



HAL
open science

Scientific knowledge gaps on the biology of non-fish marine species across European Seas

Luisa Abucay, Patricia Sorongon-Yap, Kathleen Kesner-Reyes, Emily Capuli,
Rodolfo Reyes, Eva Daskalaki, Carmen Ferrà, Giuseppe Scarcella, Gianpaolo
Coro, Francesc Ordines, et al.

► To cite this version:

Luisa Abucay, Patricia Sorongon-Yap, Kathleen Kesner-Reyes, Emily Capuli, Rodolfo Reyes, et al..
Scientific knowledge gaps on the biology of non-fish marine species across European Seas. *Frontiers
in Marine Science*, 2023, 10, 10.3389/fmars.2023.1198137 . hal-04254781

HAL Id: hal-04254781

<https://hal.science/hal-04254781>

Submitted on 25 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Scientific knowledge gaps on the biology of non-fish marine species across European Seas**

2

3 Luisa R. Abucay¹, Patricia Sorongon-Yap¹, Kathleen Kesner-Reyes¹, Emily C. Capuli¹, Rodolfo B. Reyes
4 Jr¹, Eva Daskalaki², Carmen Ferrà Vega^{3,4}, Giuseppe Scarcella³, Gianpaolo Coro⁵, Fransesc Ordines⁶,
5 Paula Sánchez⁶, Georgi Dakalov⁷, Stefania Klayn⁷, Liesa Celie⁸, Marco Scotti^{9,10}, David Grémillet^{11,12},
6 Charlotte Lambert¹³, Gideon Gal¹⁴, Maria Lourdes Deng Palomares^{15,16}, Donna Dimarchopoulou^{17,18},
7 Athanassios C. Tsikliras²

8

9 ¹ Quantitative Aquatics, Los Banos, Philippines

10 ² Laboratory of Ichthyology, School of Biology, Aristotle University of Thessaloniki, Thessaloniki,
11 Greece

12 ³ National Research Council - Institute for Biological Resources and Marine Biotechnologies, Ancona,
13 Italy

14 ⁴ Department of Biological, Geological and Environmental Sciences (BiGeA), University of Bologna,
15 Bologna, Italy

16 ⁵ National Research Council - Institute of Information Science and Technologies "Alessandro Faedo",
17 Pisa, Italy

18 ⁶ IEO - Centre Oceanogràfic de les Balears, Moll de Ponent s/n, 07015 Palma, Spain

19 ⁷ Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria

20 ⁸ Institute for Agricultural, Fisheries and Food Research, Animal Sciences Unit, Oostende, Belgium

21 ⁹ GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

22 ¹⁰ Institute of Biosciences and Bioresources, National Research Council of Italy, Sesto Fiorentino, Italy

23 ¹¹ CEFE, Univ Montpellier, CNRS, EPHE, IRD, Montpellier, France

24 ¹² FitzPatrick Institute, DST/NRF Excellence Centre at the University of Cape Town, South Africa

25 ¹³ LIENSs UMR 7266, La Rochelle University – CNRS, La Rochelle, France

26 ¹⁴ Kinneret Limnological Laboratory, Israel Oceanographic and Limnological Research, Migdal, Israel

27 ¹⁵ Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, Canada

28 ¹⁶ Sea Around Us, University of British Columbia, Vancouver, Canada

29 ¹⁷ Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada

30 ¹⁸ Department of Biology, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA

31 **Abstract**

32 Available information and potential data gaps for non-fish marine organisms (cnidarians,
33 crustaceans, echinoderms, molluscs, sponges, mammals, reptiles, and seabirds) covered by the
34 global database SeaLifeBase were reviewed for eight marine ecosystems (Adriatic Sea, Aegean Sea,
35 Baltic Sea, Bay of Biscay/Celtic Sea/Iberian Coast, Black Sea, North Sea, western Mediterranean
36 Sea, Levantine Sea) across European Seas. The review of the SeaLifeBase dataset, which is based on
37 published literature, analysed information coverage for eight biological characteristics (diet,
38 fecundity, maturity, length-weight relationships, spawning, growth, lifespan, and natural mortality).
39 These characteristics are required for the development of ecosystem and ecological models to
40 evaluate the status of marine resources and related fisheries. Our analyses revealed that information
41 regarding these biological characteristics in the literature was far from complete across all studied
42 areas. The level of available information was nonetheless reasonably good for sea turtles and
43 moderate for marine mammals in some areas (Baltic Sea, Bay of Biscay/Celtic Sea/Iberian Coast,
44 Black Sea, North Sea and western Mediterranean Sea). Further, seven of the areas have well-studied
45 species in terms of information coverage for biological characteristics of some commercial species
46 whereas threatened species are generally not well studied. Across areas, the most well-studied
47 species are the cephalopod common cuttlefish (*Sepia officinalis*) and the crustacean Norway lobster
48 (*Nephrops norvegicus*). Overall, the information gap is narrowest for length-weight relationships
49 followed by growth and maturity, and widest for fecundity and natural mortality. Based on these
50 insights, we provide recommendations to prioritize species with insufficient or missing biological
51 data that are common across the studied marine ecosystems and to address data deficiencies.

52

53

54 **Keywords:** data gaps, marine biodiversity, marine mammals, seabirds, marine reptiles, marine
55 invertebrates, SeaLifeBase, European waters

56

57 **Introduction**

58 Ecocentric (=ecosystem centred) fisheries management requires detailed knowledge of the structure
59 and functioning of the marine ecosystems, from abiotic data to the status of all ecosystem
60 components (Dimarchopoulou 2020). This includes the fishing pressure applied on commercial and
61 non-commercial marine populations and their respective biomasses (Tsikliras et al. 2023) and
62 biological information (growth, maturity, spawning, fecundity, mortality, lifespan and diet) of all
63 organisms in an ecosystem because marine organisms respond differently to fishing pressure and
64 population time to recovery depends upon their life-history strategy and ecological traits
65 (Dimarchopoulou et al. 2017). Ecosystem structure is usually described using mass balance
66 ecosystem models (Heymans et al. 2020) while the stock status is derived from age-based or surplus
67 production stock assessments (Tsikliras & Froese 2019). Ecosystem models and stock assessments
68 are thereby required to examine fisheries management and marine policy scenarios (Piroddi et al.
69 2022) within the context of environmental (Piroddi et al. 2021), oceanographic (Coll et al. 2019) and
70 climatic change factors (Corrales et al. 2018), whilst also incorporating economic and social
71 parameters (Link 2010).

72 The development of ecosystem models demands specific biological data, mainly growth
73 parameters, natural mortality and diet composition per species or functional group of species
74 (Christensen & Walters 2004), as well as catch data that are available per fleet through official
75 landings statistics (global and regional databases of the Food and Agricultural Organisation of the
76 United Nations: FAO 2020) and catch datasets (Sea Around Us: Pauly & Zeller 2016). Similarly, the
77 simpler age-based stock assessments require growth parameters, size at maturity, spawning and
78 natural mortality data (Jardim et al. 2015) while some surplus production models use the maximum
79 intrinsic population growth that is based on several biological characteristics including growth,
80 fecundity, maturity and natural mortality (Froese et al. 2018a,b, 2020).

81 Among European Seas, the North East (NE) Atlantic Ocean is a marine ecosystem with a long
82 scientific history of investigations across all marine science disciplines (Lotze & Worm 2009). As a

83 result, long time-series of biological, oceanographic and fisheries data exist, most of which are
84 publicly available. These datasets have supported many ecosystem models (Keramidas et al. 2023)
85 and the official full stock assessments in most marine ecosystems of the NE Atlantic (ICES 2022). In
86 contrast, the Mediterranean and the Black Seas, despite their longer history of fisheries exploitation
87 (Stergiou et al. 2016) and the early scientific work on biology and fisheries by Aristotle and Oppian,
88 respectively (Deacon 1997), lack long time series of biological, oceanographic and fisheries data
89 (Fortibuoni et al. 2017, but see Ravier & Fromentin 2004). Consequently, data-limitations have
90 constrained ecosystem models to specific and well-studied areas of the northern and eastern
91 Mediterranean coastline that are well studied (Adriatic Sea: Barausse et al. 2009, Libralato et al.
92 2015; Catalan coast: Coll et al. 2008, 2009; Aegean Sea: Dimarchopoulou et al. 2019;
93 Dimarchopoulou et al. 2022; Keramidas et al. 2022; Levantine Sea: Corrales et al. 2017, 2019;
94 Shabtay et al. 2018, Ofir et al. 2023). This also restricted full analytical stock assessments to a
95 proportionally low number of exploited stocks (Piroddi et al. 2020) despite the increasing efforts of
96 the Expert Working Groups (EWG) of the Scientific, Technical and Economic Committee for Fisheries
97 (STECF) of the European Union and the General Fisheries Commission for the Mediterranean Sea
98 (GFCM) of the FAO. However, the most important issues in Mediterranean fisheries are the north-
99 south gradient in marine research and data, with more scientific output along the northern
100 Mediterranean coastline (Stergiou & Tsikliras 2006), and that valuable datasets are not openly
101 available (McManamay & Utz 2014). This is because some people/institutions (and countries, which
102 were historically amongst the most scientifically advanced) do not believe in open science – a policy
103 priority for the European Commission – even when supported by public funds (Damalas et al. 2018).

104 Robust and adaptive fisheries management policies require understanding their key sources
105 of uncertainty, such as knowledge gaps in biology of marine species (Link et al. 2012). A recent
106 update on the gaps in the biological knowledge of Mediterranean marine fishes (Daskalaki et al.
107 2022) indicated that efforts were made to reduce these gaps in knowledge across the Mediterranean
108 Sea compared to previous records (Dimarchopoulou et al. 2017). This is especially true for

109 threatened species fishes such as sharks and rays (Tsikliras & Dimarchopoulou 2021) as well as for
110 alien species that rapidly colonized the Mediterranean during the last decades (Katsanevakis et al.
111 2014). Filling the gaps in ecological and biological knowledge and assessing anthropogenic impacts
112 marine ecosystems are prerequisites for developing robust ecosystem models (Heymans et al. 2020)
113 hence for promoting effective ecocentric management (Claudet et al. 2019).

114 The principal aim of the present work was to review available information on key biological
115 characteristics (diet, fecundity, maturity, length-weight relationships, spawning, growth, lifespan,
116 and natural mortality) of non-fish marine species across European Seas. This allowed a gap analysis
117 and a comparison of the availability of biological data across areas and taxonomic groups, leading to
118 recommendations to reduce knowledge gaps (if and where required). Thus, future research will have
119 a baseline to prioritise species of special interest based on specific criteria such as conservation
120 status. This review covers the non-fish marine organisms belonging to eight taxonomic groups
121 occurring in the European Seas. Fish species will be covered in a separate publication that will follow
122 the same methodology and spatial coverage and will expand the review of the Mediterranean
123 marine fishes (Daskalaki et al. 2022) to European Seas.

124

125 **Materials and methods**

126 This review was based on information that was extracted from the literature and captured in
127 SeaLifeBase (www.sealifebase.org; Palomares & Pauly 2021, consulted in December 2021) for eight
128 marine ecosystems (Adriatic Sea, Aegean Sea, Baltic Sea, Bay of Biscay/Celtic Sea/Iberian Coast,
129 Black Sea, Levantine Sea, North Sea, and western Mediterranean Sea) (Figure 1). SeaLifeBase is a
130 global biodiversity information system on non-fishes that covers a wide range of information on
131 taxonomy, biology, trophic ecology, life history and uses (Palomares & Pauly 2021). The
132 extensiveness of information in the database has catered to a diversity of stakeholders (scientists,
133 researchers, policy-makers, fisheries managers, donors, conservationists, teachers, and students) for
134 various applications targeting sustainable fisheries management (Froese et al. 2018a), ecosystem

135 modelling (Grüss et al. 2019), biodiversity conservation (Stasolla et al. 2021) and environmental
136 protection (Jams et al. 2020).

137 Eight major groups of marine non-fish species were considered, including cnidarians (corals,
138 jellyfishes, other cnidarians like hydrozoans, hydroids, anemones, and sea pens), crustaceans
139 (decapods, other malacostraca like shrimps, amphipods, isopods, copepods and ostracods),
140 echinoderms (sea cucumbers, sea urchins, starfishes, brittle stars, crinoids, basket stars), molluscs
141 (bivalves, cephalopods, gastropods, chitons, solenogasters and tusk shells), sponges, mammals
142 (dolphins, whales, seals), reptiles (sea turtles), and seabirds.

143 The working species lists for the review were drawn from a combination of ecosystem,
144 country, and FAO area assignments in SeaLifeBase that approximate the areas covering each of the
145 eight study areas (Palomares & Pauly 2021). Thus, the species lists for the Adriatic Sea and the
146 Aegean Sea come from the SeaLifeBase faunal records under the Adriatic Sea and Aegean Sea marine
147 ecoregions, whereas those for the Baltic Sea, Black Sea, and North Sea come from the faunal records
148 under the Large Marine Ecosystem (LME) units of the same name (Figure 1). The species list for the
149 western Mediterranean Sea area combines faunal records for the Balearic Islands, Tyrrhenian Sea,
150 Sardinia Island, Corsica Island, as well as marine records for the Mediterranean coasts of Spain and
151 France, i.e., excluding the southern Mediterranean coastline (Figure 1). The list for the Levantine Sea
152 consolidates records from the Levantine Sea ecosystem, marine records for Cyprus, Syria, Lebanon as
153 well as from the side of Israel, Egypt, and Turkey (excluding the Aegean Sea) in FAO area 37. The Bay
154 of Biscay/Celtic Sea/Iberian Coast combines faunal lists for two LMEs, namely, Celtic-Biscay Shelf
155 and Iberian Coast, and thus includes species in an area that extends from the Gulf of Cadiz and north
156 to the Outer Hebrides (Figure 1). An assessment of the representativeness of the species coverage in
157 each site, however, was not within the scope of this work.

158 The review of biological information covered in SeaLifeBase largely follows the approach of
159 two recent gap analyses reviews on the biology of fishes in the Mediterranean Sea (Dimarchopoulou
160 et al. 2017; Daskalaki et al. 2022).

