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Backdating first records of non-indigenous species in the Mediterranean: are initial findings underestimated?

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Abstract

This work lists 75 cases of backdated non-indigenous species (NIS) first records in the Mediterranean Sea which constitute 7.6% of the total marine NIS diversity of the region. Of the backdated first records, approximately one-third belong to species of Mollusca, with the second most important group being Macrophyta, followed by Polychaeta and Crustacea. The backdating time spans in our dataset vary between 1 and 52 years with an average of approximately 8 years but considerable differences exist among taxonomic groups. Among reasons for NIS backdating delays in publishing due to a lack of taxonomic expertise emerges as a prominent factor. Backdating in Mollusca is partly attributed to shell collectors, who may delay in publishing their findings. In fish species backdating is primarily attributed to unreported findings that were only accidentally noticed. Misidentifications of species, often due to confusion with native or cryptogenic species, has also contributed to backdating, particularly in polychaetes. This challenge can be addressed by combining morphological identification with molecular analyses. A third reason for backdating is the volume of overlooked species in museums and/or private collections. In many cases, multiple factors such as misidentification and overlooked specimens in museum collections may contribute to large backdating intervals. It is expected that the number of backdated NIS will increase as overlooked specimens in museum drawers or private collections are re-examined and as new identification techniques are applied. Re-examination of older samples, using both morphological and molecular methods, may reveal even earlier entries of NIS.

Keywords: backdated records; NIS; marine diversity; first introduction; management; Mediterranean Sea.

Introduction

The redistribution of global biodiversity through anthropogenic activities with the introduction of species into areas outside their natural range has been recognised as one of the major pressures on native species, habitats, and ecosystems as well as the services they provide (IPBES, 2023). Biological invasions have fascinated naturalists and scientists for almost two centuries, often regarded as biogeographical curiosities (Richardson & Pyšek, 2008). However, their potentially severe ecological and socio-economic consequences have motivated a much more systematic effort over the past five decades to research, catalogue, assess, and combat species invasions beginning with studies on their spatial and temporal patterns (Carlton, 1989).

Species checklists are increasingly recognised as invaluable tools for biodiversity studies, conservation purposes, and management strategies (Lo Brutto, 2023). In particular, non-indigenous species (NIS) inventories provide baseline information to understand and monitor the arrival of these species in a region and to relate them to changes in vector intensity and environmental conditions (e.g., Gittenberger *et al.*, 2023; Png-Gonzalez *et al.*, 2023).

NIS inventories typically consist of the first record of each NIS in a geographic or administrative area, with the year the species was detected or/and collected, the associated publication, its ecological status (casual, established, or invasive), and the most likely pathway(s) of introduction (e.g., Çinar *et al.*, 2011; Galil *et al.*, 2021; Zenetos *et al.*, 2020). Since the actual introduction event is rarely observed, the date of first collection in any publication is often known to lag behind the actual date of introduction (Bailey *et al.*, 2020). Occasionally, later publications present findings that show that a NIS was present in an area earlier than previously documented, resulting in what is known as backdated first records of species.

Sometimes the reason can be as simple as a delay in the publication of findings (Zenetos *et al.,* 2019); on the other hand, the emergence of new information on species taxonomy and/or the (re)examination of material collected prior to the registered first record of a species can also lead to backdating of first records.

Whatever the reason may be, it is important that backdating changes are documented and examined, as they constitute a step towards a more accurate reconstruction of NIS invasion history and can help better elucidate potential introduction pathways as well as means and patterns of spread (Carlton & Schwindt, 2024). One typical example is the backdating of *Bursatella leachii* Blainville, 1817 in the Western Mediterranean from 1996 in Spain (Oliver & Terrasa, 2004) to 1969 in Naples, Italy, based on an overlooked specimen in the collections of the Stazione Zoologica Anton Dohrn by Travaglini & Crocetta (2019). The species, with a circumtropical distribution including the Red Sea, was first reported in the Mediterranean in 1940 in Israel (O'Donoghue & White, 1940) and was considered a Lessepsian migrant due to its typical east-west progression, presumably by natural dispersal (Selfati *et al.*, 2017). The overlooked Italian specimen, however, casted doubts on this hypothesis, suggesting at least the presence of simultaneous secondary vectors (Travaglini & Crocetta, 2019). Furthermore, later molecular studies indicated a possible Atlantic origin of *B. leachii* in the Mediterranean (Bazzicalupo *et al.*, 2018; 2020), with the status of the species still regarded as debatable among Mediterranean experts (Galanidi *et al.*, 2023).

Moreover, backdated records can inform NIS risk assessment and prioritisation efforts but also NIS evaluation in the framework of dedicated policy instruments at national and regional level. For example, the most widely used NIS indicator for Good Environmental Status (GES) within the framework of European Marine Strategy Framework Directive (MSFD) and Mediterranean Integrated Monitoring and Assessment Programme of the Mediterranean Sea (IMAP) policies currently relies on species first record dates to calculate temporal trends in marine NIS introduction rates (EC, 2008; 2017; UNEP/MAP, 2017). Last, but not least, backdated records can reveal gaps and deficiencies in invasion research and knowledge, and bring to light neglected and/or underexplored research areas and resources, providing critical insights for improving future monitoring, assessment, and management strategies.

In this work, we collate and present information on backdated NIS first records at the Mediterranean scale documented in the past 20 years, aiming to highlight the most common underlying reasons and discuss the implications for species' invasion histories and NIS assessments.

