxonomic group (Phylum): Chlorophyta

Natural range: Western Australia

First Mediterranean record: 2006, Turkey (Cevik et al., 2007)

Mediterranean mode of entry: Shipping (Galil, Marchini, & Occhipinti-Ambrogi, 2018), aquarium release (EASIN)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 2013 (Schembri, Barbara, Deidun, Lanfranco, & Lanfranco, 2015)

Mode of entry into Malta: Shipping

Notes on Mode of entry: Secondary dispersal., shipping and fishing gear have been suggested as modes of dispersal within the Mediterranean. For Malta shipping is regarded as the most likely vector (Schembri et al., 2015).

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
June 2013	White Rocks	35.942122	14.455217	30	Schembri *et al.,* 2015
July 2014	White Rocks	35.937236	14.463183	235 (± 21.25 SD)	Schembri *et al.,* 2015
July 2014	White Rocks	35.937572	14.463092	317.5 (± 24.75 SD)	Schembri *et al.,* 2015
July 2014	Exiles, Sliema	35.920642	14.499161	340	Schembri *et al.,* 2015
July 2014	Exiles, Sliema	35.920489	14.498928	180	Schembri *et al.,* 2015
2014	Qawra	35.958100	14.426900	-	Ellul *et al.,* 2019
2016	Bahar ic-Caghaq	35.938200	14.462600	972.00 (± 417.01 SD)	Ellul *et al.,* 2019
2016	Exiles (Sliema)	35.919600	14.498500	230.67 (± 355.71 SD)	Ellul *et al.,* 2019

2016	Qawra	35.958100	14.426900	298.67 (± 161.93 SD)	Ellul *et al.*, 2019
2016	Xwejni, Gozo	36.079800	14.248000	324.00 (± 312.35 SD)	Ellul *et al.*, 2019
2016	San Niklaw, Comino	36.018200	14.330000	450.67 (± 192.34 SD)	Ellul *et al.*, 2019
2016	Santa Maria, Comino	36.018300	14.337000	302.67 (± 119.43 SD)	Ellul *et al.*, 2019
2016	Cominotto	36.012000	14.320800	90.67 (± 162.36 SD)	Ellul *et al.*, 2019
2016	Crystal Lagoon, Comino	36.009600	14.325500	532.00 (± 311.61 SD)	Ellul *et al.*, 2019
2016	Cirkewwa	35.987300	14.326100	153.33 (± 170.08 SD)	Ellul *et al.*, 2019
2016	Mistra	35.958200	14.391500	165.33 (± 68.00 SD)	Ellul *et al.*, 2019
2016	Qalet Marku	35.942800	14.456100	516.00 (± 487.70 SD)	Ellul *et al.*, 2019
2016	Pembroke	35.932600	14.486500	340.00 (± 189.08 SD)	Ellul *et al.*, 2019
2016	Marsamxett	35.902200	14.515500	481.33 (± 398.89 SD)	Ellul *et al.*, 2019
2016	Marsaskala	35.866200	14.571300	630.67 (± 357.54 SD)	Ellul *et al.*, 2019
2016	San Tumas	35.853900	14.566900	417.33 (± 205.75 SD)	Ellul *et al.*, 2019
2016	Hofra z-Zghira (Delimara)	35.836700	14.561500	298.67 (± 136.51 SD)	Ellul *et al.*, 2019
2016	Qala, Gozo	36.038100	14.335300	-	Ellul *et al.*, 2019
2016	Reqqa Point, Gozo	36.081600	14.234800	-	Ellul *et al.*, 2019
2016	Armier	35.996900	14.365800	-	Ellul *et al.*, 2019
2016	Mgiebah (Selmun)	35.969500	14.383600	-	Ellul *et al.*, 2019
2016	Xemxija	35.953100	14.408700	-	Ellul *et al.*, 2019
2016	Hofra il-Kbira	35.841000	14.564900	-	Ellul *et al.*, 2019
2016	San Blas	36.059000	14.300200	-	Ellul *et al.*, 2019
2017	Bahar ic-Caghaq	35.938200	14.462600	-	Ellul *et al.*, 2019
2017	Marsaskala	35.866200	14.571300	-	Ellul *et al.*, 2019
2017	Qajjenza	35.831300	14.535700	-	Ellul *et al.*, 2019
2017	Gnejna bay	35.922000	14.341300	-	Ellul *et al.*, 2019
2017	Ghajn Tuffieha	35.929100	14.342500	-	Ellul *et al.*, 2019
2017	Ramla tal-Qortin	35.989700	14.351200	-	Ellul *et al.*, 2019