161 Eight categories of biological characteristics were examined and include corresponding
162 records in SeaLifeBase: Diet (D) covered diet composition, prey items, and feeding preferences;
163 fecundity (F) included absolute and relative number of oocytes produced per female; maturity
164 covered length/size at first maturity (L_m); spawning (S) looked at onset and duration of spawning (i.e.,
165 spawning period); mortality (M) considered the rate of natural mortality regardless of the estimation
166 method; life span (t_{max}) covered maximum age; growth (G) refers to the growth parameters
167 asymptotic length (L_∞) and the rate at which it is approached (K), while length-weight relationships
168 (LWR) considered the slope and intercept of the LWR function (Dimarchopoulou et al. 2017;
169 Daskalaki et al. 2022). Gaps arise from the difference between the level of current knowledge and
170 that of desired knowledge. For the present review, well-studied species were identified as those with
171 available information for at least six out of eight of the biological characteristics described above,
172 and which have 30 or more records available in SeaLifeBase. The desired knowledge for an area was
173 defined as the area with at least half of the reported species being well-studied. The least-studied
174 species were those that do not meet the above criteria (Table 1). Overall, the number of unique
175 references for data on biological characteristics from the literature captured in SeaLifeBase total 637
176 records (Palomares & Pauly 2021).

177 Species were categorized as threatened/non-threatened according to the species
178 conservation status in SeaLifeBase which follows the IUCN Red List of Threatened Species (version
179 2021-1) considering the global classification of species (EX: Extinct; EW: Extinct in the Wild; CR:
180 Critically Endangered; EN: Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concern; DD:
181 Data deficient; NE: Not Evaluated). For this review, species categorized as threatened included only
182 those flagged as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Near-Threatened
183 (NT).

184 This review assesses how much information on biological traits is available for species,
185 examining species with and without biological information, identifying where data gaps are smallest
186 and widest, and identifying the most and least-studied species. Where a species list is short, full

187 details for the species are included in the table, otherwise the list is summarized according to
188 Order/Family and species count. An overall assessment of information that follows a basic traffic
189 light classification of Good, Moderate and Poor information coverage and the criteria for each
190 category are also provided (Table 1).

191 Recommendations for filling data gaps are provided in two levels. The first consists of specific
192 recommendations on species and aims at addressing deficiencies or missing information on
193 biological characteristics. The second focuses on filling the gaps with respect to biological
194 characteristics, and particularly on prioritising species with insufficient or missing biological data that
195 are common to most areas.

196

197 **Results**

198 *Adriatic Sea*

199 A total of 359 non-fish species were recorded for the Adriatic Sea in SeaLifeBase, including 349
200 native, five endemic and five introduced species that belong to 168 Families, 68 Orders and 15
201 Classes. Regarding the number of biological characteristics studied, there is no information for 248
202 species (69%). There are 48 species (13%) with information for only one characteristic (mostly on
203 length-weight relationships), while two species (1%) have studies for all eight biological
204 characteristics (Figure 2).

205 The individual biological characteristics of the non-fish species of the Adriatic Sea, from
206 most-studied to least-studied, are: length-weight relationships (97 species, 27%), followed by growth
207 (52 species, 14%), size at maturity (33 species, 9%), spawning (22 species, 6%), maximum age (22
208 species, 6%), natural mortality (16 species, 4%), fecundity (11 species, 3%), and diet (6 species, 2%)
209 (Figure 3).

210 Five species are included in the IUCN Red List and are listed under the categories CR [Noble
211 pen shell (*Pinna nobilis*)], VU [Leatherback turtle (*Dermochelys coriacea*)], Common spiny lobster
212 (*Palinurus elephas*), Horned grebe (*Podiceps auritus*)], and NT [Dalmatian pelican (*Pelecanus*

213 *crispus*]. These five species have a relatively small gap for one biological characteristic, growth (3
214 species, 60% studied). This is followed by larger gaps regarding six biological characteristics: length-
215 weight (2 species, 40% studied), maturity (2 species, 40% studied), lifespan (2 species, 40% studied),
216 fecundity (1 species, 20% studied), spawning (1 species, 20% studied), and natural mortality (1
217 species, 20% studied). The largest data gap is for diet, where no information was available for any of
218 the threatened species (Figure 3).

219 The most-studied species of the Adriatic Sea make up about 2% (6 species) of non-fish
220 species reported from the area. These species belong to two Classes and six Families (Table 2). The
221 six most-studied Adriatic species in terms of biological characteristics are the Blue crab (*Callinectes*
222 *sapidus*), which is an introduced species, and Common cuttlefish (*Sepia officinalis*), each with
223 available information on eight biological characteristics. Deep-water rose shrimp (*Parapenaeus*
224 *longirostris*), Giant red shrimp (*Aristaeomorpha foliacea*), Spottail mantis shrimp (*Squilla mantis*) and
225 Common spiny lobster (*Palinurus elephas*) have seven studied biological characteristics. Out of these
226 six species, only the Common spiny lobster is included in the IUCN Red List as VU (Table 2).

227 The least-studied species make up about 98% (353 species) of non-fish species reported in
228 the Adriatic Sea (15 Classes and 164 Families) (Table S1) including four IUCN Red List species (Table
229 2).

230

231 *Aegean Sea*

232 A total of 355 non-fish species were recorded for the Aegean Sea in SeaLifeBase, including 347
233 native, six endemic and two introduced species, and belong to 166 Families, 61 Orders and 15
234 Classes. Regarding the number of biological characteristics studied, there is no information for 269
235 species (76%). There are 42 species (12%) with information for only one characteristic (mostly length-
236 weight relationships), while for one species all eight biological characteristics are available (Figure 2).

237 The individual biological characteristics of the non-fish species of the Aegean Sea, from most-
238 studied to least-studied, are length-weight relationships (77 species, 22%), growth (39 species, 11%),

239 maturity (19 species, 5%), spawning (17 species, 5%), lifespan (13 species, 4%), natural mortality (11
240 species, 3%), fecundity (7 species, 2%), and diet (5 species, 1%) (Figure 2).

241 Eight species are threatened and listed under the IUCN Red List categories as endangered
242 (EN) and vulnerable (VU), and have large gaps regarding all biological characteristics: length-weight
243 (2 species, 25%), maturity (2 species, 25%), growth (2 species, 25%), fecundity (1 species, 13%), diet
244 (1 species, 13%), spawning (1 species, 13%), natural mortality (1 species, 13%) and lifespan (1
245 species, 13%) (Figure 3).

246 The most-studied species of the Aegean Sea make up about 1% (5 species) of non-fish
247 species reported from the area and cover two Classes and five Families (Table 3). The five most
248 studied Aegean species in terms of biological characteristics are the Common cuttlefish (*Sepia*
249 *officinalis*) with available information on eight biological characteristics, as well as the Deep-water
250 rose shrimp (*Parapenaeus longirostris*), Giant red shrimp (*Aristaeomorpha foliacea*), Spottail mantis
251 shrimp (*Squilla mantis*) and Common spiny lobster (*Palinurus elephas*) that have seven studied
252 biological characteristics. Of these, only the Common spiny lobster is included in the IUCN Red List as
253 VU (Table 3).

254 The least-studied species make up about 99% (350 species) of the non-fish species reported
255 in the Aegean Sea, covering 15 Classes and 162 Families (Table S2). Seven of the least-studied species
256 are included in the IUCN Red List. These include the Mediterranean monk seal (*Monachus*
257 *monachus*), listed as EN, with available information on one biological characteristic, the Leatherback
258 turtle (*Dermochelys coriacea*), listed as VU, with three studied biological characteristics, as well as
259 the coral (*Crassophyllum thessalonicae*) and the sea anemone (*Paranemonia vouliagmeniensis*) listed
260 as CR. The Pink sea fan (*Eunicella verrucosa*), Horned grebe (*Podiceps auritus*), and, Levantine
261 shearwater (*Puffinus yelkouan*) are listed as VU, and have no available biological information (Table
262 3).

263

264 *Baltic Sea*

265 A total of 606 non-fish species were retrieved for the Baltic Sea from SeaLifeBase, including 595
266 native and 11 introduced species. The species of the area belong to 263 Families, 75 Orders and 23
267 Classes. Regarding the number of biological characteristics studied, there is no information for 434
268 species (72%). There are 112 species (18%) with information on one biological characteristic (mostly
269 on length-weight relationships) while one species has studies for all eight biological characteristics
270 (Figure 2).

271 The individual biological characteristics of the non-fish species of the Baltic Sea, from most-
272 studied to least-studied, are length-weight relationships (140 species, 23%), growth (46 species, 8%),
273 diet (29 species, 5%), lifespan (29 species, 5%), maturity (24 species, 4%), spawning (15 species, 2%),
274 natural mortality (11 species, 2%) and fecundity (7 species, 1%) (Figure 3). Out of all 606 non-fish
275 species reported from the Baltic Sea there are no species that could be considered as well-studied
276 (Table S3). All the Baltic species range from having none to moderately sufficient information on
277 their biological characteristics.

278 Eight species are listed in IUCN Red List, and have large gaps regarding four biological
279 characteristics: growth (3 species, 33% studied), length-weight relationships (2 species, 22% studied),
280 maturity, (2 species, 22% studied) and diet (2 species, 22% studied). Species listed as VU are
281 Leatherback turtle (*Dermochelys coriacea*), Sperm whale (*Physeter macrocephalus*), Long-tailed duck
282 (*Clangula hyemalis*), Velvet scoter (*Melanitta fusca*), Horned grebe (*Podiceps auritus*), and Steller's
283 eider (*Polysticta stelleri*) all of which have no available biological information. Those listed as NT
284 include Eurasian river otter (*Lutra lutra*) with information on one biological characteristic, and
285 Common eider (*Somateria mollissima*) with no biological information available (Table 4). There is no
286 available record on these species regarding fecundity, spawning, natural mortality, and lifespan
287 (Figure 3).

288

289 *Bay of Biscay/Celtic Sea/Iberian Coast*

290 A total of 362 non-fish species from the Bay of Biscay/Celtic Sea/Iberian Coast have records in

291 SeaLifeBase, including 356 native and six introduced species. The species within this area belong to
292 206 Families, 78 Orders and 22 Classes. Regarding the number of biological characteristics studied,
293 there is no information for 236 species (65%), whereas there are 65 species (18%) with information
294 for only one characteristic (mostly on length-weight relationships), and one species has studies for all
295 eight biological characteristics (Figure 2).

296 The individual biological characteristics of the non-fish species of the Bay of Biscay/Celtic
297 Sea/Iberian Coast, from most studied to least studied, are length-weight relationships (112 species,
298 31%), growth (53 species, 15%), maturity (28 species, 8%), diet (24 species, 7%), spawning (22
299 species, 6%), lifespan (21 species, 6%), natural mortality (11 species, 3%) and fecundity (10 species,
300 3%) (Figure 3).

301 Ten species listed under the IUCN Red List have relatively smaller gaps regarding four
302 biological characteristics: length-weight (10 species, 83%), growth (10 species, 83%), diet (7 species,
303 58%), and maturity (7 species, 58%). Larger gaps were observed in fecundity (3 species, 25%),
304 spawning (3 species, 25%), lifespan (2 species, 17%) and natural mortality (2 species, 17%) (Figure 3).
305 These species are Hawksbill turtle (*Eretmochelys imbricata*; CR), Kemp's ridley turtle (*Lepidochelys*
306 *kempii*; CR), North Atlantic right whale (*Eubalaena glacialis*; CR), Sei whale (*Balaenoptera borealis*;
307 EN), Blue whale (*Balaenoptera musculus*; EN), Loggerhead turtle (*Caretta caretta*; VU), Leatherback
308 turtle (*Dermochelys coriacea*; VU), Fin whale (*Balaenoptera physalus*; VU), Hooded seal (*Cystophora*
309 *cristata*; VU), and Cape Verde petrel (*Pterodroma feae*; NT).

310 The most studied non-fish species in the Bay of Biscay/Celtic Sea/Iberian Coast make up
311 about 1% (4 species) and cover three Classes and four Families (Table 5). The four most studied
312 species from the area in terms of biological characteristics were the Common cuttlefish (*Sepia*
313 *offinialis*) with information on eight biological characteristics, and the Green sea turtle (*Chelonia*
314 *mydas*), Giant red shrimp (*Aristaeomorpha foliacea*) and Spottail mantis shrimp (*Squilla mantis*)
315 which have seven studied biological characteristics. Out of these species, only the Green sea turtle is
316 included in the endangered list of IUCN (Table 5).

317 The least studied species make up about 99% (358 species) of non-fish species reported in
318 the Bay of Biscay/Celtic Sea/Iberian Coast, covering 22 Classes and 205 Families (Table S4)
319 including the ten species of the IUCN Red List (Table 5).

320

321 *Black Sea*

322 A total of 97 non-fish species recorded from the Black Sea in SeaLifeBase, including seven introduced
323 species. The species of the area belong to 57 Families, 40 Orders and 13 Classes. Regarding the
324 number of biological characteristics studied, there is no information for 58 species (56%). There are
325 19 species (16%) with information on one biological characteristic (mostly on length-weight
326 relationships), whereas one species (1%) has studies for all eight biological characteristics (Figure 2).

327 The individual biological characteristics of the non-fish species of the Black Sea, from most
328 studied to least studied, are length-weight relationships (41 species, 35%), growth (30 species, 26%),
329 maturity (14 species, 12%), spawning (9 species, 8%), lifespan (9 species, 8%), diet (9 species, 8%),
330 natural mortality (7 species, 6%), and fecundity (6 species, 5%) (Figure 3).

331 Five species are listed under the categories CR, endangered EN and vulnerable VU of the
332 IUCN Red List and have large gaps regarding seven biological characteristics: diet (2 species, 33%),
333 growth (2 species, 33%), fecundity (1 species, 17%), maturity (1 species, 17%), spawning (1 species,
334 17%), lifespan (1 species, 17%) and length-weight relationships (1 species, 17%). The widest
335 information gap refers to natural mortality, where no biological information is available (Figure 3).

336 The only well-studied non-fish species in the Black Sea is the Blue crab (*Callinectes sapidus*),
337 an introduced species, having information for all eight biological characteristics (Table 6). The least
338 studied species make up about 96% (93 species) of non-fish species reported in the Black Sea,
339 covering 13 Classes and 57 Families (Table S5). The least-studied species reported from the Black Sea
340 are 28 species in total, covering seven Classes and 23 Families belonging to five taxonomic groups
341 (Table 6). Amongst these species, the Mediterranean monk seal (*Monachus monachus*) with one
342 biological characteristic and the Loggerhead turtle (*Caretta caretta*), with six biological

343 characteristics, are listed as endangered (EN) and vulnerable (VU), respectively (Table 6). The former
344 is considered extinct in the Black Sea and the latter is reported in occasional sightings, without an
345 established population. Three species that are listed as VU [Velvet scoter (*Melanitta fusca*), Horned
346 grebe (*Podiceps auritus*), and the Levantine shearwater (*Puffinus yelkouan*)], have no available
347 biological information (Table 6).

348

349 *Levantine Sea*

350 A total of 401 non-fish species recorded from the Levantine Sea are found in SeaLifeBase, including
351 388 native, one endemic and 12 introduced species that belong to 172 Families, 60 Orders and 17
352 Classes. Regarding the number of biological characteristics studied, there is no information for 235
353 species (59%). There are 77 species (19%) with information on one biological characteristic (mostly
354 on length-weight relationships), while two species have studies for all eight biological characteristics
355 (Figure 2).