Methodology

The Mediterranean NIS inventory has been periodically enriched and revised since the early 2000s (Streftaris *et al.*, 2005; Zenetos *et al.*, 2005; Galil, 2008), motivated by policy needs (e.g., Zenetos *et al.*, 2010, 2012; Tsiamis *et al.*, 2019*,* 2021; Galanidi *et al.*, 2023) and taxonomic or quality control considerations (Zenetos *et al.*, 2017; 2022a, b).

Data for this paper have been assembled during the course of approximately 20 years, starting from one of the first Mediterranean full NIS inventories with first record dates (Zenetos *et al.,* 2005), with continuous curation of the dataset, which forms part of the Hellenic Centre for Marine Research (HCMR) offline database, up until November 2024 based on published and grey literature. All first record dates in the database are accompanied by their primary reference. During the process of revision and updating, there were cases where more recent literature would demonstrate the presence of a species in the Mediterranean at an earlier time than previously documented by older literature. All these cases were recorded and annotated as "backdated" records. This applies both to new publications, e.g., published after the establishment of the first NIS inventories, and to older publications that were supposed to be available at the time of the first published inventories but were erroneously missed during the initial evaluation of the literature and came to the attention of the authors at a later time. In other words, "backdating" occurs any time more recent literature documents the first presence of a NIS in a region earlier than previously thought, based on older available literature. For the purposes of this work, the superseded first record dates are referred to as "original" first records.

In a small number of cases an accurate collection date was not provided in the publication but rather the presence of the species was reported before a certain year (e.g., < 1970); in those cases, the collection date was set as that year. Moreover, when no temporal information at all was supplied about the collection of a species, which is not uncommon in older literature cataloguing species lists of a region, the year of the publication was registered as the year of the species record.

Regarding taxonomic groups, NIS were listed under the following groups: Ascidiacea, Bryozoa, Chlorophyta, Cnidaria, Ctenophora, Crustacea, Echinodermata, Fishes, Foraminifera, Mollusca, Ochrophyta, Platyhelminthes, Polychaeta, Porifera, and Rhodophyta. Chlorophyta, Ochrophyta, and Rhodophyta were then merged under the ''Macrophyta'' group, while Bryozoa, Ctenophora, Platyhelminthes, and Porifera (i.e., taxa with only one backdated species in our dataset) were grouped under the category "Miscellaneous taxa".

Results and Discussion

This work catalogued a total of 75 cases of backdated NIS first records in the Mediterranean Sea (Table 1), with an initial detection date until 2020. This subset constitutes 7.5% of the total marine NIS diversity of the region, which amounts to 1006 valid NIS according to the latest Mediterranean NIS baseline (Galanidi *et al.*, 2023). Even though most of these backdates have been incorporated

Table 1. Backdated species first records in the Mediterranean NIS inventory. Group abbreviations: ASC=Ascidiacea, BRY=Bryozoa, CHL=Chlorophyta, CNI=Cnidaria, CRU=Crustacea, CTE=Ctenophora, FISH=Fishes, FOR=Foraminifera, MOL=Mollusca, OCH=Ochrophyta, PLAT=Platyhelminthes, POL=Polychaeta, POR=Porifera, RHO=Rhodophyta. The column "Changes" presents the original (top) and backdated (bottom) first record dates with the associated references. Country codes follow the internationally accepted two-letter codes for countries https://www.worldatlas.com/aatlas/ctycodes.htm)