Establishment status in Malta: Invasive

Notes on Establishment status: Found on multiple locations and in high numbers (Schembri et al., 2015), more records in a recent survey show that the species has spread to numerous locations (Ellul, Evans, & Schembri, 2019)

Known impacts from Malta: Little impact on assemblages recorded (Schembri et al., 2015)

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Alter species composition to more opportunistic species (Musco et al., 2014).

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***Fistularia commersonii* Rüppell, 1838**

Taxonomic group (Kingdom): Animalia

Taxonomic group (Phylum): Chordata

Natural range: Indo-Pacific, Eastern Central Pacific

First Mediterranean record: 1975, Lebanon (Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Mediterranean mode of entry: Canals (Lessepsian Immigrant) (EASIN; Galil et al., 2018)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 2005 (Cini, 2006)

Mode of entry into Malta: Secondary dispersal

Notes on Mode of entry: Mode of entry is not stated by Cini (2006), but secondary dispersal is the most plausible mode of entry according to Evans, Barbara, and Schembri (2015)

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
December 2005	Xwejni Bay	36.079506	14.248431	1	Cini, 2006
January 2008	Munxar Point	35.849444	14.571667	4-6	Deidun & Germanà, 2011
March 2008	Marsascala	35.861389	14.575833	5	Deidun & Germanà, 2011
December 2009	Xrobb l-Ghagin	35.834167	14.563889	3 shoals of 3 each	Deidun & Germanà, 2011

August 2010	Munxar Point	35.849444	14.571667	3-4	Deidun & Germanà, 2011
September 2010	Santa Marija Bay, Comino	36.018056	14.337222	1	Deidun & Germanà, 2011
December 2010	Ras il-Hobz, Gozo	36.016389	14.279444	4-6	Deidun & Germanà, 2011
December 2010	St. Thomas Bay	35.853889	14.563611	3	Deidun & Germanà, 2011
February 2011	Zurrieq	35.821389	14.457778	5-8	Deidun & Germanà, 2011
February 2011	Birzebbuga	35.820278	14.530833	3	Deidun & Germanà, 2011
February 2011	Zurrieq	35.821389	14.457778	5	Deidun & Germanà, 2011
February 2011	Qawra	35.965000	14.424444	4	Deidun & Germanà, 2011
February 2011	Xwejni Bay	36.079506	14.248431	2	Deidun & Germanà, 2011
February 2011	Cirkewwa	35.986389	14.328056	2	Deidun & Germanà, 2011
February 2011	Qawra	35.965000	14.424444	1	Deidun & Germanà, 2011
February 2011	Zurieq	35.821389	14.457778	3	Deidun & Germanà, 2011

February 2011	Qajjenza	35.832222	14.543889	3	Deidun & Germanà, 2011
February 2011	Manoel Island	35.904722	14.498056	1	Deidun & Germanà, 2011
February 2011	Zurrieq	35.821389	14.457778	3-4	Deidun & Germanà, 2011
March 2011	Zurrieq	35.821389	14.457778	4-5	Deidun & Germanà, 2011

Establishment status in Malta: Invasive

Notes on Establishment status: Became common quickly and started forming shoals (Sciberras & Schembri, 2007).

