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European marine biodiversity inventory and taxonomic resources: state of the art and gaps in knowledge

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ABSTRACT: The European Register of Marine Species (ERMS) project has compiled a list of marine species in Europe and a bibliography of marine species identification guides. ERMS has also surveyed species identification and taxonomic expertise, and the state of marine species collections in Europe. A total of 29 713 species-level taxa were catalogued from European seas. Overall, 90% of the taxon checklists were satisfactory, but non-halacarid Acarina, diatoms, lichens and cyanobacteria were not included, and geographical coverage of the European seas was incomplete for Rotifera and Brachiopoda. Lists that would benefit from further input include (1) those that have not yet been checked by an expert on European fauna, namely lists of the non-epicarid Isopoda, Cephalochordata, Appendicularia, Hemichordata, Hirudinea, Gnathostomulida, Ctenophora and Placozoa; (2) preliminary lists, including some of the above and lists of protists; and (3) lists with many species but which have been reviewed by only a few experts. These gaps are now being addressed in an online version of ERMS (www.marbef.org/data/erms.php). The bibliography of 842 identification guides shows that there are fewer guides for southern European seas, although they contain more species, than for those in northern Europe. Adequate guides for all of Europe's seas exist only for fishes. New guides are especially needed for the species-rich, but small-sized taxa, such as polychaete, oligochaete and turbellarian worms, and harpacticoid copepods. A database of >600 experts (individuals who stated themselves to be experts) and a subset of these recognised by their peers as being taxonomic experts was established. While there were generally more experts for taxa with a large number of species, there was no correlation between the number of taxonomists and the number of species per taxon; some taxa with thousands of species are studied by relatively few taxonomists. Such gaps in marine biodiversity knowledge and resources must be addressed by funding the production of additional species identification guides.

KEY WORDS: Database · Species · Taxonomy · Identification

INTRODUCTION

The unprecedented rate at which human activities around the world are causing species extinction is alarming (World Conservation Monitoring Centre 1992, Kirchner & Weil 2000). The patterns in the extinction of large predatory species on land are now occurring in oceans (Carlton 1993, Malakoff 1997, Casey & Myers 1998, Carlton et al. 1999, Roberts & Hawkins 1999, Baum et al. 2003, Myers & Worm 2003, 2005, Baum & Myers 2004). In addition, marine habitat degradation is reducing available living space and could lead to the extinction of other species. That extinctions are occurring before even half of the world's species have been described (May 1992, Barnes 1998, Gordon 2001) or named is evidence of a global information crisis. Such a gap in our knowledge of the world's biodiversity is thus a critical weakness in the world's 'knowledge

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economy'. The global economy is directly (e.g. food, materials) and indirectly (ecosystem services) dependent on biodiversity (Costanza et al. 1997, Costello 2000a, 2001). Considering that fisheries have never been so heavily harvested and that aquaculture is rapidly growing, one may expect concomitant growth in understanding what biodiversity exists in the oceans. However, there is no evidence of increased resources to identify and inventory marine biodiversity. Indeed, members of the scientific community have asserted that expertise in the form of taxonomists able to identify, describe and classify species is declining (e.g. Boero 2001, Giangrande 2003). However, these assertions are anecdotal and unsubstantiated. Where data have been provided, such as for Chile (Simonetti 1997), South Africa (Gibbons et al. 1999), the USA (Winston 1988) and globally (Diversitas 2000), they show that more taxonomists are needed to address the mismatch between the number of species in certain taxa and the corresponding number of taxonomists, but do not demonstrate a decline in the number of taxonomists. On the contrary, in Latin America, notably in Brazil, there has been increased employment and training in taxonomy since the 1980s (Carvalho et al. 2005).

Clearly, there have been insufficient taxonomic resources to describe the earth's present species, but there is no quantitative evidence of a decline in these resources in the available literature. Indeed, publications on marine biodiversity have been increasing in recent decades (Moustakas & Karakassis 2005). Because a taxonomist's reputation will grow during his/her lifetime, the fact that some taxonomic experts may be retired or nearing retirement may be more of a reflection of the fact that they have made lifetime contributions to the science than of the absence of successors; younger scientists have not had the time to build up a widely recognised reputation and thus may be overlooked when considering taxonomic expertise. Winston (1988) cites a study of taxonomists in the USA, which determined an average age of 44 yr, but felt it was biased by including students. Her 'impression' was that the average age was closer to 54 yr.

In addition to the age and number of taxonomic experts, other measures of taxonomic resources include the availability of organised species inventories, the currency of species identification guides and the condition of specimen collections. Fundamental to the management of any resource is an inventory of its parts and their abundance. The inventory of all species occurring in European seas (Costello et al. 2001) is the largest all-taxon marine species inventory available. This 'European Register of Marine Species' (ERMS) provides a means to indicate in which taxa most new species remain to be discovered; these findings may also be applicable globally. In the present paper, we compare the number of species per taxon in ERMS (Costello et al. 2001) to the available expertise.

The most basic requirement for people studying and working on aspects of biodiversity is the availability of species identification guides. Without such guides it is impractical for most people to know or study a group of species and consequently the biology, ecology and potential economic value of these species will remain unknown. People need rapid access to species identification guides, and funding agencies and publishers must know which guides are most urgently needed to fill taxonomic and geographic gaps. Thus, we analysed the taxonomic and geographic coverage of identification guides for marine species in Europe from a checklist we had previously compiled (Bouchet & Marmayou 2001).

The gathering of data in a standardised format facilitates gap analysis (e.g. Kelly & Costello 1996, Moustakas & Karakassis in press). Thus, in association with producing ERMS, we compiled (1) a database of expertise (including expert's age), (2) a catalogue of marine species identification guides (Bouchet & Marmayou 2001) and (3) a survey of museum collections (Legakis & Emblow 2003). Results of the survey of marine species collections have previously been reported (Legakis & Emblow 2003), but key points are also discussed in the present paper, to provide a more comprehensive review of the state of marine taxonomic resources in Europe.