Group	Species	Changes
CRU	*Actaea savignii* (H. Milne Edwards, 1834)	2010: Karhan *et al.*, 2013 (IL); 2006: Crocetta *et al.*, 2015 (LB)
MOL	*Afrocardium richardi* (Audouin, 1826)	1997: Bogi & Galil, 1999 (IL); 1991: Zenetos *et al.*, 2024 (TR)
MOL	*Alveinus miliaceus* (Issel, 1869)	2016: Steger *et al.*, 2018 (IL); 2009: Albano *et al.*, 2024 (IL)
MOL	*Anadara kagoshimensis* (Tokunaga, 1906)	1969: Ghisotti, 1973 (IT); 1966: Parenzan, 1976 (IT)
CNI	*Aurelia solida* Browne, 1905	2002: Scorrano *et al.*, 2016 (FR); 1994: Gueroun *et al.*, 2020 (TN)
POL	*Branchiomma boholense* (Grube, 1878)	1933: Monro 1937 (EG); 1927: Fauvel, 1955 (IL)
CRU	*Callinectes sapidus* Rathbun, 1896	1949: Giordani Soika, 1951 (IT); 1947: Serbetis, 1959 (GR)
CNI	*Calyptospadix cerulea* Clarke, 1882	1978: Morri, 1979 (IT); 1977: Gili, 1986 (ES)
RHO	*Caulacanthus okamurae* Yamada	2004: Mineur *et al.*, 2007 (FR); 2002: Petrocelli *et al.*, 2020 (IT)
CHL	*Caulerpa cylindracea* Sonder	1990: Nizamuddin, 1981 (LY); 1985: Hamza, 1995 (TN)
CHL	*Caulerpa racemosa* var. *lamourouxii* f. *requienii* (Montagne) Weber Bosse	1954: Huve, 1957 (SY); 1951: Rayss & Edelstein, 1960 (IL)
CHL	*Caulerpa scalpelliformis* (R.Brown ex Turner) C.Agardh	1930: Hamel, 1930 (IL); 1929: Carmin, 1934 (SY, LB)
CHL	*Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini	2006: Çevik *et al*., 2007 as *C. taxifolia* (TR); 2003: Bitar, 2010 misidentified as a dwarf form of *C. mexicana* (SY)
BRY	*Celleporaria brunnea* (Hincks, 1884)	2004: Koçak, 2007 (TR); 2003: Harmelin, 2014 (LB)
RHO	*Chondria curvilineata* F.S.Collins & Hervey	1981: Boudouresque *et al.*, 1983 (FR); 1980: Athanasiadis, 1987 (GR)
RHO	*Chondria pygmaea* Garbary & Vandermeulen	1991: Cormaci *et al.*, 1992 (IT); 1974: Kashta & Pizzuto, 1995 (AL)
MOL	*Circenita callipyga* (Born, 1778)	1980: Barash & Danin 1986 (IL); 1972: Mienis, 2000 (IL)
RHO	*Colaconema codicola* (Børgesen) H.Stegenga, J.J.Bolton, & R.J.Anderson	1973: Meñez & Mathieson, 1981 (TN); 1952: Bidoux & Magne, 1989 (FR)
OCH	*Colpomenia peregrina* Sauvageau	1956: Méndez-Domingo, 1957 (FR); 1939: Blackler, 1967 (IT); 1918: Ville, 1968 (FR)
MOL	*Crepidula fornicata* (Linnaeus, 1758)	<1970: Parenzan, 1970 (IT); 1957: Clanzig, 1989 (FR)
MOL	*Cycloscala hyalina* (G. B. Sowerby II, 1844)	1992: Cecalupo & Quadri, 1994 (TR); 1986: Slieker *et al.*, 2023 (TR)
CRU	*Cymodoce fuscina* Schotte & Kensley, 2005	2015: Ulman *et al.*, 2017 (GR); 2002: Castelló *et al.*, 2020 (LB)
MOL	*Dendostrea folium* (Linnaeus, 1758)	1993: Çeviker, 2001 (TR); 1989: Zenetos *et al.*, 2024 (TR)
OCH	*Dictyota acutiloba* J. Agardh	2014: Katsanevakis *et al.*, 2020 (IL); 2010: Galil *et al.*, 2021 (IL)
OCH	*Dictyota cyanoloma* Tronholm, De Clerck, Gomez Garreta & Rull Lluch	1987: Rull Lluch *et al.*, 2007 (ES); 1935: Steen *et al.*, 2016 (HR)

Continued

Table 1 continued

Group	Species	Changes
ASC	*Didemnum perlucidum* Monniot F., 1983	2019: Novak & Shenkar, 2020 (IL); 2018: Karahan *et al.*, 2023 (TR)
MOL	*Dikoleps micalii* Agamennone, Sbrana, Nardi, Siragusa & Germanà, 2020	2016: Agamennone *et al.*, 2020 (GR); 2015: Albano *et al.*, 2021 (IL)
MOL	*Divalinga arabica* Dekker & Goud, 1994	1976: Mienis, 1979 (IL); 1956: Barash & Danin, 1986 (EG)
POL	*Dorvillea similis* (Crossland, 1924)	2005: Çınar, 2009 (TR); 2002: Toso *et al.*, 2024 (LB)
MOL	*Elysia nealae* Ostergaard, 1955	2019: Manousis *et al.*, 2020 (GR); 2018: Trainito *et al.*, 2022 (IT)
MOL	*Ervilia scaliola* Issel, 1869	2013: Zenetos & Ovalis, 2014 (TR); 2011: Albano *et al.*, 2024 (IL)
CNI	*Eudendrium carneum* Clarke, 1882	1983: Gili, 1986 (ES); 1950: Schuchert, 2008 (FR)
CNI	*Eudendrium merulum* Watson, 1985	1984: Bavestrello & Piraino, 1991 (IT); 1977: Marques *et al.*, 2000 (TR)
POL	*Ficopomatus enigmaticus* (Fauvel, 1923)	1927: Seurat, 1927 (TN); 1919: Lindegg, 1934 (IT)
FISH	*Fistularia commersonii* Rüppell, 1838	2000: Golani, 2000 (IL); 1975: Bariche *et al.*, 2014 (LB)
MOL	*Gari pallida* (Deshayes, 1855)	2017: Lubinevsky *et al.*, 2018 (IL); 2016: Albano *et al.*, 2021 (IL)
MOL	*Goniobranchus annulatus* (Eliot, 1904)	2004: Daskos & Zenetos, 2007 (GR); 2000: Bitar, 2013 (LB)
CRU	*Gonioinfradens giardi* (Nobili, 1905)	2010: Corsini-Foka *et al.*, 2010 as *Gonioinfradens paucidentatus* (GR); 2009: Karhan & Yokeş, 2012 (TR)
MOL	*Hemiliostraca clandestina* (Mifsud & Ovalis, 2019)	2014: Mifsud & Ovalis, 2019 (TR); 1999: Crocetta *et al.*, 2020 as *Sticteulima clandestina* (LB)
POL	*Iphione muricata* (Lamarck, 1818)	2015: Goren *et al.*, 2017 (IL); 2010: Boudaya *et al.*, 2019 (TN)
MOL	*Isognomon bicolor* (C. B. Adams, 1845)	2015: Mienis *et al.,* 2016 as *I. legumen* (IL); 1997: Crocetta, 2018 (LY), correctly identified by Garzia *et al.*, 2022 and Albano *et al.*, 2024
RHO	*Kapraunia schneideri* (Stuercke & Freshwater) Savoie & G.W.Saunders	2016: Wolf *et al.*, 2018 (IT); 2014: Ragkousis *et al.*, 2023 (IL)
CRU	*Laticorophium baconi* (Shoemaker, 1934)	2018: Gouillieux & Sauriau, 2019 (ES); 2010: Guerra-García *et al.*, 2023 (IT)
MOL	*Lioberus ligneus* (Reeve, 1858)	1999: Crocetta *et al.*, 2013 (LB); 1993: Delongueville & Scailet, 2023 (TR)
PLAT	*Maritigrella fuscopunctata* (Prudhoe, 1978) Newman & Cannon, 2000	2014: Crocetta *et al.*, 2015 (MT); 2013: Velasquez *et al.*, 2018 (IL)
CRU	*Metapenaeopsis mogiensis consobrina* (Nobili, 1904)	1996: Galil, 1997 (IL); 1995: Kevrekidis *et al.*, 1998 (GR)
CRU	*Micippa thalia* (Herbst, 1803)	1994: Enzenross & Enzenross, 1995 (TR); 1993: Hasan & Noel, 2008 (SY)
MOL	*Microcirce consternans* P. G. Oliver & Zuschin, 2001	2012: Ovalis & Mifsud, 2013 (TR); 2011: Van Aartsen *et al.*, 2015 (IL)
CTE	*Mnemiopsis leidyi* A. Agassiz, 1865	1992: Uysal & Mutlu, 1993 (TR); 1990: Shiganova *et al.*, 2001 (GR)
CRU	*Paracaprella pusilla* Mayer, 1890	2011: Ros *et al.*, 2013 (ES); 2010: Lo Brutto *et al.*, 2019 (IL)
CRU	*Paracartia grani* Sars G.O., 1904	1978: Rodríguez & Vives, 1984 (ES); 1975: Bradford-Grieve, 1999 (ES)
POR	*Paraleucilla magna* Klautau, Monteiro & Borojevic, 2004	2001: Longo *et al.*, 2004 (IT); 2000: Frotscher & Uriz, 2008 (ES)