Known impacts from Malta: Unknown

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Unknown

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***Lophocladia lallemandii* (Montagne) F.Schmitz, 1893**

Taxonomic group (Kingdom): Plantae

Taxonomic group (Phylum): Rhodophyta

Natural range: Indo-Pacific

First Mediterranean record: 1908, Greece (Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Mediterranean mode of entry: Canals (Lessepsian Immigrant) (EASIN; Galil et al., 2018), Shipping (EASIN)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: Prior to 1994 (Cormaci et al., 1997)

Mode of entry into Malta: Unknown

Notes on Mode of entry: Not given by Cormaci et al. (1997)

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
September 1994	Ahrax	35.997981	14.369180	-	Cormaci *et al.,* 1997
September 1994	Blue Grotto	35.819355	14.462996	-	Cormaci *et al.,* 1997
September 1994	Ponta l-Irqieqa	36.003738	14.326157	-	Cormaci *et al.,* 1997
September 1994	Gozo, Wardija Point	36.039166	14.187808	-	Cormaci *et al.,* 1997
July 1995	Delimara	35.822658	14.562673	-	Cormaci *et al.,* 1997
July 1995	Rdum il Wahx	35.942729	14.327893	-	Cormaci *et al.,* 1997

Establishment status in Malta: Invasive

Notes on Establishment status: Has shown to be established and have a negative impact on the native ecosystem

Known impacts from Malta: Can modify floristic components of its habitat (Evans, Barbara, & Schembri, 2015).

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

L. allemandii is highly invasive and can cover most substrates, which reduces biodiversity of the benthic landscape. It can colonize *Posidonia oceanica* meadows and form extensive mats, thereby decreasing the seagrass density and growth, which can lead to a loss of said seagrass. It also outcompetes native invertebrates that live on the leaves of *P. oceanica*, by outcompeting them for space (Otero, Cebrian, Francour, Galil, & Savini, 2013).

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***Percnon gibbesi* (H. Milne Edwards, 1853)**

Taxonomic group (Kingdom): Animalia

Taxonomic group (Phylum): Arthropoda

Natural range: Tropical and subtropical regions of the west and east Atlantic Ocean and East Pacific Ocean

First Mediterranean record: 1999, Italy (Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Mediterranean mode of entry: Shipping (EASIN; Galil et al., 2018) and Aquarium release (EASIN)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 2001 (Borg, 2002)

Mode of entry into Malta: Secondary dispersal

Notes on Mode of entry: Most likely mode given its duration of the larval stage (Evans, Barbara, & Schembri, 2015)

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
June 2001	Tigne Beach	35.905367	14.513336	1	Borg, 2002
July 2001	Sliema Pitch	35.914017	14.508421	1	Borg, 2002
September 2001	Tigne Beach	35.905367	14.513336	2	Borg, 2002
October 2001	Tigne Beach	35.905367	14.513336	1	Borg, 2002
October 2001	Tigne Beach	35.905367	14.513336	1	Borg, 2002
October 2001	Tigne Beach	35.905367	14.513336	1	Borg, 2002
October 2001	Ghar id-Dud pool	35.913101	14.507187	1	Borg, 2002
October 2001	Tigne Beach	35.905367	14.513336	2	Borg, 2002
October 2001	Tigne Beach	35.905367	14.513336	5	Borg, 2002
November 2001	Tigne Beach	35.905367	14.513336	6	Borg, 2002
Summer 2002	Il-Qaliet	35.918352	14.492500	5	Borg, 2002