356 The individual biological characteristics of the non-fish species of the Levantine Sea, from
357 most studied to least studied, are length-weight relationships (136 species, 34%), growth (83 species,
358 21%), maturity (45 species, 11%), spawning (38 species, 9%), lifespan (33 species, 8%), diet (23
359 species, 6%), natural mortality (22 species, 5%) and fecundity (20 species, 5%) (Figure 3).

360 Eight species are listed under the IUCN Red List categories near threatened (NT), vulnerable
361 (VU), endangered (EN) and critically endangered (CR) and have smaller gaps regarding four biological
362 characteristics: growth (7 species, 87%), diet (6 species, 75%), maturity (6 species, 75%) and length-
363 weight relationships (6 species, 75%). Larger gaps were observed in spawning (4 species, 50%),
364 fecundity (3 species, 33%), lifespan (3 species, 33%) and natural mortality (2 species, 22%) (Figure 3).
365 These species are the Mediterranean monk seal (*Monachus monachus*; EN), Loggerhead turtle
366 (*Caretta caretta*; VU), Sperm whale (*Physeter macrocephalus*; VU), Leatherback turtle (*Dermochelys*
367 *coriacea*; VU), Levantine shearwater (*Puffinus yelkouan*; VU), Armenian gull (*Larus armenicus*; NT),
368 False killer whale (*Pseudorca crassidens*; NT), and Noble pen shell (*Pinna nobilis*; CR).

369 The well-studied species of the Levantine Sea make up about 2% (8 species) of non-fish
370 species reported from the area and cover three Classes and seven Families (Table 7). The eight most
371 studied Levantine species in terms of biological characteristics are: the alien Blue crab (*Callinectes*
372 *sapidus*) and Common cuttlefish (*Sepia officinalis*), both having eight biological characteristics, the
373 Speckled shrimp (*Metapenaeus monoceros*), which is another introduced species, Green sea turtle
374 (*Chelonia mydas*), Deep-water rose shrimp (*Parapenaeus longirostris*), Giant red shrimp
375 (*Aristaeomorpha foliacea*), Spottail mantis shrimp (*Squilla mantis*) and Common spiny lobster
376 (*Palinurus elephas*), all of which have seven biological characteristics. Out of these eight species only
377 two are included in the IUCN Red List, the Green sea turtle as EN and the Common spiny lobster as
378 VU (Table 7).

379 The least studied species make up about 98% (393 species) of non-fish species reported in
380 the Levantine Sea, covering 17 Classes and 170 Families (Table S6). Including the eight species
381 reported in the IUCN Red List (Table 7).

382

383 *North Sea*

384 A total of 1,084 non-fish species were recorded from the North Sea in SeaLifeBase, including 1043
385 native species and 41 introduced ones. These species belong to 389 Families, 101 Orders and 24
386 Classes. There is no information on biological characteristics for 800 species (74%). Furthermore,
387 there are 170 species (16%) with information on one biological characteristic (mostly on length-
388 weight relationships), and three species have studies for all eight biological characteristics (Figure 2).

389 The individual biological characteristics of the non-fish species of the North Sea, from most
390 studied to least studied, are length-weight relationships (216 species, 20%), growth (112 species,
391 10%), diet (55 species, 5%), maturity (49 species, 5%), lifespan (48 species, 4%), spawning (36
392 species, 3%), natural mortality (24 species, 2%) and fecundity (18 species, 2%) (Figure 3).

393 Twenty-two species are listed under the categories near threatened (NT), vulnerable (VU),
394 endangered (EN) and critically endangered (CR) of the IUCN Red List. These species show smaller

395 gaps regarding two biological characteristics: growth (16 species, 73%) and length-weight
396 relationships (14 species, 64%), but larger gaps were observed in diet (10 species, 45%), maturity (9
397 species, 41%), fecundity (4 species, 18%), spawning (4 species, 18%), natural mortality (3 species,
398 14%) and lifespan (3 species, 14%) (Figure 3). The twenty-two species that are included in IUCN Red
399 List are Hawksbill turtle (*Eretmochelys imbricata*; CR), Kemp's ridley turtle (*Lepidochelys kempii*; CR),
400 North Atlantic right whale (*Eubalaena glacialis*; CR), Sei whale (*Balaenoptera borealis*; EN), Blue
401 whale (*Balaenoptera musculus*; EN), Loggerhead turtle (*Caretta caretta*; VU), Sperm whale (*Physeter*
402 *macrocephalus*; VU), Leatherback turtle (*Dermochelys coriacea*; VU), Fin whale (*Balaenoptera*
403 *physalus*; VU), Walrus (*Odobenus rosmarus*; VU), Hooded seal (*Cystophora cristata*; VU), North
404 Atlantic bottlenose whale (*Hyperoodon ampullatus*; NT), Balearic shearwater (*Puffinus mauretanicus*;
405 CR), Black-legged kittiwake (*Rissa tridactyla*; VU), Atlantic puffin (*Fratercula arctica*; VU), Velvet
406 scoter (*Melanitta fusca*; VU), Horned grebe (*Podiceps auritus*; VU), Steller's eider (*Polysticta stelleri*;
407 VU), Starlet anemone (*Nematostella vectensis*; VU), Sooty shearwater (*Puffinus griseus*; NT), Red
408 knot (*Calidris canutus*; NT) and Common eider (*Somateria mollissima*; NT).

409 The most studied species of the North Sea make up about 0.5% (5 species) of non-fish
410 species reported in the area and cover four Classes and five Families (Table 8). These five species are
411 the alien Blue crab (*Callinectes sapidus* and Common cuttlefish (*Sepia officinalis*), with information on
412 eight biological characteristics, the Japanese carpet shell (*Ruditapes philippinarum*), which is another
413 introduced species, Green sea turtle (*Chelonia mydas*) and Common spiny lobster (*Palinurus elephas*)
414 all have information on seven biological characteristics. Out of these five species, the Green sea
415 turtle is listed as EN and the Common spiny lobster as VU (Table 8).

416 The least studied species make up about 99.5% (1079 species) of non-fish species reported in
417 the North Sea and cover 24 Classes and 387 Families (Table S7) including the 22 species reported in
418 the IUCN Red List (Table 8).

419

420 *Western Mediterranean Sea*

421 A total of 470 non-fish species are recorded from the Western Mediterranean Sea in SeaLifeBase,
422 including 462 native, two endemic and six introduced species, belonging to 210 Families, 73 Orders
423 and 19 Classes. Regarding the number of biological characteristics studied, there is no information
424 for 308 species (66%). There are 79 species (17%) with information on one biological characteristic
425 (mostly on length-weight relationships), while only one species has studies for all eight biological
426 characteristics (Figure 2).

427 The individual biological characteristics of the non-fish species of the Western
428 Mediterranean Sea, from most studied to least studied, are: length-weight relationships (136 species,
429 29%), followed by growth (80 species, 17%), maturity (42 species, 9%), spawning (29 species, 6%),
430 lifespan (26 species, 6%), natural mortality (22 species, 5%), fecundity (16 species, 3%) and diet (15
431 species, 3%) (Figure 3).

432 Thirteen species are included in the IUCN Red List under the categories near threatened (NT),
433 vulnerable (VU), endangered (EN) and critically endangered (CR). These species have a small gap
434 regarding one biological characteristic (growth) with information available for 10 species (67%).
435 Larger gaps were observed for the rest biological characteristics: length-weight relationships (7
436 species, 47%), maturity (7 species, 47%), diet (4 species, 27%), fecundity (4 species, 27%), spawning
437 (4 species, 27% studied), natural mortality (3 species, 20%), and lifespan (2 species, 13%) (Figure 3).
438 The thirteen included in the IUCN Red List are Hawksbill turtle (*Eretmochelys imbricata*; CR), Kemp's
439 ridley turtle (*Lepidochelys kempii*; CR), Loggerhead turtle (*Caretta caretta*; VU), Leatherback turtle
440 (*Dermochelys coriacea*; VU), Olive ridley turtle (*Lepidochelys olivacea*; VU), Noble pen shell (*Pinna*
441 *nobilis*; CR), Balearic shearwater (*Puffinus mauretanicus*; CR), Audouin's gull (*Larus audouinii*; VU),
442 Velvet scoter (*Melanitta fusca*; VU), Horned grebe (*Podiceps auritus*; VU), Levantine shearwater
443 (*Puffinus yelkouan*; VU), Sooty shearwater (*Puffinus griseus*; NT) and Common eider (*Somateria*
444 *mollissima*; NT).

445 The most studied species of the western Mediterranean Sea make up about 1% (6 species) of
446 non-fish species reported from the area and cover three Classes and six Families (Table 9). The six

447 most studied western Mediterranean species in terms of biological characteristics were the Common
448 cuttlefish (*Sepia officinalis*), the only species with eight studied biological characteristics, while the
449 Green sea turtle (*Chelonia mydas*), Deep-water rose shrimp (*Parapenaeus longirostris*), Giant red
450 shrimp (*Aristaeomorpha foliacea*), Spottail mantis shrimp (*Squilla mantis*) and Common spiny lobster
451 (*Palinurus elephas*) have seven biological characteristics studied. Out of these six species, only the
452 Common spiny lobster is included in the list of IUCN as VU (Table 9).

453 The least-studied species make up about 98% (464 species) of non-fishes reported in the
454 western Mediterranean Sea, cover 19 Classes and 210 Families (Table S8). Of the least-studied
455 species, there are thirteen species that are included in the IUCN Red List (Table 9).

456

457 **Discussion**

458 *Common patterns*

459 The general pattern, observed across all studied ecosystems, is that data availability on biological
460 characteristics of non-fish marine organisms are rather poor, with only two taxonomic groups (sea
461 turtles and marine mammals) appearing to have been adequately studied across most study areas.
462 There is moderately good information coverage for sea turtles in the Celtic Sea/Bay of Biscay/Iberian
463 coast, Black Sea, Levantine Sea, North Sea and western Mediterranean Sea, whereas information
464 coverage for marine mammals is moderate for the Baltic Sea, Celtic Sea/Bay of Biscay/Iberian coast,
465 Black Sea, Levantine Sea, North Sea and western Mediterranean Sea (Table 10). Data on biological
466 characteristics was lowest for cnidarians, whereas there were no available biological information on
467 sponges; the latter group of organisms being globally understudied in terms of biological
468 characteristics (Bell et al. 2015).

469 Because of the low total number of species recorded compared to the other areas, the Black
470 Sea appears to be among the better studied areas together with the Bay of Biscay/Celtic Sea/Iberian
471 Coast, the Levantine Sea and the western Mediterranean Sea. The Adriatic Sea is the area with the
472 most data gaps compared to the other study areas. This area, for instance, does not have

473 information available on any of the present marine mammal species (Lotze et al. 2011). Likewise,
474 there are no data reported on the biological characteristics of sponges in the Black Sea, where their
475 checklist has been recently updated, at least for part of this area (Topaloglu & Alper 2014). The
476 difference in species composition among areas has certainly contributed to the number of species
477 studied and the extent of the available information.

478 There are seven well-studied species across the reviewed ecosystems: Common cuttlefish
479 (*Sepia officinalis*), Giant red shrimp (*Aristaeomorpha foliacea*), Spottail mantis shrimp (*Squilla*
480 *mantis*), Common spiny lobster (*Palinurus elephas*), Blue crab (*Callinectes sapidus*), Green sea turtle
481 (*Chelonia mydas*) and Deep-water rose shrimp (*Parapenaeus longirostris*). These species have good
482 coverage of biological information and sufficient data records for use in ecosystem assessments and
483 modelling. Of these, the most common well-studied species include the Common cuttlefish (*Sepia*
484 *officinalis*), which is reported within six sites and is highly commercial (Pereira et al. 2015). The
485 current absence of data for the studied taxonomic groups may be due to actual absence of real data
486 (i.e., lack of studies on non-fish marine organisms) or time-lagged entering of research publications in
487 SeaLifeBase or that source of information has not been considered (for instance, grey literature or
488 local journals).

489 In terms of biological characteristics, the information gap for all species is largest for
490 fecundity, natural mortality and diet, with the better studied characteristics being length-weight
491 relationships (LWR) followed by spawning, lifespan, maturity and growth. The most-studied
492 characteristic (LWR) is common and well-studied across areas but the least-studied ones differ
493 between the Atlantic and the Mediterranean areas. Consequently, research priorities and survey
494 data availability often differ (e.g., Uglund 1976), as well as to scientific tradition and historical data
495 records (Lotze & Worm 2009) that are generally scarce in the Mediterranean (Stergiou & Tsikliras
496 2006; Fortibuoni et al. 2017). It is worth mentioning here that LWR is the most common even though
497 it is not a trait that is measured for many non-fish taxonomic groups such as marine mammals,
498 reptiles and seabirds. Contrary to LWR that are easier to collect and compute, the sample collection

499 and laboratory work required to determine the diet and fecundity of specimens are costly and time-
500 consuming and require technological equipment and advanced expertise (Dimarchopoulou et al.
501 2017). In contrast, natural mortality can be easily calculated using existing datasets based on the
502 many known empirical equations that are available (constant across ages/sizes: Pauly 1980, Then et
503 al. 2015; size/age-based: Chen & Watanabe 1989, Gislason et al. 2010) without any extra cost or
504 sampling that would be required if other methods were selected (tagging: Krause et al. 2020; length-
505 based and age structured models: Lorenzen 2022). Therefore, it is strongly recommended, at least
506 for decapod crustaceans and cephalopods, to report maximum age in every study in which growth
507 parameters are determined and, if possible, to calculate and report natural mortality.

508 For the species that are exploited such as many crustaceans and cephalopods, commercially
509 targeted species are indeed better-studied compared to by-catch and discarded ones that are
510 generally neglected (Baran 2002). The biological information of the former is more complete due to
511 historically more intensive sampling effort across the studied marine ecosystems because of their
512 economic importance to the fisheries and frequent assessments (Dimarchopoulou et al. 2017). For
513 non-commercial groups, there is generally less information on threatened species compared to those
514 with high commercial value, as it has recently reported for fishes (Dimarchopoulou et al. 2017;
515 Daskalaki et al. 2022) due to the low accessibility of deep-water non-fish marine species that are
516 generally less sampled in routine surveys that rarely extend to deep waters (Sarda et al. 2004).
517 Therefore, the study of threatened, deep-water and non-indigenous species should be prioritised
518 over the well-studied commercial species similar to recommendations for marine fishes(Daskalaki et
519 al. 2022). When threatened species cannot be sampled with non-destructive methods, such as
520 underwater censuses or tagging experiments, it is suggested that if dead after capture, the
521 specimens should be exhaustively studied across their biological characteristics to ensure the
522 maximum economy of sampling (Dimarchopoulou et al. 2017). The study of threatened species
523 should be a priority as they are all good candidates for field data collection. However, the existing
524 gaps on species that are routinely sampled during scientific surveys should also be considered by

525 scientists. The basic characteristics of a species (measurement of length and weight) should always
526 be recorded even from single individuals in the market (in the case of crustaceans and cephalopods)
527 or stranded individuals in the case of marine mammals and reptiles (see the importance of single
528 specimen characteristics for sharks in Tsikliras & Dimarchopoulou 2021).