MATERIALS AND METHODS

ERMS was a 2 yr project involving 22 organisations and 170 scientists (Costello 2000b). Groups of scientists within the project addressed the work described below, and others focused on communication with the scientific community and related organisations, including potential end-users.

Species lists. The ERMS project included species occurring from the strandline and 'splash zone' of the intertidal (littoral) through the subtidal (sublittoral) to the deep sea, including brackish waters to 0.5 salinity. The northern parts of the Baltic Sea are more freshwater than brackish, and it was left to the discretion of list compilers whether to include these species. The study area defined broadly as 'European seas' followed the database of European Mollusca (CLEMAM) (Fig. 1), and thus ranged from the North Pole along the east coast of Greenland to Iceland, along the mid-Atlantic ridge, across the 26° parallel to the coast of Africa, and into the Mediterranean and Black Seas. Inclusion of the islands of Madeira, Azores and Canaries brought sub-tropical species into ERMS; these had generally been excluded from previous reviews of European marine fauna and flora. Only taxonomically named species, and species whose occurrence

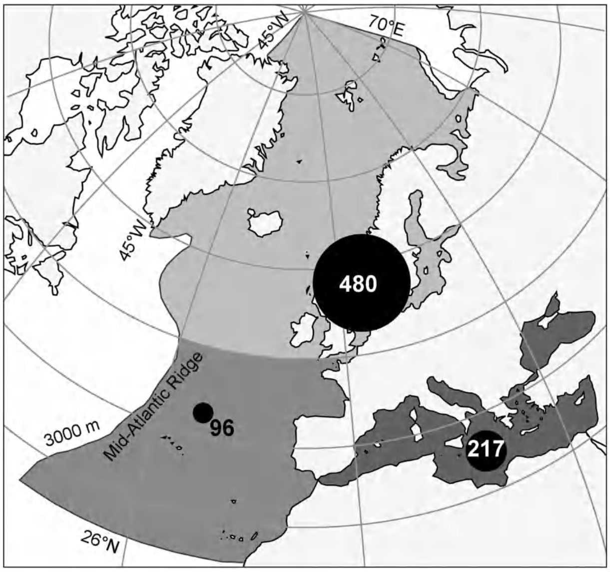

Fig. 1. Geographic scope of the European Register of Marine Species (ERMS) project. Numbers of identification guides for each of the 3 geographical areas are shown. In addition, 10 identification guides deal specifically with the NE Atlantic deep sea area

in the ERMS area had been previously published, were included. Synonyms and other names for a species were included in some instances. Saltmarsh angiosperm plants were excluded, as these are generally included in terrestrial plant inventories. Bacteria (Eubacteria and Archaea) were also excluded from the project. Where recognised, comments on the weaknesses of lists are made in the preface to that list (Costello et al. 2001). These comments, and criteria developed by M. J. Costello, were used to score the status of each list. The criteria were based on the source of information, expertise of the list compiler and involvement of >1 expertin compiling the list (Table 1).

Identification guides. Our review included identification guides with illustrations and keys to the larger metazoan groups and excluded (1) specialised literature dealing with a single genus or family; (2) non-illustrated checklists; (3) old literature that may be essential to a specialist, but is unobtainable to a general marine biologist; and (4) protists and microbia. It compiled all marine titles in major series (see Table 4), even if outdated or hard to obtain. Popular and semi-popular guides were listed separately, but they have not been comprehensively covered or included in the present analysis.

Table 1. Criteria used to indicate the quality of the species lists compiled during the ERMS (European Register of Marine Species) project, and the numbers of lists falling into these categories. For further information on scoring see 'Materials and methods'

Score	Criteria	No. of lists
+	Preliminary list, known to be or likely to be incomplete	4
++	Compiled from recent authoritative literature	7
+++	Compiled by expert in the group	28
++++	Checked by additional expert in the group	43
+++++	Checked by several experts in the group	31
	Total	113

Expertise. ERMS project participants supplied contact details for marine biologists from either their geographic or their taxonomic area. Lists of marine biologists from Britain, Germany, Greece, Italy, Ireland, Scandinavia, Spain and the western and eastern Mediterranean, as well as a list of European experts on algae, were received. In addition, lists of contact details for other marine biologists were obtained from the Internet. The focus of the project was on persons with expertise in marine species from countries of the European Union and the European Economic Area, so expertise in Eastern Europe has not been assessed. An initial list of 1200 people from 38 countries (29 European) with expertise in European marine species was compiled by the project. These people passed the list and an accompanying questionnaire on to an additional 160 colleagues who replied. Of the total of 614 respondents, 590 gave permission for their name to be entered in the database (i.e. they were still active and available for such work).

Each person in the database was asked to verify their contact details and provide their year of birth, the taxonomic groups in which they had expertise, their level of expertise, the geographic coverage of their expertise and their professional status. Requests were sent in the form of a standard questionnaire, with a summary of the project. A web-based submission form was also put on the web, and a general call for submissions made to various email discussion groups.

Because it proved difficult to set universal criteria to define a taxonomist, 2 registers were established: (1) persons with self-declared expertise in the identification of marine species in Europe and (2) peer-selected specialist or taxonomic experts in certain species groups. The persons producing lists of species for the project identified the latter 'taxonomic experts'.