Continued

Table 1 continued

Group	Species	Changes
FISH	*Paranthias furcifer* (Valenciennes, 1828)	2011: Dulčić & Dragičević, 2012 (HR); 2007: *et al.*, 2015 (LB); 2003: Çinar *et al.*, 2021 (TR)
RHO	*Phrix spatulata* (E.Y.Dawson) M.J.Wynne, M.Kamiya & J.A.West	1992: Sartoni & Boddi, 1993 (IT); 1988: Clavell & Polo, 1998 (ES)
POL	*Polycirrus twisti* Potts, 1928	2005: Çinar, 2009 (TR); 1983: Simboura, 2011 (GR)
POL	*Polydora cornuta* Bosc, 1802	1990: Tena *et al.*, 1991 (ES); 1986: Çinar *et al.*, 2005 (TR)
POL	*Prionospio depauperata* Imajima, 1990	2005: Dağli & Çinar, 2009 (TR); 2000: Dağli *et al.*, 2011 (TR)
FOR	*Hauerina diversa* Cushman, 1946	<1997: Avşar, 1997 (TR); 1993: Yanko *et al.*,1998 (IL)
FOR	*Pseudomassilina reticulata* (Heron-Allen and Earland, 1915)	<1993: Yanko *et al.*, 1993 (IL); 1988: Avşar *et al.*, 2001 (TR)
FOR	*Pyrgo denticulata* (Brady, 1884)	1996: Hyams, 2000 (IL); 1994: Samir *et al.*, 2003 (EG)
MOL	*Rugalucina angela* (Melvill, 1899)	2016: Steger *et al.*, 2018 (IL); 2013: Albano *et al.*, 2024 (IL)
MOL	*Sabia conica* (Schumacher, 1817)	1980: Barash & Danin, 1986 (IL); 1954: Mienis, 2004 (IL)
FISH	*Saurida lessepsianus* (Russell, Golani and Tikochinski, 2015)	1952: Ben Tuvia, 1953 (IL); 1951: Ben Tuvia, 1966 (TR)
FISH	*Scarus ghobban* Forsskål, 1775	2001: Goren & Aronov, 2002 (IL); 1999: Bariche & Saad, 2005 (LB)
MOL	*Smaragdia souverbiana* (Montrouzier in Souverbie & Montrouzier, 1863)	1989: Buzzurro & Greppi, 1994 (TR); 1987: Rothman & Mienis, 2011 (IL)
POL	*Streblospio gynobranchiata* Rice & Levin, 1998	2003: Çinar *et al.*, 2005 (TR); 2000: Dağli *et al.*, 2011 (TR)
POL	*Syllis cf. crassicirrata* (Treadwell, 1925)	2020-21: Chatzigeorgiou *et al.*, 2022 (GR); 2002: Toso *et al.*, 2024 (LB)
ASC	*Symplegma brakenhielmi* (Michaelsen, 1904)	1999: Bitar & Kouli-Bitar, 2001 (LB); 1975: Zenetos *et al.*, 2017 (IL)
FISH	*Synanceia verrucosa* Bloch & Schneider, 1801	2010: Edelist *et al.*, 2011 (IL); 2008: Abd Rabou *et al.*, 2023 (Palestine Authority)
MOL	*Syrnola fasciata* Jickeli, 1882	1963: van Aartsen, 1977 (TR); 1949: van Aartsen *et al.*, 1989 (IL)
MOL	*Turbonilla cangeyrani* Ovalis & Mifsud, 2017	2016: Ovalis & Mifsud, 2017 (TR); 2014: Öztürk *et al.*, 2023 (TR)
CHL	*Ulva ohnoi* M.Hiraoka & S.Shimada	2011: Armeli Minicante *et al.*, 2014 (IT); 2002: Krupnik *et al.*, 2018 (IL)
CHL	*Uronema marinum* Womersley	2008: Sfriso *et al.*, 2014 (IT); 1989: Zenetos *et al.*, 2017 (FR)
MOL	*Zafra savignyi* (Moazzo, 1939)	1958: van Aartsen, 1963 (IL); 1954: Mienis, 1972 (IL); 1952: Mienis, 1976 (IL)
MOL	*Zafra selasphora* (Melvill & Standen, 1901)	1989: Palazzi, 1993 (TR); 1980: Tringali & Villa, 1995 (TR); 1976: van Aartsen, 1997 (IL)