529 Better research coverage on the diets of all marine organisms would greatly benefit future
530 ecosystem models and improve future versions of the current ones (Dimarchopoulou et al. 2017),
531 while more studies on growth, mortality, maturity and spawning of exploited populations will
532 improve the quality of stock assessments within the framework of STECF and GFCM. This, in turn, will
533 reduce uncertainty on the outcome of stock assessment and ecosystem models and will eventually
534 lead to improvements in ecosystem based fisheries management, especially in the Mediterranean
535 and the Black Sea (Rodriquez-Perez et al. 2023). In many areas that experience an influx of non-
536 indigenous species, such as the eastern Mediterranean Sea (Galil et al. 2015), the study of non-
537 indigenous species biology should also be prioritized. Their biological characteristics in the new
538 habitats/areas should be compared to those in native range, aiming to identify the potential effects
539 of alien species on local populations, habitats and communities (Daskalaki et al. 2022).

540

541 *Adriatic Sea*

542 In the Adriatic Sea, there is currently poor biological information coverage for non-fish species, with
543 relatively more information being available for sea turtles compared to crustaceans, echinoderms
544 and cnidarians, while no data exists for marine mammals (Table 10). Only sea turtles qualify as
545 moderate data coverage with all other areas being data poor (Table 10). In general, the gap is widest
546 for information on diet and fecundity. The information coverage for the Adriatic is good for only a
547 few well-studied species of crustaceans and one cephalopod that are commercially important.

548 Compared to other Mediterranean areas, the Adriatic Sea is an overall well-studied
549 ecosystem in terms of stock assessments (Froese et al. 2018b) and ecosystem models (Barausse et al.
550 2009), with important contributions on the effects of fishing (Coll et al. 2007), filling gaps in survey

551 datasets (Coro et al. 2022), the effect of COVID-19 on fish stocks (Scarcella et al. 2022) and fisheries
552 in general, especially in the western part of the sea (Lotze et al. 2011). There are even some historical
553 data available for large marine animals (Lotze & Worm 2009). Non-indigenous species have also been
554 extensively studied in terms of their effect on the food web dynamics (Libralato et al. 2010, 2015). It
555 appears that the data collected from scientific surveys on non-fish marine organisms either remain
556 unpublished, or do not include the biological characteristics covered in this review. Furthermore,
557 they have potentially not yet been included in SeaLifeBase.

558

559 *Aegean Sea*

560 Within the Aegean Sea, Sea turtles have better coverage, in terms of biological characteristics,
561 compared to all other groups, (Table 10). However, similarly to the Adriatic, only sea turtles qualify as
562 moderately studied while in all other areas are poorly studied (Table 10). The knowledge gap is
563 widest for information on diet followed by fecundity. Good biological information is available for a
564 few well-studied species of crustaceans and one cephalopod, all being commercially exploited.

565 Official stock assessments are generally scarce in the Aegean Sea and cover only a handful of
566 commercial stocks owing to several years missing from data collection framework (Tsikliras et al.
567 2021). Nevertheless, over 100 fish and invertebrate Aegean Sea stocks have been recently assessed
568 using data-poor methods (Froese et al. 2018b, Tsikliras et al. 2021). Several EwE ecosystem models
569 have been recently developed for parts of the Aegean Sea (Thracian Sea: Tsagarakis et al. 2010;
570 Pagassitikos Gulf: Dimarchopoulou et al. 2019; Thermaikos Gulf: Dimarchopoulou et al. 2022) and a
571 recent one for the entire Aegean Sea (Keramidas et al. 2022) along with temporal simulations
572 (Dimarchopoulou et al. 2022; Papantoniou et al. 2021), while spatial models are still not available
573 (Keramidas et al. 2023). Besides overfishing, which is considered the main driver of exploited marine
574 populations in the Mediterranean Sea (Dimarchopoulou et al. 2021), the direct (sea warming and
575 species distribution shifts) and indirect (entering and expansion of alien species) effects of climate
576 change are major issues in the eastern Mediterranean Sea that concern the scientific community

577 (Cherif et al. 2020).

578

579 *Baltic Sea*

580 Although there are no well-studied species in the Baltic Sea, marine mammals and echinoderms have
581 higher counts of species with studied biological characteristics compared to molluscs, crustaceans,
582 seabirds, and cnidarians (Table 10). The biological information coverage is moderate for sea turtles
583 and marine mammals and poor for all other groups (Table 10). The knowledge gap is widest for
584 information on fecundity and natural mortality and narrowest for length-weight relationships. An
585 introduced species, Harris mud crab (*Rhithropanopeus harrisii*) is considered as a near well-studied
586 species, having eight biological characteristics and 17 records available.

587 The Baltic Sea is a well-studied ecosystem (Feistel et al. 2008) with many stock assessments
588 available (Froese et al. 2018b, 2021) and ecosystem models using various approaches (Österblom et
589 al. 2007, Bauer et al. 2019) that geographically cover basins of the entire sea (see Scotti et al. 2022
590 and references in their Table S2). Status and dynamics of several ecosystem components have been
591 studied in the Baltic Sea including hypotheses on alien species (Dobrzycka-Kraheil & Medina-Villar
592 2020) and their effect on ecosystem services (Ojaveer et al. 2023), eutrophication (Bauer et al. 2019),
593 fisheries (Scotti et al. 2022) but also climate change (Niiranen et al. 2013) and grey seal (*Halichoerus*
594 *grypus*) interaction with fisheries (Costalago et al. 2019). The study of non-indigenous species, which
595 are numerous in the Baltic Sea (Reusch et al. 2018), and their effects on marine ecosystems should
596 be prioritised. With such a wealth of biotic and abiotic information on the ecosystems of the Baltic
597 Sea ecosystems, with long-term datasets of many marine groups available since the 1950s and some
598 expeditions dating back to 1850s (Ojaveer et al. 2010), it is surprising that the basic biological
599 characteristics for many marine organisms supporting ecosystem models and assessments have not
600 been published. The possibility that this information is published but has not yet been scrutinised by
601 SeaLifeBase is also a potential explanation especially in case of local or not yet digitised journals.

602

603 *Bay of Biscay/Celtic Sea/Iberian Coast*

604 In the Bay of Biscay/Celtic Sea/Iberian Coast (combined), vertebrates (marine mammals, sea turtles
605 and seabirds) have higher counts of species with biological information compared to invertebrates
606 (echinoderms, molluscs, crustaceans and cnidarians) (Table 10). The biological information coverage
607 is good for sea turtles, moderate for marine mammals and poor for all other groups (Table 10). The
608 knowledge gap is widest for information on fecundity and natural mortality and narrowest for
609 length-weight relationships. In the Bay of Biscay/Celtic Sea/Iberian Coast area, there is good
610 biological information for a few well-studied species of crustaceans, one cephalopod (all commercial)
611 and one species of sea turtle.

612 The three combined areas of the NE Atlantic (Celtic Sea, Bay of Biscay, Iberian Coast) are
613 all high biodiversity areas with many habitats and marine species, including endangered and
614 protected species like cetaceans (Laran et al. 2017; Spitz et al. 2018) and seabirds (Morley et al.
615 2016). The Celtic Sea and Bay of Biscay are often considered as a single ecosystem in modelling
616 studies (Moullec et al. 2017). They are all rich in terms of scientific output (Borja et al. 2011),
617 with many ecosystem models developed, simulated (Lassalle et al. 2011; Corrales et al. 2022) and
618 compared (Moullec et al. 2017). Several ecological hypotheses have been examined based on
619 ecosystem and ecological models (Le Marchand et al. 2020). The number of stocks that have been
620 assessed covers the majority of commercial fisheries (Guénette & Gascuel 2012; Froese et al. 2018a,
621 2021).

622

623 *Black Sea*

624 Marine mammals and molluscs have higher counts of species with biological information compared
625 to crustaceans and cnidarians in the Black Sea (Table 10). The biological information coverage is good
626 for sea turtles, moderate for marine mammals and poor for all other groups (Table 10). The biological
627 knowledge gap is widest for information on fecundity and natural mortality and narrowest for
628 length-weight relationships. An introduced crustacean, Blue crab (*Callinectes sapidus*) has sufficient

629 information for eight biological characteristics and is considered the best studied organism in the
630 Black Sea of those with records in SeaLifeBase.

631 The Black Sea together with the Mediterranean marine ecosystems are rather poorly studied
632 compared to the NE Atlantic ones (Güneroğlu et al. 2019). However, the Black Sea ecosystem
633 structure (Akoglu et al. 2014) and fisheries (Prodanov et al. 1997; Daskalov 2002; Gucu 2002) are
634 relatively well studied in certain parts of the sea. The effect of non-indigenous species on the
635 populations and ecosystem of the Black Sea (Shiganova 1998) and the overall status of the
636 ecosystem after anthropogenic impacts has been evaluated (Zaitsev 1992; Kideys 2002; Daskalov et
637 al. 2017). Furthermore, some of the commercial fish and invertebrate Black Sea stocks have been
638 assessed using catch-based (Tsikliras et al. 2015) and other data-limited methods (Froese et al.
639 2018a; Daskalov et al. 2020; Demirel et al. 2020).

640

641 *Levantine Sea*

642 In the Levantine Sea, marine mammals, sea turtles, seabirds and crustaceans have higher counts of
643 species with information on biological characteristics compared to echinoderms, molluscs and
644 cnidarians (Table 10). The biological information coverage is good for sea turtles, moderate for
645 marine mammals and poor for all other groups (Table 10). In general, the knowledge gap is widest
646 for information on fecundity and natural mortality. Overall, current coverage on biological
647 information is good for a few well-studied species of crustaceans, one sea turtle and one
648 cephalopod.

649 Due to its proximity to the Suez Canal, the Levantine Sea is the first to receive the non-
650 indigenous species migrating into the Mediterranean Sea from the Red Sea, which have altered the
651 biodiversity of the area (Galil et al. 2015). Despite the existence of local journals with long
652 publishing history in the area (*Israel Journal of Ecology & Evolution/Israel Journal of Zoology*,
653 published since 1963; *Turkish Journal of Zoology*, published since 1977; *Egyptian Journal of*
654 *Aquatic Biology and Fisheries*, published since 1997) and some recent attempts (e.g., *Syrian*

655 *Journal of Agricultural Research* since 2014), the amount of data on the biology of non-fish
656 marine organisms is rather limited (Stergiou & Tsikliras 2006) and the Syrian coast has been
657 characterized as one of the least-studied areas for marine mammals in the Mediterranean Sea
658 (Saad & Mahfoud 2022). Although the extent of scientific surveys is rather limited and historical
659 biological data are generally lacking or concentrated in specific countries (Tsikliras et al. 2010),
660 there has been an increase of scientific output in the Levantine Sea during the last decades (Tsikliras
661 & Stergiou 2014). Despite the data deficiencies and the lack of long time series, EwE ecosystem
662 models have been developed to examine the effect of non-indigenous species, climate change and
663 other anthropogenic affects in Israel (Corrales et al. 2017, 2018; Shabtay et al. 2018; Grossowicz et
664 al. 2020; Ofir et al. 2023) in addition to bioeconomic models (Peled et al. 2020; Michael-Biton et al.
665 2022) and non-indigenous species in Cyprus (Michailidis et al. 2019), including lionfish *Pterois miles*
666 (Savva et al. 2020) and silver-cheeked toadfish *Lagocephalus sceleratus* (Ulman et al. 2021).

667

668 *North Sea*

669 Similarly to the Bay of Biscay/Celtic Sea/Iberian Coast (combined), marine vertebrates (sea turtles,
670 marine mammals and seabirds) have higher counts of species with information on biological
671 characteristics compared to the marine invertebrates (echinoderms, molluscs, crustaceans and
672 cnidarians) (Table 10). Biological coverage is good for sea turtles, moderate for marine mammals and
673 poor for all other groups (Table 10). In general, the knowledge gap is widest for information on
674 fecundity and natural mortality, and narrowest for length-weight relationships. Overall, the current
675 coverage on biological information is good for a few well-studied species of crustaceans, sea turtle,
676 cephalopod and Harris mud crab (*Rhithropanopeus harrisi*), an introduced non-commercial species,
677 is considered a near well-studied species, having eight biological characteristics and 17 records
678 available.

679 The North Sea marine ecosystem is one of the most biotically-rich and productive seas in
680 Europe (Quante et al. 2016) and has been well studied for many decades with respect to ecosystem

681 structure (Stabler et al. 2018), effects of fishing and climate (Heath 2005), system dynamics (Luczak
682 et al. 2012), and regime shifts (Beaugrand 2004), as well as ecological models (Fransz et al. 1991).
683 There are several ecosystem models available for the North Sea (Burkhard et al. 2011; Mackinson et
684 al. 2018), including temporal (Mackinson et al. 2009), spatial (Puts et al. 2020) and bioeconomic
685 (Beattie et al. 2002) models, while the majority of commercial fish and invertebrate stocks are being
686 regularly assessed (Froese et al. 2021).

687

688 *Western Mediterranean Sea*

689 Marine mammals and sea turtles have higher counts of species with studied biological characteristics
690 compared to seabirds, crustaceans, molluscs, echinoderms and cnidarians in the western
691 Mediterranean Sea with good biological information coverage for sea turtles, moderate for marine
692 mammals and poor for all other groups (Table 10). In general, the knowledge gap is widest for
693 information on diet followed by fecundity. Overall, the current coverage on biological information is
694 better for a few well-studied species of crustaceans, one sea turtle and one cephalopod.

695 Parts of the western Mediterranean Sea, especially the northern coastline, have been well
696 studied in terms of ecosystem modelling (Catalan Sea: Coll et al. 2006, 2008; Gulf of Lions: Villas et al.
697 2021), even in deep waters (Tecchio et al. 2013), and invertebrate stock assessments (Froese et al.
698 2018a). Specific aspects of the biology of many marine taxonomic groups have been studied in
699 various parts of the area (feeding/crustaceans: Cartes et al. 2002; maturity/cephalopods: Quetglas et
700 al. 2010; cnidarians/growth and spawning: Rosa et al. 2013). This is partly due to the presence of
701 scientific journals in the area with long publication history (e.g., *Scientia Marina* published since 1955
702 as *Investigación Pesquera*) devoted to the biology of marine organisms and of course due to the long
703 and consistent scientific tradition of western Mediterranean countries in marine sciences. It should
704 be noted here that the southern Mediterranean countries have a long scientific tradition in fisheries
705 and marine biology (Stergiou & Tsikliras 2006) and have produced significant scientific output on the
706 biology of marine populations for over a century (Tsikliras et al. 2010).