RESULTS

Species lists

A total of 29 713 species-level taxa were catalogued from European seas, with the quality of information differing for different taxa. It was not expected that all

Table 2. Species lists in ERMS, the persons who compiled them and assisted in their compilation, the number of species per group and an indicator of how complete a list is of the described species (from Costello et al. 2001). C = confident of reasonable coverage of all European seas, including the Arctic, deep sea and Black Sea. See Table 1 for the status scoring system

Species group	Compiler (assisted by)	No. of species	Status	
Crytophytes	S. Brandt	14	+	
Euglenids Heterotrophic euglenoids	S. Brandt	26	+	
Haptophytes	S. Brandt	36	+	
Prasinophytes	S. Brandt	24	+	
Apicomplexa (free-living species)	S. Brandt	3	++	
Dinoflagellates	S. Brandt (M. Elbrächter)	718	++	
Kathablepharids	S. Brandt	2	++	
Placozoa	J. van der Land	2	++	
Ctenophora	J. van der Land	38	++	
Rotifera	M. O'Reilly	139	++	
Hirudinea	J. van der Land	36	++	
Thermosbaenacea	J. van der Land	2	++	
Isopoda excluding Epicaridea	J. van der Land	605	++	
Brachiopoda	C. Howson	18	++	
Appendicularia	J. van der Land	53	++	
Cephalochordata	J. van der Land	2	++	
Ciliates				
Aloricate oligotrichs	S. Agatha	82	+++	
Chonotricha	A. W. Jankowski	37	+++	
Folliculinids	M. Mulisch	30	+++	
Rhynchodida	A. W. Jankowski	42	+++	
Amoebae — testate	R. Meisterfeld	97	+++	
Apusomonads	S. Brandt	3	+++	
Choanoflagellates	S. Brandt	98	+++	
Euglenids — kinetoplastids	S. Brandt	13	+++	
Bicosoecids	S. Brandt	17	+++	
Labyrinthulids	M. Dick, S. Brandt	10	+++	
Thaustrochytrids	M. Dick, S. Brandt	15	+++	
Stramenopiles incertae sedis	S. Brandt	4	+++	
Thaumatomonads	S. Brandt	17	+++	
Protista incertae sedis (heterotrophic species)	S. Brandt	40	+++	
Mesozoa	J. Hallan, J. van der Land	36	+++	
Gnathostomulida	J. van der Land	25	+++	
Euphausiacea	J. van der Land	41	+++	
Hemichordata	J. van der Land	17	+++	
Fungi	N. Clipson, E. Landy, M. Otte (G. Bremer, G. Jones)	318	++++	
Amoebae — naked	A. Rogerson, A. Goodkov	74	++++	
Xenophyophora	O. Tendal, J. van der Land	20	++++	
Porifera	R. W. M. van Soest (N. Boury-Esnault)	1640	++++	
Siphonophora	G. M. Mapstone, J. van der Land (P. R. Pugh)	105	++++	
Chilopoda	A. Minelli	6	++++	
Diplopoda	A. Minelli	2	++++	
Insecta	A. Legakis	19	++++	
Phoronida	C. Emig	9	+++++	
Echiura	J. van der Land (J. I. Saiz-Salinas)	19	+++	C
Sipuncula	J. van der Land (J. I. Saiz-Salinas)	44	+++	C
Pentastomida	J. van der Land	2	+++	C
Stomatopoda	J. van der Land (P. Noel)	22	+++	C
Foraminifera	O. Gross	1167	++++	C
Actiniaria	J. H. den Hartog, J. van der Land (J. Ryland)	243	++++	C
Antipatharia	D. M. Opresko, J. van der Land	28	++++	C
Hydrozoa	W. Vervoort, S. D. Cairns, J. van der Land, P. Schuchert	684	++++	C
Gastrotrichia	J. L. D'Hondt, J. Van der Land	240	++++	C
Cephalorhyncha (=Loricifera, Priapulida, Kinorhyncha, Nematomorpha)	J. van der Land, B. Neuhaus	52	++++	C
Nematoda				
Free-living	G. De Smet, M. Vincx, A. Vanreusel, S. Vanhove, J. Vanaverbeke, M. Steyaert (F. Riemann)	1625	++++	C
Parasitic	D. Gibson (F. Moravec, H.-P. Fagerholm)	212	++++	C
Polychaeta	G. Bellan (C. Arvanitidis, J.-C. Dauvin, F. Gentil, G. Bachelet, H. Hansson, R. Barnick, D. Fiege, M. E. Petersen, T. Brattegard, T. Holthe)	1848	++++	C
Tardigrada	J. van der Land	76	++++	C
Pycnogonida	F. Krapp, J. Van der Land (J. Stock, R. Bamber, C. A. Child)	146	++++	C
Remipedia	G. Boxshall	1	++++	C
Branchiura	G. Boxshall	2	++++	C
Cladocera — Branchiopoda	G. Boxshall	9	++++	C
Mystacocarida	G. Boxshall	2	++++	C
Copepoda				
Calanoida	G. Boxshall	649	++++	C
Cyclopoida	G. Boxshall	177	++++	C
Harpacticoida	R. Huys	1357	++++	C
Misophrioida	G. Boxshall	16	++++	C
Monstrilloida	G. Boxshall	33	++++	C
Mormonilloida	G. Boxshall	2	++++	C
Platycopioida	G. Boxshall	3	++++	C
Poecilostomatoida	G. Boxshall (M. O'Reilly, D. Zavodnik)	353	++++	C
Siphonostomatoida	G. Boxshall	354	++++	C
Tantulocarida	G. Boxshall	13	++++	C
Cirripedia				
Non-parasitic Thoracica	A. Southward	107	++++	C
Parasitic Ascothoracida	G. Boxshall	10	++++	C
Parasitic Rhizocephala	G. Boxshall	28	++++	C

Table 2 (continued)