into published regional inventories (e.g., Zenetos *et al.*, 2017, 2022b), several stem from very recent publications and are herein collectively presented for the first time. Of the 75 species, it is worth highlighting four that had their first records revised on two separate occasions during the total investigation period; these are the macrophyte *Colpomenia peregrina* Sauvageau, with a remarkable backdating interval of 38 years, the fish *Paranthias furcifer* (Valenciennes, 1828), and the two congeneric gastropods *Zafra savignyi* (Moazzo, 1939) and *Z. selasphora* (Melvill & Standen, 1901).

Furthermore, there is some uncertainty regarding the backdating accuracy of five species' first records, where no precise collection date was mentioned in the original publication. Two of these species are the foraminiferans *Hauerina diversa* Cushman, 1946 and *Pseudomassilina reticulata* (Heron-Allen and Earland, 1915), backdated by 1 and 5 years, respectively. Both species are native to the Indo-Pacific (Stulpinaite *et al.*, 2020) and have been detected in Israel and Türkiye (see details in Table 1) such that Lessepsian migration is a plausible pathway of introduction and spread (e.g., Çinar *et al.*, 2021). In that case their presence in Israel would precede records in Türkiye; nevertheless, Foraminifera can also be transported through shipping vectors, thus a first record in Türkiye is not out of the question.

Two more cases of uncertainty in backdating first records belong to the polychaete *Ficopomatus enigmaticus* (Fauvel, 1923) and the green alga *Caulerpa scalpelliformis* (R. Brown ex Turner) C. Agardh, both documented in the older literature, which is often lacking collection dates. *Caulerpa scalpeliformis* is an Indo-Pacific species, most likely having arrived via the Suez Canal, thus backdating its introduction by 1 year (backdated record in 1929 by Carmin, 1934 (Lebanon, Syria); the original first record regarded as 1930 in Hamel, 1930 (Israel)) could be a result of imprecise information in the latter publication. On the other hand, *Ficopomatus enigmaticus* is native to the Indo-West Pacific/Australasian region (Styan *et al.*, 2017; Tsiamis *et al.*, 2018) and a typical fouling species, transported with vessels throughout the world (Pernet *et al.*, 2016); consequently, an 8-year backdating interval from Tunisia (1927 by Seurat, 1927) to Italy (1919 by Lindegg, 1934) could indicate a true earlier introduction despite the lack of collection date information in Seurat (1927). Finally, an exact collection date was not provided for *Crepidula fornicata* in Italy by Parenzan (1970), and thus, the first introduction was assumed in 1970, attributed to shipping vectors by Servello *et al*. (2019). However, the 13-year backdating interval by the French record (1957 by Clanzig, 1989, at La Seyne-sur-mer lagoon) and the known association of the species with oyster farming strongly support an earlier introduction in Mediterranean France from the French Atlantic coast, where the species was already present (Zenetos *et al.*, 2004).

Approximately one third of backdated first records belong to species of Mollusca, with the second most important group being Macrophyta, followed by Annelida and Crustacea (Fig. 1A). The backdating time spans in our dataset varied between 1 and 52 years, with an average of approximately 8 years but with considerable differences among taxonomic groups. Ascidians, cnidarians, and macrophytes were characterised by the longest backdating intervals (more than 12 years), with polychaetes, molluscs, and fishes displaying backdating intervals of 7.5-8 years, while the other categories showed smaller gaps (Fig. 1B).

Regarding the country of first record of the backdated species, it can be seen in Figure 2 that the majority of the "original" first records were observed in Israel, Türkiye, Italy, Spain, and Greece. However, most of the backdated records are not from the same country as the original records and appear to be more evenly distributed among Mediterranean countries, with countries in North Africa (Tunisia, Egypt) and the Middle East (Lebanon, Syria) emerging more frequently as gateways of introduction.

Backdating intervals generally increase with time of original first record up until approximately 1970, after which they start gradually decreasing (Fig. 3A), meaning that in more recent years less time passes until the discovery of an earlier first record of a NIS. This likely indicates a faster emergence of new taxonomic information and more concerted efforts to utilise this information in the context of NIS management (Martínez-Laiz *et al.*, 2020; Golo *et al.*, 2023). At the same time, backdating of first records results in increased time lags between the collection date of a specimen and the publication of the finding (Fig. 3B). Specifically, time lags of the original first records in our dataset are generally lower than four years with an average value of 2.8 years. On the other hand, the time lags of the backdated first records are on average 19 years, with a maximum of 81 years. However, it should be pointed out that for many of the backdated records (with the exception of cases of misidentification), their presence in the Mediterranean basin was already known to the scientific community for quite some time already.