707

708 *Priority areas for future research*

709 In order to reduce knowledge gaps on the biology of non-fish marine species across European Seas,
710 future research should focus on species with insufficient or missing biological data that are common
711 to the majority of the studied areas such as sea turtles, monk seal and seabirds; more effort is
712 generally required for the Adriatic and the Aegean Seas. Invertebrate species with low or no
713 commercial value that are often collected in scientific surveys and/or as by-catch in commercial
714 fisheries should not be overlooked. Long-lived species should be prioritised in order to understand
715 their biology and potential threats to their populations other than fishing. In areas invaded by non-
716 indigenous species, such as the eastern Mediterranean Sea, research should be focused on the study
717 of life-history characteristics of these species in their new environment and a comparison with their
718 habits in their native distribution. Besides overfishing and incidental fishing, climate change is one of
719 the major threats to marine life and the response of marine populations to climate effects is directly
720 related to their population characteristics and thermal preferences. Knowledge of the latter, which
721 today is known only for a small proportion of marine species, will improve species distribution
722 models and the understanding of climate effects. Threatened species that are listed under the IUCN
723 categories should be prioritised through focused research and use of any possible data available,
724 including strandings and incidental catches (without harming the animal if still alive). This approach
725 offers an expedient strategy in addressing the gap between current and desired knowledge with
726 respect to biological characteristics through focused field studies. Despite the number of scientific
727 publications that investigate the welfare of charismatic rather than non-charismatic species (Hosey
728 et al. 2020) the gaps of biological knowledge in charismatic species are still wide and should be
729 addressed.

730

731 **References**

732 Akoglu E, Salihoglu B, Libralato S, Oguz T, Solidoro C (2014) An indicator-based evaluation of Black

733 Sea food web dynamics during 1960–2000. *Journal of Marine Systems* **134**: 113–125.

734 Baran E (2002) The importance of non-commercial fish. In: Safran P., editor. Fisheries and
735 Aquaculture: Towards Sustainable Aquatic Living Resources Management. UNESCO
736 Encyclopedia of Life Support Systems. Oxford: EOLSS Publishers; pp. 1±7.

737 Barausse A, Duci A, Mazzoldi C, Artioli Y, Palmeri L (2009) Trophic network model of the Northern
738 Adriatic Sea: Analysis of an exploited and eutrophic ecosystem. *Estuarine, Coastal and Shelf
739 Science* **83**: 577-590.

740 Bauer B, Horbowy J, Rahikainen M, Kulatska N, Müller-Karulis B, Tomczak MT, et al. (2019) Model
741 uncertainty and simulated multispecies fisheries management advice in the Baltic Sea. *PLoS ONE*
742 **14**: e0211320.

743 Beattie A, Sumaila UR, Christensen V, Pauly D (2002) A model for the bioeconomic evaluation of
744 marine protected area size and placement in the North Sea. *Natural Resource Modeling* **15**: 413-
745 437.

746 Beaugrand G (2004) The North Sea regime shift: Evidence, causes, mechanisms and consequences.
747 *Progress in Oceanography* **60**: 245-262,

748 Bell JJ, McGrath E, Biggerstaff A, Bates T, Cárdenas CA, Bennett H (2015) Global conservation status
749 of sponges. *Conservation Biology* **29**: 42-53.

750 Borja Á, Galparsoro I, Irigoien X, Iriondo A, Menchaca I, Muxika I et al. (2011) Implementation of the
751 European Marine Strategy Framework Directive: a methodological approach for the
752 assessment of environmental status, from the Basque Country (Bay of Biscay). *Marine
753 Pollution Bulletin* **62**: 889–904.

754 Burkhard B, Opitz S, Lenhart H, Ahrendt K, Garthe S, Mendel B, Windhorst W (2011) Ecosystem based
755 modeling and indication of ecological integrity in the German North Sea—Case study offshore
756 wind parks. *Ecological Indicators* **11**: 168-174

757 Cartes JE, Abelló P, Lloris D, Carbonell A, Torres P, Maynou F, Gil de Sola L. (2002) Feeding guilds of
758 western Mediterranean demersal fish and crustaceans: an analysis based in a spring survey.

759 *Scientia Marina* **66**(S2): 209-20

760 Chen S, Watanabe S (1989) Age Dependence of Natural Mortality Coefficient in Fish Population
761 Dynamics. *Nippon Suisan Gakkaishi* **55**: 205-208.

762 Cherif S, Doblas-Miranda E, Lionello P, Borrego C, Giorgi F, Iglesias A, Jebari S, Mahmoudi E,
763 Moriondo M, Pringault O, Rilov G, Somot S, Tsikliras A, Vila M, Zittis G (2020) Drivers of change,
764 p. 59-180. In: Climate and Environmental Change in the Mediterranean Basin – Current Situation
765 and Risks for the Future. First Mediterranean Assessment Report [Cramer W, Guiot J, Marini K
766 (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France

767 Christensen V, Walters C (2004) Ecopath with Ecosim: methods, capabilities and limitations.
768 *Ecological Modelling* **172**: 109–139.

769 Claudet J, Bopp L, Cheung WWL, Devillers R, Escobar-Briones E, Haugan P, et al. (2019) A roadmap for
770 using the UN decade of ocean science for sustainable development in support of science, policy,
771 and action. *One Earth* **2**: 34–42.

772 Coll M, Palomera I, Tudela S, Sardà F (2006) Trophic flows, ecosystem structure and fishing impacts in
773 the South Catalan Sea, Northwestern Mediterranean. *Journal of Marine Systems* **59**: 63-96.

774 Coll M, Santojanni A, Palomera I, Tudela S, Arneri E (2007) An ecological model of the Northern and
775 Central Adriatic Sea: Analysis of ecosystem structure and fishing impacts. *Journal of Marine*
776 *Systems* **67**: 119-154.

777 Coll M, Palomera I, Tudela S, Dowd M (2008) Food-web dynamics in the South Catalan Sea ecosystem
778 (NW Mediterranean) for 1978–2003. *Ecological Modelling* **217**: 95-116.

779 Coll M, Palomera I, Tudela S (2009) Decadal changes in a NW Mediterranean Sea food web in relation
780 to fishing exploitation. *Ecological Modelling* **220**: 2088-2102.

781 Coll M, Grazia Pennino M, Steenbeek J, Sole J, Bellido JM (2019) Predicting marine species
782 distributions: Complementarity of food-web and Bayesian hierarchical modelling approaches.
783 *Ecological Modelling* **405**: 86-101

784 Coro G, Bove P, Armelloni EN, Masnadi F, Scanu M, Scarcella G (2022) Filling Gaps in Trawl Surveys at

785 Sea through Spatiotemporal and Environmental Modelling. *Frontiers in Marine Science* **9**:
786 919339

787 Corrales X, Coll M, Ofir E, Piroddi C, Goren M, Edelist D, Heymans JJ, Steenbeek J, Christensen V, Gal
788 G (2017) Hindcasting the dynamics of an Eastern Mediterranean marine ecosystem under the
789 impacts of multiple stressors. *Marine Ecology Progress Series* **580**: 17–36.

790 Corrales X, Coll M, Ofir E, Heymans JJ, Steenbeek J, Goren M, Edelist D, Gal G (2018) Future scenarios
791 of marine resources and ecosystem conditions in the Eastern Mediterranean under the
792 impacts of fishing, alien species and sea warming. *Scientific Reports* **8**: 14284

793 Corrales X, Katsanevakis S, Coll M, Heymans JJ, Piroddi C, Ofir E, Gal G (2019) Advances and
794 challenges in modelling the impacts of invasive alien species on aquatic ecosystems. *Biological*
795 *Invasions* **22**: 907–934.

796 Corrales X, Preciado I, Gascuel D, Lopez de Gamiz-Zearra A, Hervann P-Y, Mugerza E, Louzao M,
797 Velasco F, Doray M, López-López L, Carrera P, Cotano U, Andonegi E (2022) Structure and
798 functioning of the Bay of Biscay ecosystem: A trophic modelling approach. *Estuarine, Coastal*
799 *and Shelf Science* **26**: 107658,

800 Costalago D, Bauer B, Tomczak MT, Lundström K, Winder M (2019) The necessity of a holistic
801 approach when managing marine mammal–fisheries interactions: Environment and fisheries
802 impact are stronger than seal predation. *Ambio* **48**: 552-564

803 Damalas D, Kalyvioti G, Sabatella EC, Stergiou KI (2018) Open data in the life sciences: the ‘Selfish
804 Scientist Paradox’. *Ethics in Science and Environmental Politics* **18**: 27-36

805 Daskalaki E, Koufalis E, Dimarchopoulou D, Tsikliras AC (2022) Scientific progress made towards
806 bridging the knowledge gap in the biology of Mediterranean marine fishes. *PLoS ONE* **17**:
807 e0277383

808 Daskalov G (2002) Overfishing drives a trophic cascade in the Black Sea. *MEPS* 225:53-63

809 Daskalov GM, Boicenco L, Grishin AN, Lazar L, Mihneva V, Shlyakhov VA, Zengin M (2017)
810 Architecture of collapse: regime shift and recovery in an hierarchically structured marine

811 ecosystem. *Global Change Biology*, 23: 1486-1498.

812 Daskalov GM, Demirel N, Ulman A, Georgieva Y, Zengin M (2020) Stock dynamics and predator–prey
813 effects of Atlantic bonito and bluefish as top predators in the Black Sea. *ICES Journal of Marine
814 Science* **77**: 2995–3005,

815 Deacon M (1997) *Scientists and the Sea, 1650–1900: A Study of Marine Science* (2nd ed.). Routledge.

816 Demirel N, Zengin M, Ulman A (2020) First large-scale eastern Mediterranean and Black Sea stock
817 assessment reveals a dramatic decline. *Frontiers in Marine Science* **7**: 103

818 Dimarchopoulou D (2020) *Ecosystem approach to fisheries management in the Aegean Sea*. PhD
819 Thesis, School of Biology, Aristotle University of Thessaloniki, Thessaloniki, Greece.

820 Dimarchopoulou D, Stergiou KI, Tsikliras AC (2017) Gap analysis on the biology of Mediterranean
821 marine fishes. *PLoS ONE* **12**: e0175949

822 Dimarchopoulou D, Tsagarakis K, Keramidas I, Tsikliras AC (2019) Ecosystem models and effort
823 simulations of an untrawled gulf in the central Aegean Sea. *Frontiers in Marine Science* **6**: 648

824 Dimarchopoulou D, Keramidas I, Sylaios G, Tsikliras AC (2021) Eco-trophic effects of fishing across the
825 Mediterranean Sea. *Water* **13**: 482

826 Dimarchopoulou D, Tsagarakis K, Sylaios G, Tsikliras AC (2022) Ecosystem trophic structure and
827 fishing effort simulations of a major fishing ground in the northeastern Mediterranean Sea
828 (Thermaikos Gulf). *Estuarine, Coastal and Shelf Science* **264**: 107667

829 Dobrzycka-Kraheil A, Medina-Villar S (2020) Alien species of Mediterranean origin in the Baltic Sea
830 Region: current state and risk assessment. *Environmental Reviews* **28**(3): 339-356

831 FAO (2020) *The State of World Fisheries and Aquaculture 2020. Sustainability in action*. Rome.

832 Feistel R, Nausch G, Wasmund N (2008) *State and Evolution of the Baltic Sea, 1952–2005*

833 Fortibuoni T, Libralato S, Arneri E *et al.* (2017) Fish and fishery historical data since the 19th century
834 in the Adriatic Sea, Mediterranean. *Scientific Data* **4**: 170104.

835 Fransz HG, Mommaerts JP, Radach G (1991) Ecological modelling of the North Sea. *Netherlands
836 Journal of Sea Research* **28**: 67-140,

837 Froese R, Winker H, Coro G, Demirel N, Tsikliras AC, Dimarchopoulou D, Scarcella G, Quaas M, Matz-
838 Lück N (2018a) Status and rebuilding of European fisheries. *Marine Policy* **93**: 159-170

839 Froese R, Winker H, Coro G, Demirel N, Tsikliras AC, Dimarchopoulou D, Scarcella G, Probst WN,
840 Dureuil M, Pauly D (2018b) A new approach for estimating stock status from length frequency
841 data. *ICES Journal of Marine Science* **75**: 2004-2015

842 Froese R, Winker H, Coro G, Demirel N, Tsikliras AC, Dimarchopoulou D, Scarcella G, Palomares MLD,
843 Dureuil M, Pauly D (2020) Estimating stock status from relative abundance and resilience. *ICES*
844 *Journal of Marine Science* **77**: 527-538

845 Froese R, Tsikliras AC, Scarcella G, Gascuel D (2021) Progress towards ending overfishing in the
846 Northeast Atlantic. *Marine Policy* **125**: 104282

847 Galil BS, Boero F, Campbell ML, Carlton JT, Cook E, Fraschetti S, et al. (2015) 'Double trouble': the
848 expansion of the Suez Canal and marine bioinvasions in the Mediterranean Sea. *Biological*
849 *Invasions* **17**: 973–976

850 Gislason H, Daan N, Rice JC, Pope JG (2010) Size, growth, temperature and the natural mortality of
851 marine fish. *Fish and Fisheries* **11**: 149-158

852 Grossowicz M, Ofir E, Shabtay A, Wood J, Biton E, Belkin N, Frid O, Sisma-Ventura G, Kress N,
853 Berman-Frank I, Gal G (2020) Modeling the effects of brine outflow from desalination plants on
854 coastal food-webs of the Levantine basin (eastern Mediterranean Sea). *Desalination* **496**:
855 114757.