Species group	Compiler (assisted by)	No. of species	Status
Decapoda	M. Türkay	672	++++ C
Mysidacea	J. van der Land, T. Brattegard	198	++++ C
Isopoda, Epicaridea, Bopyridae	J. C. Markham	54	++++ C
Insecta			
Chironomidae	D. Murray	15	++++ C
Chaetognatha	H. Kapp, J. Van der Land	42	++++ C
Thaliacea	J. van der Land, R. Van Soest	35	++++ C
Macroalgae of Rhodophycota, Phaeophycota, Chlorophycota, and 2 genera of Xanthophycota	M. D. Guiry (G. Furnari, F. Rindi, E. Nic Dhonncha, S. Lawson)	1702	+++++ C
Seagrass	M. D. Guiry	5	+++++ C
Myxozoa	E. Karlsbakk	230	+++++ C
Octocorallia			
Pennatulacea	G. C. Williams, J. van der Land (K. Riemann-Zürneck)	37	+++++ C
Others	L. van Ofwegen, M. Grasshoff, J. van der Land	92	+++++ C
Scleractinia	S. D. Cairns, B. W. Hoeksema, J. van der Land (H. Zibrowius)	86	+++++ C
Cubozoa	P. Cornelius	1	+++++ C
Scyphozoa	P. Cornelius, G. Jarms, Y. M. Hirano, J. van der Land	53	+++++ C
Turbellaria	A. Faubel, C. Noreña	1137	+++++ C
Aspidogastrea	D. Gibson	4	+++++ C
Digenea	D. Gibson (M. Køie, P. Bartoli)	592	+++++ C
Monogenea	R. Bray (L. Euzet, G. Kearn)	353	+++++ C
Cestoda	R. Bray (L. Euzet, B. B. Gorgiev)	312	+++++ C
Nemertea (Nemertini)	R. Gibson	478	+++++ C
Acanthocephala	D. Gibson (C. R. Kennedy, Z. M. Dimitrova)	67	+++++ C
Cycliophora	C. S. Emblow	1	+++++ C
Entoprocta	P. J. Hayward	45	+++++ C
Mollusca	S. Gofas, J. Le Renard, P. Bouchet, R. Giannuzzi-Savelli, A. Guerra, D. Heppell,	3353	+++++ C
Mollusca (continued)	T. Hoisaeter, E. Platts, S. Smith, J.-A. Sneli, A. Warén		
Oligochaeta	C. Erséus, B. Healy	190	+++++ C
Pogonophora	E. Southward, J. van der Land (T. Brattegard)	23	+++++ C
Acarina			
Halacaridae	I. Bartsch	214	+++++ C
Ostracoda	D. Horne, A. Bruce, J. Whittaker	769	+++++ C
Amphipoda	D. Bellan-Santini, M. J. Costello (S. Ruffo, J.-C. Dauvin, L. Collier)	1183	+++++ C
Cumacea	L. Watling (T. Brattegard)	188	+++++ C
Tanaidacea	G. Bird (M. Gutu)	280	+++++ C
Bryozoa	P. J. Hayward (J. Harmelin)	724	+++++ C
Echinodermata	H. G. Hansson (S. Stöhr, C. Massin, A. Gebruk, A. Mironov, A. Smirnov, D. Zavodnik, M. Garrido)	648	+++++ C
Ascidiacea & Sorberacea	C. Monniot, D. Connor, P. Lozouet	393	+++++ C
Pisces			
Agnatha	J. van der Land, M. J. Costello (L. Collier)	5	+++++ C
Chondrichthyes	J. van der Land, M. J. Costello, R. Serrão Santos and F. Mora Porteiro. (L. Collier)	145	+++++ C
Osteichthyes	J. van der Land, M. J. Costello, R. Serrão Santos F. Mora Porteiro (L. Collier)	1199	+++++ C
Tetrapoda			
Aves	J. van der Land, M. Ramos, J. Templado	74	+++++ C
Reptilia	J. van der Land, M. Ramos, J. Templado	5	+++++ C
Mammalia	J. van der Land, M. Ramos, J. Templado	50	+++++ C

lists could be produced to the same standard, because of the varying availability of recently published reviews and of expertise. Only 4% of the taxonomic lists are considered incomplete, representing probably ≤2% of the total number of described species (Tables 1 & 2). Lists with scores >2 (indicated by a corresponding number of plus signs) were considered satisfactory, and 90% of all lists were in this category. However, 63% of the lists (scores of 3 and 4) would benefit from further expert review. Non-halacarid Acarina, diatoms, lichens and cyanobacteria were not compiled, and geographical coverage of the European seas was incomplete for Rotifera and Brachiopoda. Lists that were satisfactory, but that would benefit from further input include (1) lists that had not been checked by an expert on European fauna, namely lists for the non-epicarid Isopoda, Cephalochordata, Appendicularia, Hemichordata, Hirudinea, Gnathostomulida and Ctenophora and (2) lists known to be preliminary, including some of the above and several for protists.

Lists with many species merit further attention because it is very likely that these groups will contain species newly described to science, and/or changes in nomenclature, within a short time. The lists of macroalgae, Porifera and Mollusca were derived from well-established databases, and the lists of fishes were cross-checked against other world-wide listings. However, other large lists were prepared for the first time for this project. Because of the size of these lists, no single person can be an expert on all of the species covered, and the editorial task per person is greater. Thus, the lists of Polychaeta, Amphipoda, Harpacticoida and Turbellaria may benefit from further review.

Identification guides

Of the 842 identification guides compiled, 362 titles (43%) have been published in national or regional series, some dealing specifically with marine fauna and flora (Table 3). Although volumes may be obsolete or hard to obtain (Table 4), these series are often the guides most frequently used by non-specialists attempting to identify marine species in Europe. The 'Synopses of the British Fauna' was the most comprehensive series; it was estimated that it covered 80% of the species encountered in northern and Arctic waters, and 50% of the species encountered in the Mediterranean and the Atlantic archipelagos. One series was limited to the seaweeds of the British Isles. For the Mediterranean, the most complete coverage was by Faune de France and Fauna e Flora del Golfo di Napoli, but these series are now largely obsolete. While Fauna Iberica has a number of titles in preparation, the eastern Mediterranean remains poorly covered. No series has comprehensively covered the major groups of macrobenthos from the Arctic to the Mediterranean, so accurate identification of these taxa relies on a patchwork of guides of uneven reliability and relevance to the area concerned.