On looking at the causes of NIS backdating, delay in

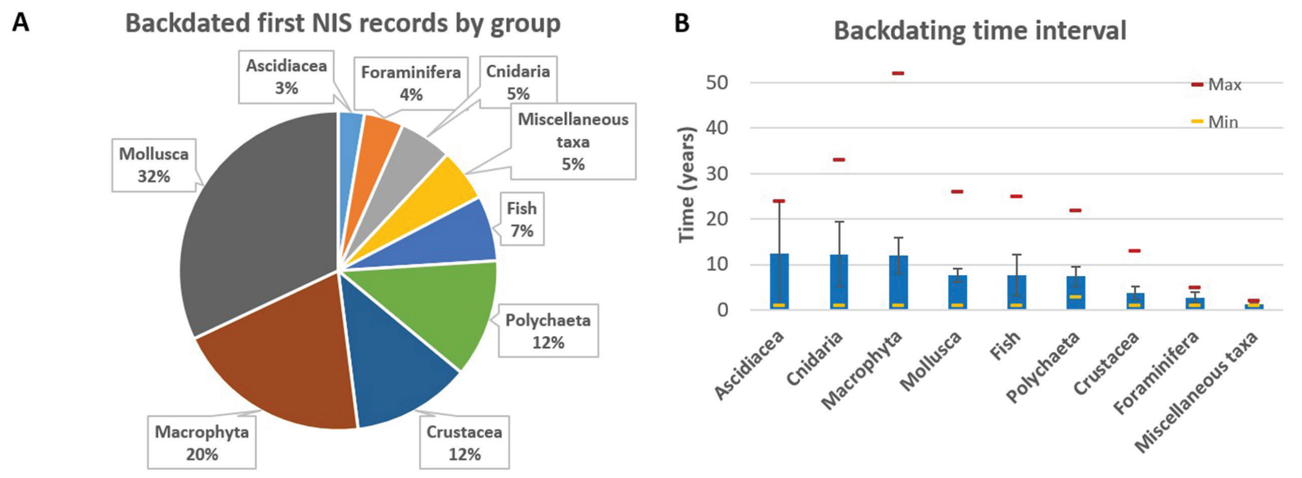

Fig. 1: Number of backdated species by taxon group (A) and average backdating interval per group (B). Bars in B indicate Standard Errors, red and yellow dashes are maximum and minimum values, respectively.

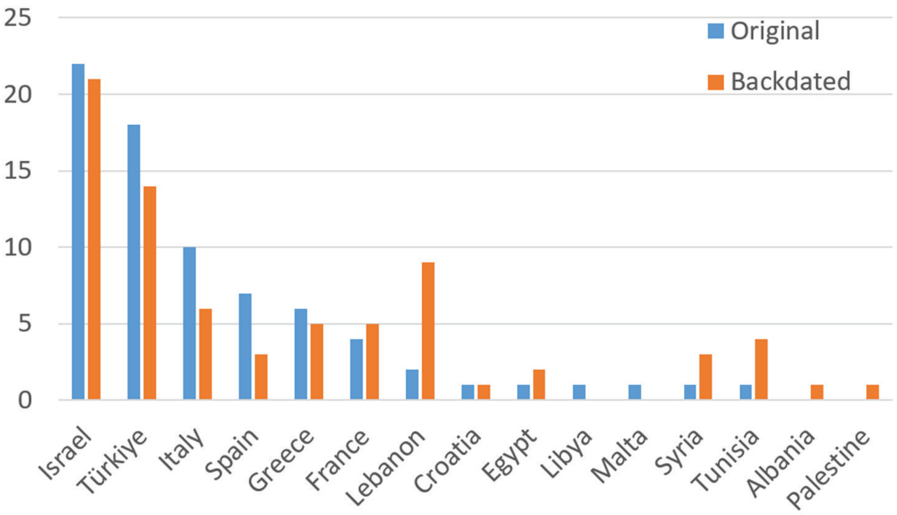

Fig. 2: Number of backdated first records by Mediterranean country. In blue the number of "original" first record dates as catalogued in early Mediterranean NIS inventories, in orange the number of "backdated" first records as revealed by subsequent publications.

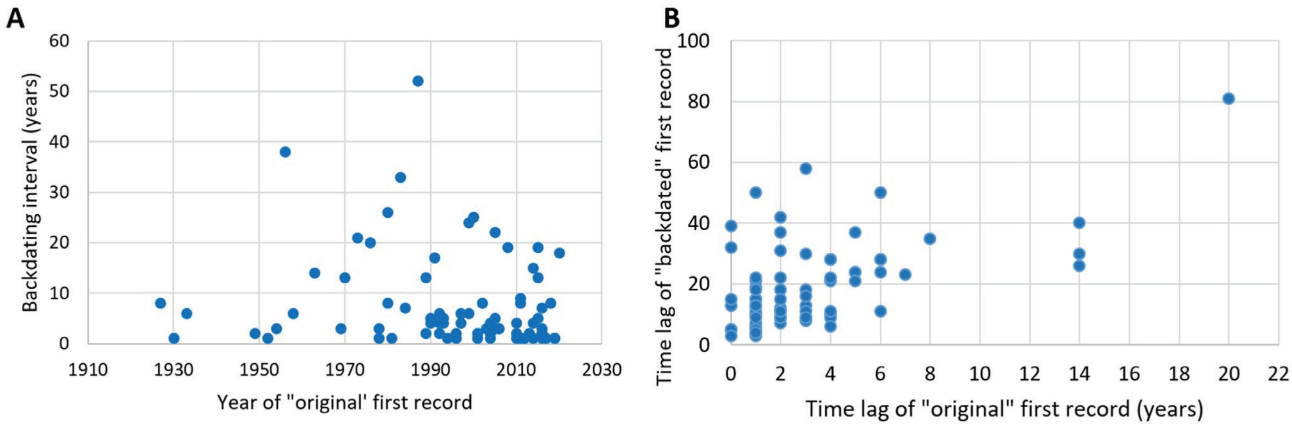

Fig. 3:Backdating interval against the year of first record as originally appearing in the literature (A); comparison of time lags (i.e., the delay in time between collection date and publication) between "original" and "backdated" first records (B).