856 Grüss A, Palomares MLD, Poelen JH, Barile JR, Aldemita CD, Ortiz SR, Barrier N, Shin Y-J, Simons J,
857 Pauly D (2019) Building bridges between global information systems on marine organisms and
858 ecosystem models. *Ecological Modelling* **398**: 1-19

859 Gucu AC (2002) Can Overfishing be Responsible for the Successful Establishment of *Mnemiopsis leidyi*
860 in the Black Sea? *Estuarine, Coastal and Shelf Science* **54**: 439-451

861 Guénette S, Gascuel D (2012) Shifting baselines in European fisheries: The case of the Celtic Sea and
862 Bay of Biscay. *Ocean & Coastal Management* **70**: 10-21

863 Güneroğlu A, Samsun O, Feyzioğlu M, Dihkan M (2019) Chapter 21 - The Black Sea—The Past,
864 Present, and Future Status, Editor(s): Eric Wolanski, John W. Day, Michael Elliott, Ramesh
865 Ramachandran. *Coasts and Estuaries* **2019**: 363-375,
866 Heath MR (2005) Changes in the structure and function of the North Sea fish foodweb, 1973–2000,
867 and the impacts of fishing and climate. *ICES Journal of Marine Science* **62**: 847–868
868 Heymans JJ, Bundy A, Christensen V, Coll M, de Mutsert K, Fulton EA, Piroddi C, Shin Y-J, Steenbeek J,
869 Travers-Trolet M (2020) The Ocean Decade: A true ecosystem modelling challenge. *Frontiers in*
870 *Marine Science* **7**: 554573
871 Hosey G, Melfi V, Ward SJ (2020) Problematic Animals in the Zoo: The Issue of Charismatic
872 Megafauna. In: Angelici, F., Rossi, L. (eds) *Problematic Wildlife II*. Springer, Cham.
873 ICES (2022) ICES Stock Information Database. Copenhagen, Denmark. ICES. [accessed 17 Nov 2022].
874 <https://sid.ices.dk>
875 Jåms IB, Windsor FM, Poudevigne-Durance T et al. (2020) Estimating the size distribution of plastics
876 ingested by animals. *Nature Communications* **11**: 1594.
877 Jardim E, Millar CP, Mosqueira I, Scott F, Osio GC, Ferretti M, Alzorriz N, Orío (2015) What if stock
878 assessment is as simple as a linear model? The a4a initiative. *ICES Journal of Marine Science* **72**:
879 232–236
880 Katsanevakis S, Coll M, Piroddi C, Steenbeek S, Ben Rais Lasram F, Zenetos A , Cardoso AC (2014)
881 Invading the Mediterranean Sea: biodiversity patterns shaped by human activities. *Frontiers in*
882 *Marine Science* **1**: 32.
883 Keramidas I, Dimarchopoulou D, Tsikliras AC (2022) Modelling and assessing the ecosystem of the
884 Aegean Sea, a major hub of the eastern Mediterranean at the intersection of Europe and Asia.
885 *Regional Studies in Marine Science* **56**: 102704
886 Keramidas I, Dimarchopoulou D, Ofir E, Tsikliras AC, Gal G (2023) Ecotrophic perspective in fisheries
887 management: A review on EWE models in European marine ecosystems. *Frontiers in Marine*
888 *Science* **10**: 1182921

889 Kideys AE (2002) Fall and rise of the Black Sea ecosystem. *Science* **297**: 1482–1484.

890 Krause JR, Hightower JE, Poland SJ, Buckel JA (2020) An integrated tagging and catch-curve model
891 reveals high and seasonally-varying natural mortality for a fish population at low stock
892 biomass. *Fisheries Research* **232**: 105725

893 Laran S, Authier M, Blanck A, Dorémus G, Falchetto H, Monestiez P, Pettex E, Stephan E, Van Canneyt
894 O, Ridoux V (2017) Seasonal distribution and abundance of cetaceans within French waters –
895 Part II: the Bay of Biscay and the English Channel. *Deep Sea Research Part II* **141**: 31-40

896 Lassalle G, Lobry J, Le Lo’h F, Bustamante P, Certain G, Delmas D, Dupuy C, Hily C, Labry C, Le Pape O
897 (2011) Lower trophic levels and detrital biomass control the Bay of Biscay continental shelf
898 food web: implications for ecosystem management. *Progress in Oceanography* **91**: 561-575

899 Le Marchand M, Hattab T, Niquil N, Albouy C, Le Loc’h F, Lasram FBR (2020) Climate change in the
900 Bay of Biscay: Changes in spatial biodiversity patterns could be driven by the arrivals of
901 southern species. *Mar Ecol Prog Ser* 647:17-31.

902 Libralato S, Coll M, Tempesta M, Santojanni A, Spoto M, Palomera I, Arneri E, Solidoro C (2010) Food-
903 web traits of protected and exploited areas of the Adriatic Sea. *Biological Conservation*
904 **143**(9): 2182-2194.

905 Libralato S, Caccin A, Pranovi F (2015) Modeling species invasions using thermal and trophic niche
906 dynamics under climate change. *Frontiers in Marine Science* **2**: 29.

907 Link JS (2010) *Ecosystem-Based Fisheries Management: Confronting Tradeoffs*. Cambridge University
908 Press, Cambridge, UK.

909 Link JS, Ihde TF, Harvey CJ, Gaichas SK, Field JC, Brodziak JKT, Townsend HM, Peterman RM (2012)
910 Dealing with uncertainty in ecosystem models: The paradox of use for living marine resource
911 management. *Progress in Oceanography* **102**: 102-114.

912 Lorenzen K (2022) Size- and age-dependent natural mortality in fish populations: Biology, models,
913 implications, and a generalized length-inverse mortality paradigm. *Fisheries Research* **255**:
914 106454.

915 Lotze HK, Worm B (2009) Historical baselines for large marine animals. *Trends in Ecology & Evolution*
916 **24**: 254-262

917 Lotze HK, Coll M, Dunne JA (2011) Historical Changes in Marine Resources, Food-web Structure and
918 Ecosystem Functioning in the Adriatic Sea, Mediterranean. *Ecosystems* **14**: 198–222

919 Luczak C, Beaugrand G, Lindley JA, Dewarumez J-M, Dubois PJ, Kirby RR (2012) North Sea ecosystem
920 change from swimming crabs to seagulls. *Biology Letters* **8**: 821–824

921 Mackinson S, Deas B, Beveridge D, Casey J (2009) Mixed-fishery or ecosystem conundrum?
922 Multispecies considerations inform thinking on long-term management of North Sea demersal
923 stocks. *Canadian Journal of Fisheries and Aquatic Sciences* **66**: 1107-1129

924 Mackinson S, Platts M, Garcia C, Lynam C (2018) Evaluating the fishery and ecological consequences
925 of the proposed North Sea multi-annual plan. *PLoS ONE* 13(1): e0190015.

926 McManamay RA, Utz RM (2014) Open-Access databases as unprecedented resources and drivers of
927 cultural change in fisheries science. *Fisheries* **39**: 417–425

928 Michael-Bitton G, Gal G, Corrales X, Ofir E, Mordechai S, Zemah-Shamir S (2022) Economic aspects of
929 fish stock accounting as a renewable marine natural capital: The Eastern Mediterranean
930 continental shelf ecosystem as a case study. *Ecological Economics* **200**: 107539.

931 Michailidis N, Corrales X, Karachle PK, Chartosia N, Katsanevakis S, Sfenthourakis S (2019) Modelling
932 the role of alien species and fisheries in an Eastern Mediterranean insular shelf ecosystem.
933 *Ocean and Coastal Management* **175**: 152-171.

934 Morley TI, Fayet AL, Jessop H, Veron P, Veron M, Clark J, Wood MJ (2016) The seabird wreck in the
935 Bay of Biscay and South-Western Approaches in 2014: A review of reported mortality. *Seabird*
936 **29**: 22-38.

937 Moullec F, Gascuel D, Bentorcha K, Guénette S, Robert M (2017) Trophic models: What do we learn
938 about Celtic Sea and Bay of Biscay ecosystems? *Journal of Marine Systems* **172**: 104-117,

939 Niiranen S, Yletyinen J, Tomczak M, Blenckner T, Hjerne O, MacKenzie BR, Müller-Karulis B,
940 Neumann T, Meier HEM (2013) Combined effects of global climate change and regional

941 ecosystem drivers on an exploited marine food web. *Global Change Biology* **19**(11): 3327-3342.

942 Ofir E, Ribas X, Coll M, Heymans JJ, Goren M, Steenbeek JG, Amitai Y, Shachar N, Gal G (2023)

943 Evaluation of fisheries management policies in the alien species-rich Eastern Mediterranean

944 under climate change. *Frontiers in Marine Science* **10**: 1155480

945 Ojaveer H, Jaanus A, MacKenzie BR, Martin G, Olenin S, Radziejewska T, et al. (2010) Status of

946 Biodiversity in the Baltic Sea. *PLoS ONE* **5**: e12467.

947 Ojaveer H, Einberg H, Lehtiniemi M, Outinen O, Zaiko A, Jelmert A, Kotta J (2023) Quantifying impacts

948 of human pressures on ecosystem services: Effects of widespread non-indigenous species in the

949 Baltic Sea. *Science of The Total Environment* **858**: 159975.

950 Österblom H, Hansson S, Larsson U. et al. (2007) Human-induced Trophic Cascades and Ecological

951 Regime Shifts in the Baltic Sea. *Ecosystems* **10**: 877–889.

952 Palomares MLD, Pauly D. Editors (2021) SeaLifeBase. World Wide Web electronic publication.

953 www.sealifebase.org, version (12/2021).

954 Papantoniou G, Giannoulaki M, Stoumboudi MT, Lefkadiou E, Tsagarakis K (2021) Food web

955 interactions in a human dominated Mediterranean coastal ecosystem. *Marine Environmental*

956 *Research* **172**: 105507.

957 Pauly D (1980) On the interrelationships between natural mortality, growth parameters, and mean

958 environmental temperatures in 175 fish stocks. *Journal du Conseil International pour*

959 *l'Exploration de la Mer* **39**:175-192

960 Pauly D, Zeller D (2016) Catch reconstructions reveal that global marine fisheries catches are higher

961 than reported and declining. *Nature Communications* **7**: 10244.

962 Peled Y, Zemah-Shamir S, Israel A, Shechter M, Ofir E, Gal G (2020) Incorporating insurance value into

963 ecosystem services assessments: mitigation of ecosystem users' welfare uncertainty through

964 biological control. *Ecosystem Services* **46**: 101192.

965 Pereira F, Vasconcelos P, Moreno A, Gaspar MB (2019) Catches of *Sepia officinalis* in the small-scale

966 cuttlefish trap fishery off the Algarve coast (southern Portugal). *Fisheries Research* **214**: 117-125,

967 Piroddi C, Colloca F, Tsikliras AC (2020) The living marine resources in the Mediterranean Sea Large
968 Marine Ecosystem. *Environmental Development* **36**: 100555

969 Piroddi C, Akoglu E, Andonegi E, Bentley JW, Celic I, Coll M, Dimarchopoulou D, Friedland R, de
970 Mutsert K, Girardin R, Garcia-Gorriz E, Grizzetti B, Hernvann P-Y, Heymans JJ, Müller Karulis B,
971 Libralato S, Lynam CP, Macias D, Miladinova S, Moullec F, Palialexis A, Parn O, Serpetti N,
972 Solidoro C, Steenbeek J, Stips A, Tomczak M, Travers-Trolet M, Tsikliras AC (2021) Effects of
973 nutrient management scenarios on marine food webs: a Pan-European Assessment in support
974 of the Marine Strategy Framework Directive. *Frontiers in Marine Science* **7**: 596797

975 Piroddi C, Coll M, Macias D, Steenbeek J, Garcia-Gorriz E, Mannini A, Vilas D, Christensen V (2022)
976 Modelling the Mediterranean Sea ecosystem at high spatial resolution to inform the
977 ecosystem-based management in the region. *Scientific Reports* **12**: 19680.

978 Prodanov K, Mikhailov K, Daskalov D, Maxim K, Ozdamar E, Shlyakhov V, Chashchin A, Arkhipov A
979 (1997) Environmental management of fish resources in the Black Sea and their rational
980 exploitation. *Studies and Reviews*, 68, GFCM, 1997, 178

981 Püts M, Taylor M, Núñez-Riboni I, Steenbeek J, Stäbler M, Möllmann C, Kempf A (2020) Insights on
982 integrating habitat preferences in process-oriented ecological models – a case study of the
983 southern North Sea. *Ecological Modelling* **431**: 109189

984 Quante M, Colijn F, Bakker JP, Härdtle W, Heinrich H, Lefebvre C, Nöhren I, Olesen JE, Pohlmann T,
985 Sterr H, Sündermann J, Tölle MH (2016). Introduction to the Assessment—Characteristics of
986 the Region. 10.1007/978-3-319-39745-0_1.

987 Quetglas A, de Mesa A, Ordines F, Grau A (2010) Life history of the deep-sea cephalopod family
988 Histioteuthidae in the western Mediterranean. *Deep Sea Research Part I: Oceanographic*
989 *Research Papers* **57**: 999-1008

990 Ravier C, Fromentin J-M (2004) Are the long-term fluctuations in Atlantic bluefin tuna (*Thunnus*
991 *thynnus*) population related to environmental changes? *Fisheries Oceanography* **13**: 145-160

992 Reusch TBH, Dierking J, Andersson HC, Bonsdorff E, Carstensen J, Casini M, Czajkowski M, Hasler B,

993 Hinsby K, Hyytiäinen K, Johannesson K, Jomaa S, Jormalainen V, Kuosa H, Kurland S, Laikre L,
994 MacKenzie BR, Margonski P, Melzner F, Oesterwind D, Ojaveer H, Refsgaard JC, Sandström A,
995 Schwarz G, Tonderski K, Winder M, Zandersen M (2018) The baltic sea as a time machine for
996 the future coastal ocean. *Science Advances* **4**: eaar8195.

997 Rodriguez-Perez A, Tsikliras AC, Gal G, Steenbeek J, Falk-Andersson J, Heymans SJJ (2023) Using
998 ecosystem models to inform ecosystem-based fisheries management in Europe: a review of
999 the policy landscape and related stakeholder needs. *Frontiers in Marine Science* **10**: 1196329

1000 Rosa S, Pansera M, Granata A, Guglielmo L (2013) Interannual variability, growth, reproduction and
1001 feeding of *Pelagia noctiluca* (Cnidaria: Scyphozoa) in the Straits of Messina (Central
1002 Mediterranean Sea): Linkages with temperature and diet. *Journal of Marine Systems* **111–112**:
1003 97-107,

1004 Saad A, Mahfoud I (2022) Marine Mammals in Syria, in HAE Kaoud (ed.), Marine Mammals,
1005 IntechOpen, London.

1006 Sardà F, Calafat A, Flexas MM, Tselepides A, Canals M, Espino M, Tursi A (2004) An introduction to
1007 Mediterranean deep-sea biology. *Scientia Marina* **68**(S3): 7-38.

1008 Savva I, Chartosia N, Antoniou C, Kleitou P, Georgiou A, Stern N, Hadjioannou L, Jimenez C, Andreou
1009 V, Hall-Spencer JM, Kletou D (2020) They are here to stay: the biology and ecology of lionfish
1010 (*Pterois miles*) in the Mediterranean Sea. *Journal of Fish Biology* **97**: 148–162.