The geographical coverage was very uneven (Table 4), with 52% of the titles particular to northern Europe (the British Isles, North Sea and Scandinavia), 22% to the Mediterranean and 11% to the Atlantic–Lusitanian region (Bay of Biscay to Morocco and the Atlantic archipelagos). (The total does not add up to 100% because some general guides have not been allocated to a geographical region.) No series considered the deep-sea fauna in particular. Guides to deep-sea fauna were lim-

Table 3. Adequacy of identification guides in northern European, other Atlantic (including Lusitanian) waters, and Mediterranean and Black Seas, compared with the number of species recorded by ERMS for each taxon **: recent; *: out of date but useful; –: no useful guides; shaded areas indicate where guides do not exist

Taxon		Northern Europe	Atlantic	Medit. and Black Sea	No. of species
Acanthocephala		–	–	–	67
Annelida	Hirudinea	–	–	–	*36*
	Oligochaeta	–	–	*	*190*
	Polychaeta	**	–	–	1848
Brachiopoda		**	–	**	*>18*
Bryozoa		**	–	**	724
Cephalochordata		*	–	–	2
Chaetognatha		**	–	–	42
Chelicerata	Halacarida	**	–	–	>214
	Pycnogonida	**	–	–	146
Cnidaria		**	**	**	1224
Crustacea	Branchiopoda	–	–	–	*9*
	Cirripedia	**	–	**	*145*
	Copepoda	**	–	–	*2957*
	Ostracoda	**	–	–	*769*
	Stomatopoda	**	–	**	*22*
	Mysidacea	*	–	–	*198*
	Amphipoda	**	–	**	*1183*
	Isopoda	**	–	–	*659*
	Tanaidacea	**	–	–	*280*
	Cumacea	**	–	–	*188*
	Decapoda	**	**	*	*672*
Ctenophora		–	–	–	38
Echinodermata		**	**	–	648
Entoprocta		**	–	–	45
Foraminifera		–	–	–	1167
Gastrotricha		–	–	–	240
Hemichordata		–	–	–	17
Insecta		–	–	–	34
Kinorhyncha		–	–	–	41
Mollusca		**	**	**	3353
Nematoda		**	–	–	1837
Nematomorpha		–	–	–	3
Nemertea		**	–	–	478
Phoronida		**	–	–	9
Platyhelminthes		**	–	–	2398
Pogonophora		–	–	–	23
Porifera		**	**	–	1640
Rotifera		**	–	**	>139
Sipunculida		**	**	**	44
Tardigrada		–	–	–	76
Tunicata		**	*	**	393
Vertebrata	Pisces	**	**	**	*1349*
	Reptilia	**	**	**	*5*
	Aves	**	**	**	*74*
	Mammalia	**	**	**	*50*
Flora		**	**	**	1707

Table 4. Summary of the titles, number of issues concerning marine species, currency (years published), language and coverage of marine species in the respective area, for the major series of identification guides that include some marine species in Europe

Series title	Area	Marine issues	Years	Language	Marine (%)
Danmarks Fauna	North Sea, Baltic Sea	17	1910–1996	Danish	40
Die Tierwelt Deutschlands	North Sea, Baltic Sea	29	1925–1996	German	60
Fauna d'Italia	Central and western Mediterranean	6	1956–1986	Italian	5
Fauna e Flora del Golfo di Napoli	Western Mediterranean	39	1880–1982	Italian	60
Fauna Graeciae	Eastern Mediterranean	3	1988–1996	English	2
Fauna Iberica	Atlantic France, Iberia and western Mediterranean	3	1992–1996	Spanish	2
Fauna Marinha de Portugal	Atlantic France and Iberia	10	1931–1936	Portuguese	<1
Fauna Republicii Socialiste România (or Fauna Republicii Populare Romîne)	Black Sea	14	1941–1983	Romanian	20
Fauna SSSR/Oprediteli po Faune SSSR	Baltic Sea, White Sea and adjacent Arctic waters	55	1932–1996	Russian	40
Fauna van Nederland	North Sea	9	1932–1956	Dutch	20
Faune de France	NE Atlantic to Norway and western Mediterranean	16	1923–1966	French	20
Guide per il riconoscimento delle specie animale delle acque lagunari e costiere italiane	Central and western Mediterranean	11	1980–1983	Italian	15
Marine Invertebrates of Scandinavia	North Sea, Baltic Sea, Arctic	10	1966–1998	English	5
Seaweeds of the British Isles	NE Atlantic	7	1977–1994	English	70
Synopses of the British Fauna	NE Atlantic	44	1944–1998	English	60
Tierwelt der Nord- und Ostsee	North Sea, Baltic Sea	71	1925–1958	German	80

ited to selected groups of Mollusca (4), Tunicata (3), Crustacea (2) and Echinodermata (1).

Taxonomic coverage was equally uneven, with current and comprehensive identification guides available only for the vertebrates of all of Europe's seas (Table 3). Other taxa that were well covered in recent guides were Mollusca, Cnidaria and Sipunculida. New guides are especially needed for the species-rich, but small-sized taxa, such as: (1) the worms Polychaeta, Oligochaeta, Nematoda, Nemerta and Platyhelminthes (Turbellaria, parasitic Digenea and Monogenea); (2) the crustaceans Copepoda, Ostracoda, Isopoda, Tanaidacea and Cumacea; and (3) the Foraminifera.

The number of guides published annually increased from the 1950s to 1980s in line with general publication trends (Fig. 2).

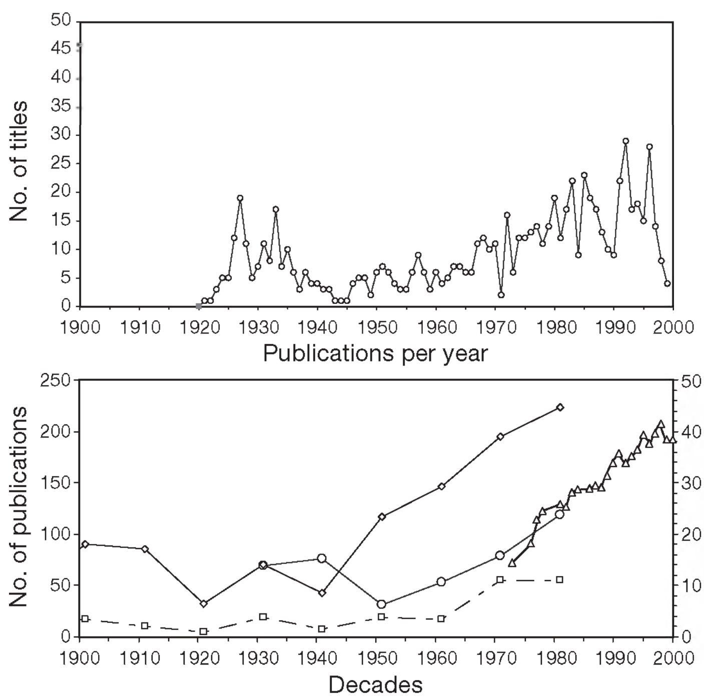

Fig. 2. (a) Total number of identification guides to European marine fauna and flora published per year and (b) number of publications in Irish periodicals (diamonds, Kelly & Costello 1996), identification guides in Europe (circles, present study), on amphipod crustaceans in Ireland (squares, Costello et al. 1990) and in ASFA (Aquatic Science and Fisheries Abstracts) (triangles, righthand y-axis, Moustakas & Karakassis 2005)