Summer 2002	Ghar Qawqla, Gozo	36.074118	14.262658	1	Borg, 2002
Summer 2002	Mgarr-ix-Xini, Gozo	36.017736	14.272853	1	Borg, 2002
Summer 2002	Xlendi, Gozo	36.029760	14.215698	4	Borg, 2002
Summer 2002	Marsalforn, Gozo	36.071708	14.260082	Several	Borg, 2002
June 2002	Tigne Beach	35.905367	14.513336	37	Borg, 2002
July – October 2004	Cirkewwa	35.988236	14.326716	3.4 ± 2.2 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	L-Ahrax tal-Mellieha	35.986694	14.375438	5.5 ± 3.5 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Mellieha Bay	35.969384	14.352607	4.8 ± 3.0 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Imgiebah	35.969050	14.381848	4.5 ± 2.2 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	St. Paul's Bay	35.950696	14.403780	4.3 ± 2.0 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Fra Ben	35.958894	14.426188	3.9 ± 2.4 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Pembroke	35.934667	14.482734	5.4 ± 3.9 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	St. Julian	35.926650	14.490085	2.4 ± 1.7 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Ghar id-Dud	35.913101	14.507187	5.2 ± 2.4 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Marsascala	35.862904	14.574233	11.9 ± 7.1 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Xrobb l-Ghagin	35.839845	14.571696	5.5 ± 2.5 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Birzebbugia	35.828640	14.543030	4.5 ± 3.3 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Ghar Lapsi	35.826742	14.424543	5.7 ± 5.2 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Golden Bay	35.933500	14.343538	4.6 ± 3.1 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Ghajn Tuffieha	35.929128	14.343831	1.6 ± 0.6 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Paradise Bay	35.982911	14.332514	5.8 ± 2.5 m^{-2}	Sciberras & Schembri, 2008

July – October 2004	Mgarr ix-Xini	36.017736	14.272853	3.7 ± 2.1 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Mgarr Harbour	36.025476	14.300220	3.3 ± 2.6 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Hondoq ir-Rummien	36.027552	14.322871	10.0 ± 6.0 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Dahlet Qorrot	36.049410	14.316603	8.9 ± 5.2 m^{-2}	Sciberras & Schembri, 2008
July – October 2004	Ramla l-Hamra Bay	36.062165	14.283748	-	Sciberras & Schembri, 2008
July – October 2004	Wied il-Ghasri	36.080658	14.229409	-	Sciberras & Schembri, 2008
July – October 2004	Dwejra (Ghar Zerqa)	36.053025	14.188261	-	Sciberras & Schembri, 2008

Establishment status in Malta: Invasive

Notes on Establishment status: Spread rapidly and affects native biota

Known impacts from Malta: Is a competitor for space with a native species, *Pachygrapsus marmoratus*. It might also be a competitor for food, but this has not been established as of yet in Malta

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Competitor for food with the native species

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***Siganus luridus* (Rüppell, 1829)**

Taxonomic group (Kingdom): Animalia

Taxonomic group (Phylum): Chordata

Natural range: Indo-Pacific

First Mediterranean record: 1931, Syria (Zenetos et al., 2017)

Mediterranean mode of entry: Canals (Lessepsian Immigrant) (EASIN; Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 2002 (Schembri, Deidun, & Anthony Falzon, 2012)

Mode of entry into Malta: Secondary dispersal

Notes on Mode of entry: Not explicitly stated by Schembri et al. (2012) but when describing the distribution through the Mediterranean it fits the profile of secondary dispersal., which is therefore the most plausible mode of entry.

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
August 2002	Malta	35.917973	14.409943	1	Schembri *et al.,2012*
September 2005	Wied iz-Zurrieq	35.819047	14.451419	7	Schembri *et al.,2012*
October 2006	Ras il-Qammieh	35.971334	14.318674	6	Schembri *et al.,2012*
June 2007	Cospicua	35.882734	14.516635	1	Schembri *et al.,2012*
August 2007	Malta	35.917973	14.409943	1	Schembri *et al.,2012*
December 2007	Ghar Lapsi	35.826874	14.424800	1	Schembri *et al.,2012*
February 2009	Marsaxlokk	35.838240	14.546012	7	Schembri *et al.,2012*
March 2010	Qbajjar, Gozo	36.076857	14.252560	3	Schembri *et al.,2012*
August 2010	Wied iz-Zurrieq	35.819047	14.451419	2	Schembri *et al.,2012*
May 2011	Wied iz-Zurrieq	35.819047	14.451419	1	Schembri *et al.,2012*

July 2011	Mouth of Grand Harbour	35.899329	14.521256	7	Schembri *et al.,2012*
July 2011	Xlendi, Gozo	36.029702	14.215329	1	Schembri *et al.,2012*
August 2011	Delimara	35.833753	14.552190	1	Schembri *et al.,2012*

Establishment status in Malta: Established.