1011 Scarcella G, Angelini S, Armelloni EN, Costantini I, De Felice A, Guicciardi S, Leonori I, Masnadi F,
1012 Scanu M, Coro G (2022) The potential effects of COVID-19 lockdown and the following
1013 restrictions on the status of eight target stocks in the Adriatic Sea. *Frontiers in Marine Science*
1014 **9**: 920974

1015 Scotti M, Opitz S, MacNeil L, Kreutle A, Pusch C and Froese R (2022) Ecosystem-based fisheries
1016 management increases catch and carbon sequestration through recovery of exploited stocks:
1017 The western Baltic Sea case study. *Frontiers in Marine Science* **9**: 879998.

1018 Shabtay A, Portman M, Ofir E, Carmel Y, Gal G (2018) Using ecological modelling in marine spatial

1019 planning to enhance ecosystem-based management. *Marine Policy* **95**: 14-23.

1020 Shiganova TA (1998) Invasion of the Black Sea by the ctenophore *Mnemiopsis leidyi* and recent
1021 changes in pelagic community structure. *Fisheries Oceanography* **7**: 305-310.

1022 Spitz J, Ridoux V, Trites AW, Laran S, Authier M (2018) Prey consumption by cetaceans reveals the
1023 importance of energy-rich food webs in the Bay of Biscay. *Progress in Oceanography* **166**: 148-
1024 158

1025 Stäbler M, Kempf A, Temming A (2018) Assessing the structure and functioning of the southern
1026 North Sea ecosystem with a food-web model. *Ocean & Coastal Management* **165**: 280-297,

1027 Stasolla G, Tricarico E, Vilizzi L (2021) Risk screening of the potential invasiveness of non-native
1028 marine crustacean decapods and barnacles in the Mediterranean Sea. *Hydrobiologia* **848**:
1029 1997–2009

1030 Stergiou KI, Tsikliras AC (2006) Underrepresentation of regional ecological research output by
1031 bibliometric indices. *Ethics in Science and Environmental Politics* **2006**: 15-17

1032 Stergiou KI, Somarakis S, Triantafyllou G, Tsiaras KP, Giannoulaki M, Petihakis G, Machias A, Tsikliras
1033 AC (2016) Trends in productivity and biomass yields in the Mediterranean Sea Large Marine
1034 Ecosystem during climate change. *Environmental Development* **17**: 57-74.

1035 Tecchio S, Coll M, Christensen V, Company JB, Ramírez-Llodra E, Sardà F (2013) Food web structure
1036 and vulnerability of a deep-sea ecosystem in the NW Mediterranean Sea. *Deep Sea Research*
1037 *Part I: Oceanographic Research Papers* **75**: 1-15.

1038 Then AY, Hoenig JM, Hall NG, Hewitt DA (2015) Evaluating the predictive performance of empirical
1039 estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of*
1040 *Marine Science* **72**: 82-92

1041 Topaloglu B, Alper E (2014) Updated checklist of sponges (Porifera) along the coasts of
1042 Turkey. *Turkish Journal of Zoology* **38**: 665-676

1043 Tsagarakis K, Coll M, Giannoulaki M, Somarakis S, Papaconstantinou C, Machias A (2010) Food web
1044 traits of the North Aegean Sea ecosystem (Eastern Mediterranean) and comparison with other

1045 Mediterranean ecosystems. *Estuarine, Coastal and Shelf Science* **88**(2): 233-248

1046 Tsikliras AC, Stergiou KI (2014) Size at maturity of Mediterranean marine fishes. *Reviews in Fish*
1047 *Biology and Fisheries* **24**: 219-268

1048 Tsikliras AC, Froese R (2019) Maximum Sustainable Yield, p. 108-115. In: Fath B (Ed) Encyclopedia of
1049 Ecology, Second Edition, Volume 1. Elsevier, Oxford

1050 Tsikliras AC, Dimarchopoulou D (2021) Filling in knowledge gaps: length-weight relations of 46
1051 uncommon sharks and rays in the Mediterranean Sea. *Acta Ichthyologica et Piscatoria* **51**: 249-
1052 255

1053 Tsikliras AC, Antonopoulou E, Stergiou KI (2010) Spawning period of Mediterranean marine fishes.
1054 *Reviews in Fish Biology and Fisheries* **20**: 499-538

1055 Tsikliras AC, Dinouli A, Tsiros V-Z, Tsalkou E (2015) The Mediterranean and Black Sea fisheries at risk
1056 from overexploitation. *PLoS ONE* **10**: e0121188

1057 Tsikliras AC, Touloumis K, Pardalou A, Adamidou A, Keramidas I, Orfanidis G, Dimarchopoulou D,
1058 Koutrakis M (2021) Status of 74 non-commercial fish and invertebrate stocks in the Aegean
1059 Sea using abundance and resilience. *Frontiers in Marine Science* **7**: 578601

1060 Tsikliras AC, Coro G, Daskalov G, Gremillet D, Scotti M, Sylaios G (2023) A need for a paradigm shift
1061 from anthropocentric to ecocentric fisheries management. *Frontiers in Marine Science*,
1062 submitted

1063 Ugland K (1976) Population studies on eastern North Atlantic minke whales, Balaenoptera
1064 acutorostrata Lacepede. *Report of International Whaling Commission (Sci. Rep.)* **26**: 366–381.

1065 Ulman A, Yildiz T, Demirel N, Canak O, Yemişken E, Pauly D (2021) The biology and ecology of the
1066 invasive silver-cheeked toadfish (*Lagocephalus sceleratus*), with emphasis on the Eastern
1067 Mediterranean. *NeoBiota* **68**: 145-175.

1068 Vilas D, Coll M, Corrales X, Steenbeek J, Piroddi C, Macias D, Ligas A, Sartor P, Claudet J (2021)
1069 Current and potential contributions of the Gulf of Lion Fisheries Restricted Area to fisheries
1070 sustainability in the NW Mediterranean Sea. *Marine Policy* **123**: 104296

1071 Zaitsev YP (1992) Recent changes in the trophic structure of the Black Sea. *Fisheries Oceanography* **1**:
1072 180-189.

1073 **Table 1.** Criteria for comparing the knowledge level of areas based on the number of studied
1074 biological characteristics and the available number of records for each characteristic.
1075

Literature coverage	Good	Moderate	Poor
Biological characteristics	At least 50% of species have data for 6 to 8 characteristics	At least 50% of species have data for 3 to 8 characteristics	More than 50% of species only have data for 2 or less characteristics, or no data at all

1076

1077

Table 2. List of the most- and least-studied non-fish species in the Adriatic Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec.) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; NE: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-studied								
Malacostraca	Portunidae	<i>Callinectes sapidus</i>	Blue crab	introduced	NE	8/8	68	2 Diet, 1 Fec, 13 L_m , 2 Spawn, 5 M, 1 t_{max} , 19 G, 25
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common cuttlefish	native	LC	8/8	30	2 Diet, 1 Fec, 4 L_m , 1 Spawn, 3 M, 1 t_{max} , 8 G, 10 LWR
Malacostraca	Penaeidae	<i>Parapenaeus longirostris</i>	Deep-water rose shrimp	native	NE	7/8	60	1 Fec, 6 L_m , 1 Spawn, 3 M, 1 t_{max} , 36 G, 12 LWR
Malacostraca	Aristeidae	<i>Aristaeomorpha foliacea</i>	Giant red shrimp	native	NE	7/8	59	2 Diet, 8 L_m , 1 Spawn, 8 M, 2 t_{max} , 28 G, 10 LWR
Malacostraca	Squillidae	<i>Squilla mantis</i>	Spottail mantis shrimp	native	NE	7/8	40	1 Fec, 2 L_m , 3 Spawn, 2 M, 1 t_{max} , 8 G, 23 LWR
Malacostraca	Palinuridae	<i>Palinurus elephas</i>	Common spiny lobster	native	VU	7/8	32	1 Fec, 7 L_m , 1 Spawn, 2 M, 1 t_{max} , 12 G, 8 LWR
Least-studied								
Reptilia	Dermochelyidae	<i>Dermochelys coriacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m , 7 G, 10 LWR
Bivalvia	Pinnidae	<i>Pinna nobilis</i>	Noble pen shell	native	CR	2/8	12	6 t_{max} , 6 G
Aves	Pelecanidae	<i>Pelecanus crispus</i>	Dalmatian pelican	native	NT	0/8	0	-
Aves	Podicipedidae	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	-

Table 3. List of the most- and least-studied non-fish species in the Aegean Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; NE: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec	No. of records per characteristic
Most-studied								
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common cuttlefish	native	LC	8/8	30	2 Diet, 1 Fec, 4 L_m , 1 Spawn, 3 M, 1 t_{max}
Malacostraca	Penaeidae	<i>Parapenaeus longirostris</i>	Deep-water rose	native	NE	7/8	60	1 Fec, 6 L_m , 1 Spawn, 3 M, 1 t_{max} , 36 G,
Malacostraca	Aristeidae	<i>Aristaeomorpha foliacea</i>	Giant red shrimp	native	NE	7/8	59	2 Diet, 8 L_m , 1 Spawn, 8 M, 2 t_{max} , 28 G,
Malacostraca	Squillidae	<i>Squilla mantis</i>	Spottail mantis	native	NE	7/8	40	1 Fec, 2 L_m , 3 Spawn, 2 M, 1 t_{max} , 8 G, 23
Malacostraca	Palinuridae	<i>Palinurus elephas</i>	Common spiny	native	VU	7/8	32	1 Fec, 7 L_m , 1 Spawn, 2 M, 1 t_{max} , 12 G, 8
Least-studied								
Reptilia	Dermochelyi	<i>Dermochelys coriacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m , 7 G, 10 LWR
Mammalia	Phocidae	<i>Monachus monachus</i>	Mediterranean monk	native	EN	1/8	1	1 Diet
Anthozoa	Pennatulidae	<i>Crassophyllum</i>		native	EN	0/8	0	-
Anthozoa	Gorgoniidae	<i>Eunicella verrucosa</i>	Pink sea fan	native	VU	0/8	0	-
Anthozoa	Actiniidae	<i>Paranemonia</i>		native	EN	0/8	0	-
Aves	Podicipedida	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	-
Aves	Procellariida	<i>Puffinus yelkouan</i>	Levantine shearwater	native	VU	0/8	0	-

Table 4. List of the most- and least-studied non-fish species in the Baltic Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; N.E.: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-studied								
-								
Least-studied								
Mammalia	Physeteridae	<i>Physeter macrocephalus</i>	Sperm whale	native	VU	4/8	34	15 Diet, 2 L_m , 3 G, 14 LWR
Reptilia	Dermochelyidae	<i>Dermochelys coriacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m , 7 G, 10 LWR
Mammalia	Mustelidae	<i>Lutra lutra</i>	Eurasian river otter	native	NT	1/8	1	1 Diet
Aves	Anatidae	<i>Clangula hyemalis</i>	Long-tailed duck	native	VU	0/8	0	-
Aves	Anatidae	<i>Melanitta fusca</i>	Velvet scoter	native	VU	0/8	0	-
Aves	Podicipedidae	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	-
Aves	Anatidae	<i>Polysticta stelleri</i>	Steller's eider	native	VU	0/8	0	-
Aves	Anatidae	<i>Somateria mollissima</i>	Common eider	native	NT	0/8	0	-

Table 5. List of the most- and least-studied non-fish species in the Bay of Biscay/Celtic Sea/Iberian Coast based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec.) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR)). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; N.E.: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-Studied								
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common cuttlefish	native	LC	8/8	30	2 Diet. 1 Fec. 4 L_m . 1 Spawn. 3 M. 1 t_{max} . 8 G. 10 LWR
Reptilia	Cheloniidae	<i>Chelonia mydas</i>	Green sea turtle	native	EN	7/8	79	12 Diet. 2 Fec. 2 L_m . 33 Spawn. 2 M. 23 G. 5 LWR
Malacostraca	Aristeidae	<i>Aristaeomorpha foliacea</i>	Giant red shrimp	native	NE	7/8	59	2 Diet. 8 L_m . 1 Spawn. 8 M. 2 t_{max} . 28 G. 10 LWR
Malacostraca	Sauillidae	<i>Sauilla mantis</i>	Spottail mantis	native	NE	7/8	40	1 Fec. 2 L_m . 3 Spawn. 2 M. 1 t_{max} . 8 G. 23 LWR
Least-studied								
Reptilia	Cheloniidae	<i>Eretmochelvs imbricata</i>	Hawksbill turtle	native	CR	6/8	74	4 Diet. 10 Fec. 7 L_m . 39 Spawn. 10 G. 4 LWR
Reptilia	Cheloniidae	<i>Caretta caretta</i>	Loggerhead turtle	native	VU	6/8	38	4 Diet. 10 Fec. 1 L_m . 9 Spawn. 12 G. 2 LWR
Reptilia	Cheloniidae	<i>Leidochelvs kempii</i>	Kemp's ridley	native	CR	5/8	28	7 Diet. 2 L_m . 2 M. 15 G. 2 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera borealis</i>	Sei whale	native	EN	4/8	10	1 Diet. 2 L_m . 1 t_{max} . 6 LWR
Mammalia	Balaenidae	<i>Eubalaena alacialis</i>	North Atlantic	native	CR	4/8	6	2 L_m . 1 t_{max} . 1 G. 2 LWR
Reptilia	Dermochelvidae	<i>Dermochelvs coriacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m . 7 G. 10 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera physalus</i>	Fin whale	native	VU	3/8	16	2 Diet. 2 G. 12 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera musculus</i>	Blue whale	native	EN	3/8	12	1 Diet. 2 G. 9 LWR
Mammalia	Phocidae	<i>Cystophora cristata</i>	Hooded seal	native	VU	2/8	4	2 G. 2 LWR
Aves	Procellariidae	<i>Pterodroma feae</i>	Cape Verde petrel	native	NT	0/8	0	-

Table 6. List of the most- and least-studied non-fish species in the Black Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; N.E.: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-studied								
Malacostraca	Portunidae	<i>Callinectes sapidus</i>	Blue crab	Introduced	NE	8/8	68	2 Diet, 1 Fec, 13 L_m , 2 Spawn, 5 M, 1 t_{max} , 19 G, 25 LWR
Least-studied								
Reptilia	Cheloniidae	<i>Caretta caretta</i>	Loggerhead turtle	native	VU	6/8	38	4 Diet, 10 Fec, 1 L_m , 9 Spawn, 12 G, 2 LWR
Mammalia	Phocidae	<i>Monachus monachus</i>	Mediterranean	native	EN	1/8	1	1 Diet
Aves	Anatidae	<i>Melanitta fusca</i>	Velvet scoter	native	VU	0/8	0	-
Aves	Podicipedidae	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	-
Aves	Procellariidae	<i>Puffinus yelkouan</i>	Levantine	native	VU	0/8	0	-