Expertise

The level of response to the survey of expertise of 37% is considered very good, because a significant number of the persons contacted may no longer have been at the

Table 5. Country and number of respondents (n) in each country, including countries not completely covered by initial lists as they were outside the study area (*)

Country	n	Country	n	Country	n
Australia*	3	Ireland	13	Seychelles*	1
Austria	5	Israel*	7	Slovenia*	1
Belgium	13	Italy	51	South Africa*	1
Brazil*	1	Japan*	1	Spain	95
Bulgaria*	2	Lebanon*	2	Sweden	11
Croatia*	7	Malta*	1	Switzerland	1
Denmark	18	New Zealand*	1	The Netherlands	12
Egypt*	7	Northern Ireland	3	Turkey*	8
Finland	5	Norway	33	UK	65
France	37	Poland	12	Ukraine*	2
Germany	62	Portugal	11	USA*	14
Greece	36	Romania*	3	Venezuela*	1
Iceland	4	Russia*	40		

Table 6. Breakdown of people by employment status

Status	No. of respondents	% of respondents	Average age
Student	19	3	30.6
Non-professional	7	1	50.2
Professional (private sector)	33	6	41.8
Professional (public service/academic)	472	80	46.6
Retired professional	29	5	67.0

address used, due to job changes, retirement, or death. The response rate of 54% of people contacted via email was almost twice that of people contacted by post. However, some email contacts replied by fax or post. It is notable that 26% of respondents were not contacted directly by the project. This suggests that despite efforts of the project team to compile individual contact details, a number of experts may still be missing from the database.

The register contained people from 29 European and 9 non-European countries (Table 5). The number of respondents was higher from countries for which lists of marine biologists had previously been compiled. Other countries had fewer respondents, as did countries which were not initially targeted by the project, in particular the Eastern European and non-European countries. Countries with the best coverage of taxonomic groups were those which were sufficiently represented in previous lists of experts. The majority of respondents stated that they had global (245) or regional (375) expertise, whilst only 113 felt they were limited to local expertise.

The age structure of respondents showed young students were clearly distinguished from older, retired professionals (Fig. 3, Table 6). The youngest person was 23 and the eldest 89 yr old. The average age was 47 yr. Of the respondents, 80% were professionals in the public service or academic sector (Table 6).

Although there were >100 people with expertise in the identification of Arthropoda (largely Crustacea) and algae (Table 7), we do not know how many are able to identify the more taxonomically difficult taxa within these groups. In our distinction between identification and taxonomic expertise, we found that there was a positive relationship between the number of people with expertise in species identification and the number of species in the phyla (Fig. 4). In contrast, the number of taxonomic experts did not correlate as well with the number of species (Fig. 4). The number of taxonomic experts was generally lower than the number of identification experts for the phyla compared, with the exception of Porifera. The numbers for Bryozoa, Phoronida and Platyhelminthes were similar for both types of experts, suggesting that only taxonomic experts identified these taxa.

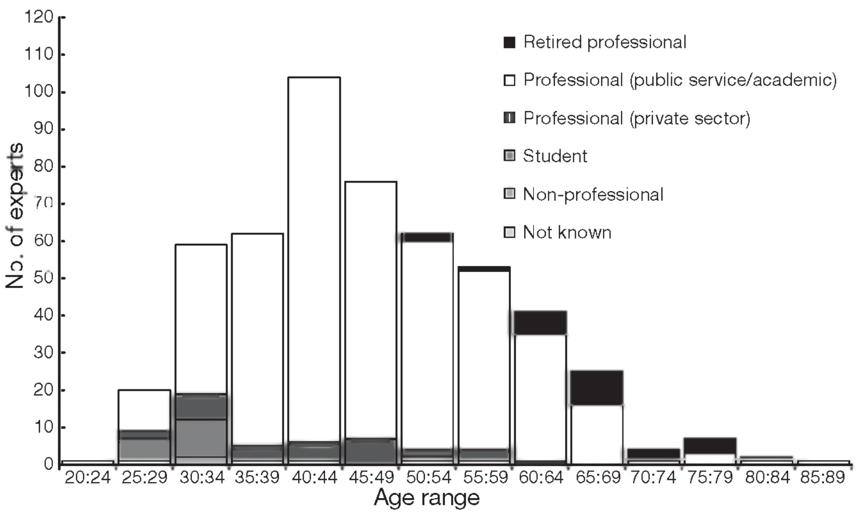

Fig. 3. Age distribution in 1999, and employment status, of people with expertise in marine species identification

DISCUSSION

Species lists

The updating of ERMS is a continuous process as new discoveries are made and nomenclature changes. This requires a management structure that is sustainable in long-term rather than project-by-project

Table 7. Number of identification experts by phyla and higher level taxonomic groups (e.g. algae are not a phylum) in the register. Some people have expertise in >1 phylum