Notes on Establishment status:

Based on the 30 specimens from the records, the species might be invasive (Evans, Barbara, & Schembri, 2015). However, Knittweis mentioned it is only caught occasionally and does not affect the fishing industry, with the lack of information the species does not seem to be in an invasive phase.

Known impacts from Malta: Unknown

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean): Unknown

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***Sphoeroides pachygaster* (Müller & Troschel, 1848)**

Taxonomic group (Kingdom): Animalia

Taxonomic group (Phylum): Chordata

Natural range: Circumglobal in tropical and temperate seas

First Mediterranean record: 1979, Spain (Oliver, 1981)

Mediterranean mode of entry: Range expansion

Overall Category: Range-expansion

Origin: Cryptogenic

Notes on Origin: The species is often considered an Atlantic immigrant (Zenetos et al., 2012), but it could also be a native species as the species might have been drawn and described in a centuries old literature from Egypt (Relini & Orsi Relini, 1995).

First Maltese record: 1994 (Cini, 1999)

Mode of entry into Malta: Range expansion

Notes on Mode of entry: Most likely mode if it is an Atlantic immigrant, which is supported by the existence records all around the Mediterranean describing a westwards range expansion, from the Atlantic to the Eastern Mediterranean, in which the Maltese record fits perfectly (Golani, Orsi-Relini, Massuti, & Quignard, 2002).

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
1994	Malta	35.917973	14.409943	-	Cini, 1999

Establishment status in Malta: Invasive

Notes on Establishment status: It is very common as it is found in trawls all around Malta (Evans, Barbara, & Schembri, 2015), but official authenticated records are lacking.

Known impacts from Malta: Unknown

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Unknown

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***Womersleyella setacea* (Hollenberg) R.E. Norris, 1992**

Taxonomic group (Kingdom): Plantae

Taxonomic group (Phylum): Rhodophyta

Natural range: Circumtropical

First Mediterranean record: 1986, Italy (Galil, Marchini, & Occhipinti-Ambrogi, 2018)

Mediterranean mode of entry: Shipping (EASIN; Galil et al., 2018)

Overall Category: Alien

Origin: Alien

Notes on Origin:

First Maltese record: 1994 (Cormaci et al., 1997)

Mode of entry into Malta: Unknown

Notes on Mode of entry: Not indicated by Cormaci et al. (1997) and there are many modes plausible.

Records from Malta:

Date	Location	Latitude	Longitude	Quantity	Reference
September 1994	Ahrax	35.997981	14.369180	-	Cormaci *et al.,* 1997
September 1994	Blue Grotto	35.819355	14.462996	-	Cormaci *et al.,* 1997
September 1994	Gozo, Wardija Point	36.039166	14.187808	-	Cormaci *et al.,* 1997
September 1994	Ponta l-Irqieqa	36.003738	14.326157	-	Cormaci *et al.,* 1997
July 1995	Delimara	35.822658	14.562673	-	Cormaci *et al.,* 1997
July 1995	Rdum il Wahx	35.942729	14.327893	-	Cormaci *et al.,* 1997
July 1995	Gozo, Mgarr ix-Xini	36.017055	14.273040	-	Cormaci *et al.,* 1997
July 1995	Kemmunett	36.012013	14.317821	-	Cormaci *et al.,* 1997

Establishment status in Malta: Invasive

Notes on Establishment status: Abundant from the upper infralittoral to the circalittoral region around all three islands, Comino,

Malta and Gozo. Species is also known to impact native flora (Sciberras & Schembri, 2007).

Known impacts from Malta: The species can modify the floristic composition of their habitat (Sciberras & Schembri, 2007) and they can bind rhodoliths in maerl that prevents them from turning (Sciberras et al., 2009).

Potential impacts in Malta (based on known impacts elsewhere in Mediterranean):

Unknown

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