Table 7. List of the most- and least-studied non-fish species in the Levantine Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec.) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; NE: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common_name	Status	IUCN	No. Char	No. Rec.	No. of records per characteristic
Most-studied								
Malacostraca	Portunidae	<i>Callinectes sanidus</i>	Blue crab	introduced	NF	8/8	68	2 Diet. 1 Fec. 13 L_m . 2 Spawn. 5 M. 1 t_{max} . 19 G. 25 LWR
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common	native	LC	8/8	30	2 Diet. 1 Fec. 4 L_m . 1 Spawn. 3 M. 1 t_{max} . 8 G. 10 LWR
Malacostraca	Penaeidae	<i>Metapenaeus monoceros</i>	Speckled	introduced	NE	7/8	106	2 Fec. 10 L_m . 8 Spawn. 31 M. 2 t_{max} . 34 G. 19 LWR
Reptilia	Cheloniidae	<i>Chelonia mydas</i>	Green sea turtle	native	EN	7/8	79	12 Diet. 2 Fec. 2 L_m . 33 Spawn. 2 M. 23 G. 5 LWR
Malacostraca	Penaeidae	<i>Parapenaeus lonairostris</i>	Deep-water	native	NE	7/8	60	1 Fec. 6 L_m . 1 Spawn. 3 M.
Malacostraca	Aristeidae	<i>Aristaeomorpha foliacea</i>	Giant red	native	NE	7/8	59	2 Diet. 8 L_m . 1 Spawn. 8 M.
Malacostraca	Sauillidae	<i>Sauilla mantis</i>	Spottail mantis	native	NE	7/8	40	1 Fec. 2 L_m . 3 Spawn. 2 M.
Malacostraca	Palinuridae	<i>Palinurus elephas</i>	Common spiny	native	VU	7/8	32	1 Fec. 7 L_m . 1 Spawn. 2 M.
Least-studied								
Reptilia	Cheloniidae	<i>Caretta caretta</i>	Loggerhead	native	VU	6/8	38	4 Diet. 10 Fec. 1 L_m . 9 Spawn. 12 G. 2 LWR
Mammalia	Delphinidae	<i>Pseudorca crassidens</i>	False killer	native	NT	6/8	26	1 Diet. 2 L_m . 1 Spawn. 2 t_{max} .
Mammalia	Physeteridae	<i>Physeter macrocephalus</i>	Sperm whale	native	VU	4/8	34	15 Diet. 2 L_m . 3 G. 14 LWR
Reptilia	Dermochelidae	<i>Dermochelys coriacea</i>	Leatherback	native	VU	3/8	19	2 L_m . 7 G. 10 LWR
Bivalvia	Pinnidae	<i>Pinna nobilis</i>	Noble pen shell	native	CR	2/8	12	6 t_{max} . 6 G
Mammalia	Phocidae	<i>Monachus monachus</i>	Mediterranean	native	EN	1/8	1	1 Diet
Aves	Laridae	<i>Larus armenicus</i>	Armenian gull	native	NT	0/8	0	-
Aves	Procellariidae	<i>Puffinus velkouan</i>	Levantine	native	VU	0/8	0	-

Table 8. List of the most- and least-studied non-fish species in the North Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced) and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; NE: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied (5 species, 5 Families, 4 Classes).

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-studied								
Malacostraca	Portunidae	<i>Callinectes sanidus</i>	Blue crab	Introduced	NF	8/8	68	2 Diet. 1 Fec. 13 L_m . 2 Spawn. 5 M. 1 t_{max} . 19 G. 25 LWR
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common cuttlefish	native	LC	8/8	30	2 Diet. 1 Fec. 4 L_m . 1 Spawn. 3 M. 1 t_{max} . 8 G.
Reptilia	Cheloniidae	<i>Chelonia mydas</i>	Green sea turtle	native	EN	7/8	79	12 Diet. 2 Fec. 2 L_m . 33 Spawn. 2 M. 23 G. 5 LWR
Bivalvia	Veneridae	<i>Ruditapes philippinarum</i>	Japanese carpet shell	introduced	NE	7/8	62	1 Fec. 4 L_m . 4 Spawn. 2 M. 3 t_{max} . 5 G. 43 LWR
Malacostraca	Palinuridae	<i>Palinurus elephas</i>	Common spiny	native	VU	7/8	32	1 Fec. 7 L_m . 1 Spawn. 2 M. 1 t_{max} . 12 G. 8 LWR
Least-studied								
Reptilia	Cheloniidae	<i>Eretmochelvs imbricata</i>	Hawksbill turtle	native	CR	6/8	74	4 Diet. 10 Fec. 7 L_m . 39 Spawn. 10 G. 4 LWR
Reptilia	Cheloniidae	<i>Caretta caretta</i>	Loggerhead turtle	native	VU	6/8	38	4 Diet. 10 Fec. 1 L_m . 9 Spawn. 12 G. 2 LWR
Reptilia	Cheloniidae	<i>Lenidochelvs kempii</i>	Kemp's ridley turtle	native	CR	5/8	28	7 Diet. 2 L_m . 2 M. 15 G. 2 LWR
Mammalia	Phvseteridae	<i>Phvseter macrocephalus</i>	Sperm whale	native	VU	4/8	34	15 Diet. 2 L_m . 3 G. 14 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera borealis</i>	Sei whale	native	EN	4/8	10	1 Diet. 2 L_m . 1 t_{max} . 6 LWR
Mammalia	Balaenidae	<i>Fuhalaena alacialis</i>	North Atlantic right	native	CR	4/8	6	2 L_m . 1 t_{max} . 1 G. 2 LWR
Reptilia	Dermochelvidae	<i>Dermochelvs cariacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m . 7 G. 10 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera physalus</i>	Fin whale	native	VU	3/8	16	2 Diet. 2 G. 12 LWR
Mammalia	Balaenopteridae	<i>Balaenoptera musculus</i>	Blue whale	native	FN	3/8	12	1 Diet. 2 G. 9 LWR
Aves	Laridae	<i>Rissa tridactyla</i>	Black-legged	native	VU	2/8	32	2 Diet. 30 G

Mammalia	Odobenidae	<i>Odobenus rosmarus</i>	Walrus	native	VU	2/8	11	9 G. 2 I WR
Mammalia	Phocidae	<i>Cystophora cristata</i>	Hooded seal	native	VU	2/8	4	2 G. 2 LWR
Mammalia	Ziphiidae	<i>Hyperoodon amullatus</i>	North Atlantic	native	NT	2/8	3	2 Diet. 1 I WR
Aves	Alcidae	<i>Fratercula arctica</i>	Atlantic puffin	native	VU	1/8	87	87 G
Aves	Procellariidae	<i>Puffinus ariseus</i>	Sooty shearwater	native	NT	1/8	2	2 G
Aves	Scolopacidae	<i>Calidris canutus</i>	Red knot	native	NT	0/8	0	
Aves	Anatidae	<i>Melanitta fusca</i>	Velvet scoter	native	VU	0/8	0	
Anthozoa	Edwardsiidae	<i>Nematostella vectensis</i>	Starlet anemone	introduced	VU	0/8	0	
Aves	Podicipedidae	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	
Aves	Anatidae	<i>Polysticta stelleri</i>	Steller's eider	native	VU	0/8	0	
Aves	Procellariidae	<i>Puffinus mauretanicus</i>	Balearic shearwater	native	CR	0/8	0	
Aves	Anatidae	<i>Somateria mollissima</i>	Common eider	native	NT	0/8	0	

Table 9. List of the most- and least-studied non-fish species in the western Mediterranean Sea based on the number of studied biological characteristics (No. Char.) and the number of records (No. Rec.) per characteristic (feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR). The status of the species in the area (Status) as origin categories (native, endemic, introduced), and the status as IUCN Red List categories (LC: least concern; EN: endangered; DD: data deficient; NE: not evaluated; NT: near threatened; VU: vulnerable; CR: critically endangered) are also included. Only species with information on at least 7 biological characteristics and at least 30 records available are considered as well studied.

Class	Family	Scientific name	Common name	Status	IUCN	No. Char.	No. Rec.	No. of records per characteristic
Most-studied								
Cephalopoda	Sepiidae	<i>Sepia officinalis</i>	Common cuttlefish	native	LC	8/8	30	2 Diet, 1 Fec, 4 L_m , 1 Spawn, 3 M, 1 t_{max} , 8 G, 10 LWR
Reptilia	Cheloniidae	<i>Chelonia mydas</i>	Green sea turtle	native	EN	7/8	79	12 Diet, 2 Fec, 2 L_m , 33 Spawn, 2 M, 23 G, 5 LWR
Malacostraca	Penaeidae	<i>Parapenaeus ionairostris</i>	Deep-water rose	native	NE	7/8	60	1 Fec, 6 L_m , 1 Spawn, 3 M, 1 t_{max} , 36 G, 12 LWR
Malacostraca	Aristeidae	<i>Aristaeomorpha foliacea</i>	Giant red shrimp	native	NE	7/8	59	2 Diet, 8 L_m , 1 Spawn, 8 M, 2 t_{max} , 28 G, 10 LWR
Malacostraca	Squillaidae	<i>Squilla mantis</i>	Spottail mantis	native	NE	7/8	40	1 Fec, 2 L_m , 3 Spawn, 2 M, 1 t_{max} , 8 G, 23 LWR
Malacostraca	Palinuridae	<i>Palinurus elephas</i>	Common spiny lobster	native	VU	7/8	32	1 Fec, 7 L_m , 1 Spawn, 2 M, 1 t_{max} , 12 G, 8 LWR
Least-studied								
Reptilia	Cheloniidae	<i>Fretmochelvs imbricata</i>	Hawkshell turtle	native	CR	6/8	74	4 Diet, 10 Fec, 7 L_m , 39 Spawn, 10 G, 4 LWR
Reptilia	Cheloniidae	<i>Caretta caretta</i>	Loggerhead turtle	native	VU	6/8	38	4 Diet, 10 Fec, 1 L_m , 9 Spawn, 12 G, 2 LWR
Reptilia	Cheloniidae	<i>Leidochelvs kempi</i>	Kemp's ridley turtle	native	CR	5/8	28	7 Diet, 2 L_m , 2 M, 15 G, 2 LWR
Reptilia	Dermochelvidae	<i>Dermochelvs coriacea</i>	Leatherback turtle	native	VU	3/8	19	2 L_m , 7 G, 10 LWR
Reptilia	Cheloniidae	<i>Leidochelvs olivacea</i>	Olive ridley turtle	native	VU	3/8	7	1 L_m , 3 G, 3 LWR
Bivalvia	Pinnidae	<i>Pinna nobilis</i>	Noble pen shell	native	CR	2/8	12	6 t_{max} , 6 G
Aves	Laridae	<i>Larus audouinii</i>	Audouin's gull	native	VU	1/8	5	5 G

Aves	Procellariidae	<i>Puffinus ariseus</i>	Sooty shearwater	native	NT	1/8	2	2 G
Aves	Anatidae	<i>Melanitta fusca</i>	Velvet scoter	native	VU	0/8	0	-
Aves	Podicipedidae	<i>Podiceps auritus</i>	Horned grebe	native	VU	0/8	0	-
Aves	Procellariidae	<i>Puffinus mauretanicus</i>	Balearic shearwater	native	CR	0/8	0	-
Aves	Procellariidae	<i>Puffinus velkouan</i>	Levantine	native	VU	0/8	0	-
Aves	Anatidae	<i>Somateria mollissima</i>	Common eider	native	NT	0/8	0	-

Table 10. Comparison regarding the status of the studied groups in European Seas and adjacent waters.

Species groups	Adriatic		Aegean		Baltic Sea		Bay of Biscay Celtic Sea Iberian Coast		Black Sea		Levantine Sea		North Sea		Western Mediterranean Sea	
	N	Status	N	Status	N	Status	N	Status	N	Status	N	Status	N	Status	N	Status
Cnidarians	100	Poor	72	Poor	74	Poor	50	Poor	8	Poor	19	Poor	149	Poor	82	Poor
Sponges	4	Poor	1	Poor	8	Poor	40	Poor	-	-	1	Poor	22	Poor	7	Poor
Echinoderms	68	Poor	67	Poor	35	Poor	19	Poor	1	Poor	8	Poor	58	Poor	16	Poor
Molluscs	86	Poor	90	Poor	205	Poor	120	Poor	51	Poor	258	Poor	314	Poor	219	Poor
Crustaceans	95	Poor	121	Poor	250	Poor	113	Poor	43	Poor	88	Poor	455	Poor	119	Poor
Seabirds	5	Poor	2	Poor	20	Poor	4	Poor	7	Poor	12	Poor	54	Poor	18	Poor
Sea turtles	1	Moderate	1	Moderate	1	Moderate	5	Good	1	Good	3	Good	5	Good	6	Good
Marine mammals	-	-	1	Poor	13	Moderate	11	Moderate	5	Moderate	12	Moderate	27	Moderate	3	Moderate
Total number of species	359		355		606		362		116		401		1084		470	
Species with 1 characteristic	48		42		112		65		19		77		170		79	
Species with 8 characteristics	2		1		1		1		1		2		3		1	

	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
LWR	97	27	77	22	140	23	112	31	41	35	136	34	216	20	136	29
Growth	52	14	39	11	46	8	53	15	30	26	83	21	112	10	80	17
Mortality	16	4	11	3	11	2	11	3	7	6	22	5	24	2	22	5
Lifespan	22	6	13	4	29	5	21	6	9	8	33	8	48	4	26	6
Maturity	33	9	19	5	24	4	28	8	14	12	45	11	49	5	42	9
Spawning	22	6	17	5	15	2	22	6	9	8	38	9	36	3	29	6
Fecundity	11	3	7	2	7	1	10	3	6	5	20	5	18	2	16	3
Diet	6	2	5	1	29	5	24	7	9	8	23	6	55	5	15	3

Figure legends

Figure 1. Map of the marine ecosystems that were reviewed.

Figure 2. Species counts by number of biological characteristics (0 to 8) studied for non-fish marine organisms in the Adriatic Sea.

Figure 3. (top) Percentage of non-fish species in the Adriatic Sea, Aegean Sea, Black Sea, Levantine Sea, Baltic Sea, Bay of Biscay/Celtic Sea/Iberian Coast, North Sea and Western Mediterranean Sea with (dark color) and without (light color) information on biological characteristics: feeding preferences (Diet), fecundity (Fec), maturity (L_m), spawning (Spawn), mortality (M), lifespan (t_{max}), growth (G), and length-weight relationships (LWR), (bottom) the same percentages calculated for species under IUCN Red List categories near threatened (NT), vulnerable (VU), endangered (EN) and critically endangered (CR).