Taxon	No. of experts	Taxon	No. of experts	Taxon	No. of experts
Acanthocephala	4	Cnidaria	22	Nematoda	15
Algae	121	Ctenophora	2	Nemertini	2
Annelida	63	Cyanophyta	11	Phoronida	4
Arthropoda	155	Cycliophora	2	Pisces	55
Bacteria	5	Echinodermata	24	Platyhelminthes	7
Brachiopoda	11	Echiurida	4	Porifera	14
Bryozoa	16	Entoprocta	1	Protista	24
Cephalorhyncha	10	Fungi	1	Rhodophyta	73
Chaetognatha	5	Gastrotricha	4	Rotatoria	1
Chlorophyta	72	Gnathostomulida	1	Sipuncula	4
Chordata	15	Granuloreticulosa	8	Spermatophyta	2
Chromophyta	82	Mesozoa	1	Tardigrada	2
Ciliata	5	Mollusca	82	Urochordata	11
				Vertebrata	13

management. Thus, a legal organisation was established by the ERMS project called the 'Society for the Management of European Biodiversity Data' (www.smebd.org) (Costello 2000b). All persons who make intellectual contributions to ERMS are life members, and they authorise the society to own and manage ERMS on behalf of the scientific community. Members elect a governing council that authorises where the top-copy of ERMS is hosted and appoints an editorial committee (the ERMS Executive Committee) to make the day-to-day decisions regarding administrative changes. The society may also facilitate the rescue of 'orphaned' biodiversity databases (e.g. where a scientist has retired and there is no successor to maintain the database) by finding suitable new hosts or managers for them. The society's ERMS Executive Committee has established an editorial board responsible for the quality control and development of ERMS. In this way, members of the board, including all taxonomic experts responsible for keeping taxonomic nomenclature within ERMS current, perform a role analogous to that of the editorial board of a scientific journal. Similarly, their time is contributed as part of their service to science, a view supported by the Consortium of European Taxonomic Facilities (2004). However, unlike paper publications, ERMS is dynamic in that errors can be corrected and new findings added, and species names can be directly connected to websites with more information about them. Thus, the Internet-accessible publication of ERMS will improve in quality and comprehensiveness over time. Where special costs arise, such as in converting ERMS to a relational database that can be edited online and making it interoperable with other databases, special project funding is sought, such as that provided by the Marine Biodiversity and Ecosystem Functioning (MarBEF project (www.marbef.org). Through MarBEF, ERMS 2.0 is being produced; this will be more complete taxonomically, will have more associated information and will also be freely available on the World Wide Web (Costello 2004). Thus, most of the gaps in ERMS that have been identified in the present paper (Table 2) will be addressed. These solutions to the long-term development and quality assurance of ERMS appear to be unparalleled in other online data resources, and merit consideration for other scientific endeavours.

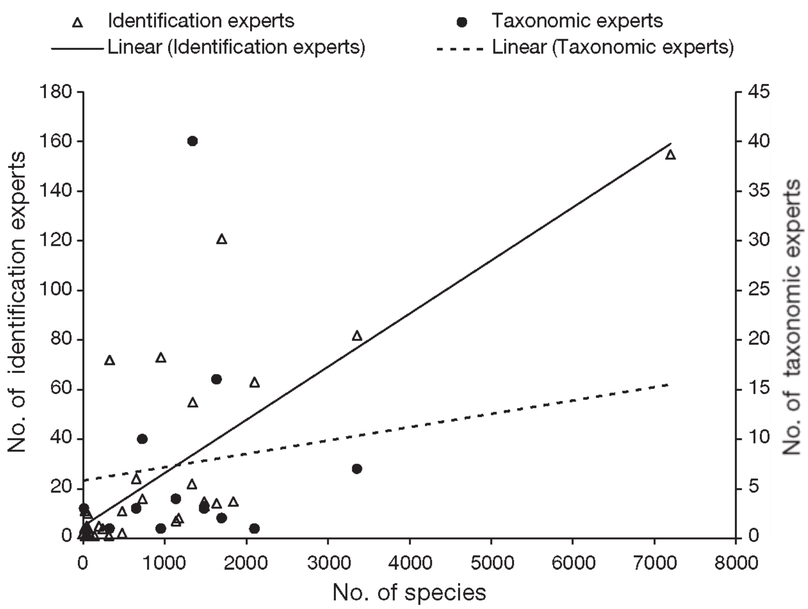

Fig. 4. Scatter plot of number of species against number of identification (triangles, solid line) and taxonomic (solid dots, dashed line) experts in the register

A global inventory of species exists for only about 20% of the estimated number of described species (Bisby et al. 2004), and we estimate that the proportion for marine species is not much greater. Without a complete inventory of a taxon it is difficult for people to know if the specimens they look at have already been described. Indeed, the time taxonomists spend describing species they were not aware had already been described, and/or correcting such mistakes, would be saved if taxonomic nomenclatures were more widely and rapidly available, and if new species were promptly registered on the Internet. If this were done, links could be made to publications, experts and other websites, and mistakes could be corrected quickly instead of waiting decades for another paper publication.

Guides

There are both taxonomic and geographic gaps in the availability of up-to-date marine species identification guides. The large, common, and/or ecologically significant species are covered in several to many guides. In contrast, many of the smaller, rarer or taxonomically difficult to identify species are not covered in any of the guides listed. Yet, these species may be of great importance to biodiversity, ecosystem function and marine resources. Although many identification guides are available for those regions of Europe in which the marine fauna and flora is least diverse (the North and Baltic Seas), there are considerably fewer guides for those regions of Europe in which the marine fauna and flora is most diverse (the Mediterranean, the Atlantic archipelagos, the deep sea). Thus, the taxonomic and geographic gaps that most urgently require attention are the smaller sized taxa in the southern European seas (both Atlantic and Mediterranean).

Although the number of guides published has increased since the 1940s, so has the number of scientific publications in general. From the 1930s to 1990s, our data showed an 88% increase in the number of identification guides. However, similar increases of 89 and 92% for marine publications on amphipod crustaceans (Costello et al. 1990) and biology periodicals in Ireland (Kelly & Costello 1996), respectively, and marine publications in 'Aquatic Sciences and Fisheries Abstracts' (Moustakas & Karakassis 2005) suggest that the number of identification guides has not increased relative to other marine biology publications (Fig. 2). One reason why fewer identification guides are being produced is that evaluations for careers and funding rely strongly on impact factor, which favours multiple publications in journals rather than as books or volumes in series.