publishing due to lack of taxonomic expertise emerges as a prominent reason. There is a shortage of taxonomists worldwide (Engel *et al.*, 2021). Taxonomic works are long-lasting and require specific skills that must be handed from one generation to the next to preserve historical knowledge and allow new generations to have a more comprehensive awareness of biological changes (Gravina *et al.*, 2020). Although molluscs, macroalgae, polychaetes, and crustaceans are among the most rich NIS taxa, taxonomic expertise varies among Mediterranean countries with some countries in North Africa and the Middle East lagging behind in the most challenging taxonomic groups (Galanidi *et al.*, 2023). The increasing collaboration among Mediterranean experts, in parallel with the emergence of new knowledge, has led to the correct identification of previously collected specimens in a number of groups, such as polychaetes (e.g., Toso *et al.,* 2024) and molluscs (e.g., Crocetta *et al.*, 2020; Albano *et al.*, 2024), and is likely another factor contributing to a more even distribution in the countries of the backdated first records in the basin (Fig. 2). A good example is that of *Caulerpa taxifolia var. distichophylla* (Sonder) Verlaque, Huisman & Procaccini, which was distinguished as a separate taxonomic entity to *C. taxifolia* only in 2013 (Jongma *et al.*, 2013). Subsequently, it was determined that the species had first been recorded in Syria in 2003, but misidentified as a dwarf form of *C. mexicana* Sonder ex Kützing, 1849 (Bitar *et al.,* 2010, 2017).

Backdates have been reported in almost all taxonomic groups but mostly related to the phylum Mollusca. This is attributed partly to shell collectors, who may delay in publishing their findings [e.g., *Afrocardium richardi* (Audouin, 1826) was first reported from Israel (1997: Van Aartsen & Goud, 2000) and backdated from Türkiye by six years (1991: Zenetos *et al.*, 2024)] or publish their earlier findings only after the species identity has been unequivocally determined and published. Such is the case of *Lioberus ligneus* (Reeve, 1858) reported from Lebanon (Crocetta *et al.*, 2013) and backdated from Türkiye (Delongueville & Scaillet, 2023). However, in many cases amateur naturalists are those who publish first and the scientists follow (e.g., for the crab *Micippa thalia* (Herbst, 1803), the molluscs *Microcirce consternans* P. G. Oliver & Zuschin, 2001 and *Divalinga arabica*

Dekker & Goud, 1994).

Backdating in fish species is primarily attributed to unreported findings accidentally noticed, e.g., *Paranthias furcifer* listed in Croatia in 2011 was backdated in 2015 by four years back to 2007 via a photograph (Crocetta *et al.*, 2015). A further update of the first record was reported in 2021 from Türkiye (Çinar *et al.*, 2021). *Paranthias furcifer* was observed and photographed during scuba dives in 2003 but the finding remained unpublished until 2021 since a specimen could not be captured. Similarly, the first record of *Fistularia commersoni* has been backdated to 1975 (Bariche *et al.*, 2014) based on a dried specimen of the species found in a private collection of a fisherman in Lebanon, whilst its original invasion was presumed in 2000 in Israel (Golani, 2000), creating a remarkable time lag of 25 years.

Misidentifications of species due to their confusion with native /cryptogenic species can also lead to backdating species first records, particularly so in polychaetes. Detection of the polychaete *Dorvillea similis* (Crossland, 1924) found in 2019 in Capraia, Italy (Dragičević *et al.*, 2019) in previous surveys might have been hindered by its superficial similarity with the native *D. rubrovittata*. Indeed, recent examination of old material from Lebanon has revealed the presence of *D. similis* since 2002 (Toso *et al.,* 2024). Another example in the Mediterranean is the non-native polychaete *Polycirrus twisti* Potts, 1928 that might have been confused in the past with *Polycirrus plumosus* Wollebaek, 1912 originating in the Red Sea (Çinar, 2009). Simboura (2011) re-examined older specimens of *P. plumosus* from Greek waters and re-assigning them to *P. twisti*. Outside polychaetes, a remarkable case is that of the amphipod *Laticorophium baconi* (Shoemaker, 1934), first recorded in 2018 in Spain and already suspected to have been misidentified in the past as the cryptogenic *Apocorophium acutum* (Chevreux, 1908) (Gouillieux & Sauriau, 2019). Prompted by these findings, Guerra-García *et al.* (2023) re-examined previously collected material, in addition to collecting new samples, aiming to clarify the species' invasion history. Their research not only verified the presence of *L. baconi* in Mediterranean waters since 2010 in Italy, but also provided the first records of *L. baconi* in Morocco, Tunisia, France (Corsica), Greece, and Egypt.