Identification guides are not only important as a resource, but also because they enable many more scientists to begin to recognise and study previously little known species. Thus, plots of the accumulated rate of discovery of marine species (e.g. Costello et al. 1996) have a sigmoid shape, from little discovery in the early stages, to rapid discovery once some guides have been published, and then decreasing rates of discovery as the taxa become well known. Unfortunately, for European marine species as a whole, these discovery rates are still in the second stage, and the point at which all species will be described is still nowhere in sight (M. J. Costello unpubl. data).

Expertise

It is difficult to assess expertise whether by self-evaluation or by peer evaluation, because people can only assess based on what they know about the limitations of their own skills and the skills of others, and these views may differ across taxonomic groups (e.g. not many people describe new species of mammals and birds). An identification expert in taxa that are difficult to identify may have more skills than a taxonomic expert in a species group with a few easily identified species. Despite these problems, it was possible to assess the relative abundance of identification and taxonomic experts in European marine species. It was also possible to identify that gaps do exist in identification and taxonomic expertise with respect to European marine species, and that further work should be focused where gaps exist.

Our results, which gave an average age of 47 yr for experts in the identification of European marine species, supports Winston's (1988) view that an average age of 44 for taxonomists in a US survey was an underestimate due to inclusion of students. However, our survey probably under-sampled younger scientists (Fig. 3) because they are less well-known and more mobile, and does not support Winston's (1988) view that their average age may be closer to 54. Neither does it suggest that most taxonomists will be retiring within the next 10 yr.

For taxa that are considered to have a relatively complete list, the number of identification experts for each group was higher than the number of taxonomic experts. However, in some phyla (e.g. Porifera), classes and orders, more taxonomic experts than identification experts were listed. When the number of identification experts or taxonomists is similar, it suggests that only taxonomists work on these groups, and that they are not widely studied by ecologists (we assume that the majority of non-taxonomist species identification experts are ecologists). In the case of readily identiable taxa it may be correct to assume that all taxonomic experts were also identification experts, while a number of identification experts would not be taxonomists. However, in the case of taxa that are difficult to identify without the use of specialised techniques (e.g. Porifera), this may not be the case, and the numbers of taxonomic experts are closer to the number of identification experts.

The age distribution did not indicate any imminent extinction of identification expertise. The peer-selected top experts in taxonomy are at later stages in their careers, because their publication record, expertise and peers' knowledge of their expertise will increase over time. Thus, it may always be the case that the leading taxonomists will be nearing retirement. Some of the identification experts will include younger people, who will be able to do taxonomic work as the need arises. However, while our data do not support the common assertion that there is a danger of losing taxonomic expertise, they do identify important gaps in expertise that must be filled by new positions if biodiversity is to be discovered, conserved and used sustainably. There were generally more people identifying taxa with more species, although there was no correlation between the number of taxonomists and species in their taxa. It was evident that some taxa with thousands of species have insufficient taxonomists. Thus, a mismatch between taxonomic need and expertise exists for European marine species, as has been found across all taxa in Chile (Simonetti 1997), South Africa (Gibbons et al. 1999), the USA (Winston 1988) and globally (Diversitas 2000). New species reported in the online Zoological Record in 2002 and 2003 include 118 from off the coasts of southern Europe (Mediterranean, Black Sea, Iberia, Canary Islands, Azores, Madeira), 88 from the Atlantic coasts of western Europe, and 36 from Arctic Europe. However, 36% of the Mediterranean species were described from Italy, and 25% of the Atlantic species from Spain, illustrating the relative strength of taxonomy in these countries. This may be an indication that the geographic mismatch between species richness and the need for taxonomic effort has begun to be addressed in Europe.

Collections

Both large and small collections of marine species shared a common problem—insufficient resources for proper maintenance (Legakis & Emblow 2003). Most (64%) of the collections were incompletely catalogued, and only 10% had their catalogue in electronic form (Table 8). New funding is therefore essential if the knowledge included in the collections is to be available on the Internet. Almost half the collections had specimens from around the world, and making information from collections available through the Internet would help share and repatriate this knowledge to the source countries.

Table 8. Presence and extent of coverage of collection catalogues in paper and electronic (computerised) form (data from Legakis & Emblow 2003)

	Paper		Electronic	
	No.	%	No.	%
Full coverage	29	36	8	10
Part coverage	35	44	38	54
No coverage	16	20	31	36

Sourcing type specimens through online databases will facilitate the production of guides and taxonomic training. Collection managers should include electronic databases as part of the routine management of their collections and seek special funding to help integrate past collection knowledge into such databases, as demonstrated by Martin et al. (2004).

CONCLUSIONS

A priority for further infrastructure research should be the production of guides for the identification of species, especially those taxa prioritised in the present study. Their preparation will require increased funding of taxonomic research into areas of European seas where most species have yet to be described. Funding may be direct, such as through the US National Science Foundation's PEET (Partnerships for Enhancing Expertise in Taxonomy) programme, or indirect, through ecological, fisheries, informatics and molecular research projects, including funds for the necessary supporting taxonomic research and infrastructure. This will have the 2-fold benefit of providing employment for taxonomists to produce the guides, and the guides will enable many others to be trained to identify and work with the species covered. These guides should not only illustrate and describe the species, but review existing knowledge on their habitat and distribution (e.g. as done by the Synopses of the British Fauna at present). This information should be available electronically and help extend the ERMS species register into a species information system. These guides could be published on the Internet, a compact disc, and/or as a book. The advantage of electronic publication is that species identification is possible through electronic keys that can be more user-friendly and functional than traditional paper keys. Thus, 'biodiversity informatics', the use of information technology in biodiversity data management, must join molecular techniques (e.g. DNA bar-coding) as a new tool in taxonomy. Informatics and molecular tools are not alternatives to taxonomy. The need to identify species in practical ways still requires taxonomic descriptions and images, type specimens as standards for comparative analysis, and a species naming system that enables communication of 'what it is'. Biodiversity informatics can increase the visibility and availability of taxonomic knowledge and its associated data, thereby facilitating more cost-effective use of resources.

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