Today, integrative approaches combining morphological identification with molecular analyses (DNA) enable the unambiguous assignment of non-indigenous status to specimens previously surrounded by uncertainty concerning their identity and origin. The bivalve *Isognomon bicolor* (C. B. Adams, 1845) was originally reported from Israel under the name *I. legumen* (Gmelin, 1791) by Mienis *et al.* (2016) and was subsequently backdated by 18 years based on morphological features from Libya (Crocetta, 2018). As the species identity was disputed, Garzia *et al.* (2022) performed a molecular analysis which showed that specimens morphologically similar to the records in Libya and Israel in fact belong to the Caribbean species *Isognomon bicolor*. Also worth mentioning is the case of the polychaete *Branchiomma bairdi* (McIntosh, 1885). According to morphological and genetic diversity of specimens from Mediterranean locations, some samples were re-designated as *Branchiomma boholense* (Grube, 1878), another non-indigenous species originally described from Philippines (Del Pasqua *et al.*, 2018)

A third reason for backdating is the volume of overlooked species in museums and/or private collections. A sound example of this is the hydrozoan *Eudendrium carneum.* Its first record from Spain by Gili (1986) should be backdated by 33 years based on a colony from France found at the Muséum d'histoire naturelle de Genève, Switzerland, accession no. MHNG INVE39470 (Schuchert, 2008). Similarly in the case of the tunicate *Symplegma brakenhielmi*: its first record from Lebanon in 1999 (Bitar & Kouli-Bitar, 2001) should be backdated by 24 years according to museum samples at Steinhardt *Museum* of Natural History, Tel Aviv University, Israel (Zenetos *et al.*, 2017).

More than one reason, e.g., misidentification and museum collections, may be implicated for large backdating intervals as in the case of the brown seaweed *Dictyota cyanoloma.* The species was first reported from Spain in 1987 as *Dictyota ciliolata* by Rull Lluch *et al.* (2007). Sequence data, however, demonstrated unequivocally that the Iberian specimens were clearly distinct from *D. ciliolata* (Tronholm *et al.*, 2010). Molecular sequence information from historical herbarium samples proved the presence of *D. cyanoloma* in the Adriatic Sea as early as 1935 (Steen *et al.*, 2016).

Recent initiatives in collecting large sets of unpublished data so as to enrich spatio-temporal information on the distribution of alien, cryptogenic, and neonative species in the Mediterranean (Katsanevakis *et al.*, 2020; Ragkousis *et al.*, 2023) has brought to light some thousands of unreported records including backdating of NIS at national level but also at Mediterranean level, e.g., *Kapraunia schneideri* from Israel, two years prior to its first record from Italy (Wolf *et al.*, 2018).

Museum collections, citizen scientists, and re-examination of specimens from a new perspective may lead to the backdating of many more species. It is expected that the number of backdated NIS will increase once several overlooked specimens stored in drawers or museum collections are re-examined and /or new techniques are applied. Re-examination of older samples, not only for morphological analysis but also for molecular analyses, since also DNA recovery from formalin-preserved specimens (Palero *et al*., 2010) is feasible, may reveal older entries of NIS. For example, the identity and distribution of native and introduced *Padina* species has recently been re-evaluated in the Mediterranean, based on more detailed morphological characters and molecular analyses (Win *et al.*, 2011). With this renewed knowledge, Pagana *et al.* (2023) re-examined herbarium material from Sicilian coasts, attributed to *P. pavonica* (Linnaeus) Thivy, 1960, and demonstrated that it belonged to five different *Padina* species. Of these, the species *Padina tetrastromatica* Hauck, 1887 is currently considered of uncertain taxonomic position due to its possible synonymy with *P. antillarum* (Wynne, 1998; Verlaque *et al.*, 2015; Zenetos *et al.*, 2022). The species was first reported in the

Mediterranean in Syria in 2004 (Mayhoub 2004) but was found to be present in Sicily already in 1966 by Pagana *et al.* (2023). This backdate is not included in our list until the taxonomic position of the species is fully resolved. Phylogenetic methods that are now applied to identify NIS and/ or cryptic species (Albano et al., 2024) could also reveal backdating of species. Increased backdating will lengthen reporting time lags, as we see in Fig. 3B, alter temporal and spatial trends in NIS inventories, and may affect policy indices that only consider species introduced after 1970 for the calculation of time trends (e.g., Zenetos *et al.*, 2022c; UNEP/MAP, 2023).

In conclusion, the current work serves to showcase how the meticulous and continuous curation of NIS inventories helps increase accuracy of NIS datasets for purposes of assessment and improve our confidence in assigning pathways of introduction, which has been identified as a pressing need within the context of various policy instruments (Stæhr *et al.*, 2022). It also highlights the variable sources of NIS data and the importance of bringing them together in a framework of increased collaborations and modern methodologies in order to advance NIS research. Collaborative initiatives, such as those by Katsanevakis *et al.* (2020) and Ragkousis *et al.* (2023), have demonstrated that new data are continuously being produced that need to be validated, harmonised, and openly shared. Furthermore, journals and article series dedicated to publishing species records (e.g., Marine Biodiversity Records, Bioinvasions Records, and the Collective Series of Mediterranean Marine Science) have contributed to shorter time-lags between findings and publications (Zenetos *et al*., 2019). Cryptogenic and questionable species are also being increasingly reported in national and regional inventories (Tsiamis *et al.*, 2021; Galanidi *et al.*, 2023), providing valuable information for future studies. In this context of increased NIS data availability, it is important to foster expert networks, promote taxonomic expertise and revisit older material in collections in order to enhance our understanding of marine bioinvasions (Ricciardi *et al.*, 2021; Guerra-García *et al.*, 2023).

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