

How diverse is aquatic biodiversity research?

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Abstract

The use of the term ‘biodiversity’ in the aquatic bibliography has expanded during the last 10 years at an almost exponential rate. A quantitative analysis of the bibliography addressing the issue of biodiversity showed that it is mainly dominated by reviews or policy-oriented articles rather than articles referring to field data or models. The scientific effort is largely biased in terms of geographic distribution of the areas studied, country of origin of the first author and the biota studied. The number of institutions using the term ‘biodiversity’ in their title also increased dramatically with time after 1992. The proportion of references using molecular or genetic approaches to study aquatic biodiversity changed little during the last decade and ranged between 4 and 10% of the total. Our current perception of the earth’s aquatic biodiversity has been formed mainly from research carried out in the developed countries of the Northern Hemisphere. Most publications refer to commercial, charismatic or large size species, as well as to taxa of well known taxonomy; this is perhaps more compatible with traditional views of conservation of K-selection species rather than with concepts linking biodiversity to ecosystem function.

Introduction

After the Rio Summit in June 1992 and the adoption of the Convention on Biological Diversity, the term ‘biodiversity’ has become a component of research policy in many countries and international bodies and initiatives. Biodiversity however, is not a concept but an umbrella term (Haila and Kouki 1994); the content of which is quite diverse as can be inferred by definitions provided in many different texts (Wilson 1988; Reid and Miller 1989; CBD 1992; Margalef 1997). The distinction between ‘diversity’ and ‘biodiversity’ is also fairly unclear in many studies (Margalef 1997).

As with most other issues in *Ecology and Evolution*, paradigms dominating the study of biodiversity on both global and regional scales come mainly from the terrestrial environment despite the marked distinctive features of marine biodiversity and the fact that the aquatic environment occupies more than two thirds of the Earth’s surface (Vanaverbeke et al. 1997; Gessner et al. 2004). Marine organisms play crucial roles in many biogeochemical processes that sustain the biosphere, and provide a variety of products and functions which are essential to mankind’s well-being, including the production of food and natural substances, the assimilation of waste and regulation

of the world's climate. The rate and efficiency of any processes that marine organisms mediate, as well as the range of goods and services that they provide, are determined by interactions between organisms and interactions between organisms and their environment; and therefore by biodiversity (Gaston 1996; Gaston and Spicer 1998). These relationships have not yet been quantified, and we are at present unable to predict the consequences of loss of biodiversity resulting from environmental change in ecological, economic or social terms (Ehrlich and Ehrlich 1981; Walker 1992; Lawton 1994; Lawton and Brown 1994; Vitousek and Hooper 1994). The influence of species diversity on the productivity of marine ecosystems on a large scale is still unclear (Cardinale et al. 2004).

Terrestrial paradigms do not necessarily apply to marine biota. Our understanding of the role and regulation of aquatic biodiversity lies far behind that of terrestrial biodiversity, to such an extent that we do not have enough scientific information to underpin management issues such as conservation and sustainable use of marine resources. Many of these paradigms may not be applicable to the marine situation because of differences to terrestrial ecosystems (Heip et al. 1998; Gessner et al. 2004). A greater variety of species at a higher trophic level are exploited in the sea than on land. Exploitation of marine biodiversity is also far less managed than on land (Heip et al. 1998; Giller et al. 2004). Environmental change in the sea has a much lower frequency than on land, both temporally and spatially. Marine systems are more open than terrestrial and dispersal of species may occur over much broader ranges than on land (Heip et al. 1998). The main marine primary producers are very small and often mobile, whereas on land primary producers are large and static. The standing stock of grazers is higher than that of primary producers in the sea, the reverse of the situation on land. In the largest part of the ocean, beneath the shallow surface layers, no photosynthesis occurs at all (Heip et al. 1998; Giller et al. 2004). In addition, pollution from the air, land and freshwater ultimately enters the sea and therefore marine biodiversity is most exposed to, and critically influences the fate of, pollutants in the world (Heip et al. 1998).

Published research affects decision making on conservation of biodiversity. Conservation measures taken for biodiversity of an area depend also

on the areas ecological, economic and social importance, as evaluated by science and society (CDB 1992; Constanza et al. 1997; Wackernagel 1999). On the other hand, while conservation measures are usually taken for some species, there are several cases where species of virtually no commercial value become extinct almost unnoticed (Casey and Myers 1998).

Questions that we addressed in this paper are:

1. What is the general trend of published research on aquatic biodiversity and what is the ratio of the publications referring to marine vs. freshwater ecosystems?
2. What is the percentage of publications reporting field data, reviews or models/methods and how does it change over time? Has the molecular/genetic analysis approach increased in percentage over time?
3. Where, as indicated by the affiliation of the first author, does most research originate?
4. Which ocean zones have been investigated more?
5. How was scientific effort distributed among taxa?
6. Has biodiversity research affected the structure of research institutions?

Materials and methods

We used the Aquatic Sciences and Fisheries Abstracts (ASFA 1978–2001) database, which contains the abstracts of all published papers dealing with aquatic ecosystems. From the database we downloaded abstracts that contained the terms 'biodiversity' or 'biological diversity' from 1973, when the terms first appeared in a publication, until the end of December 2001. A total of 1897 publications were retrieved. In addition, we downloaded (for each abstract) the country of the first author, publication year, name of the institution with which the main author was affiliated and the ecosystem that the publication referred to (marine, freshwater or both). For the publications that referred to marine ecosystems, we also downloaded the respective ocean zones, if any. Clustering is not mutually exclusive; therefore a publication referring to biodiversity of more than one ocean zone would be counted

under all respective ocean zones. A publication about marine biodiversity that did not focus on any specific ocean zone was not categorized. To obtain a more detailed spatial distribution of the research, we used 14 ocean zones including the Atlantic (Northeast, Northwest, Southeast, Southwest), the Indian Ocean, the Mediterranean, the Pacific (Northeast, Northwest, Southeast, Southwest), the Antarctic (Eastward, Westward) and the Arctic (Eastward, Westward).

We then categorized the publication's content indicating whether it was field data, review/politics or model/method (using mutually exclusive categorization). Under politics we considered publications which stated the necessity of preserving biodiversity. Field data publications were those containing measurements of physical or chemical characteristics of an area or information concerning flora and fauna of that area. In the category of models or methods were clustered papers that proposed a way of predicting or studying an ecosystem or parts of it. We also examined if the publication was using molecular or genetic techniques to study biodiversity. Dividing the annual number of publications using genetics or molecular techniques by the total number of publications of that year, we attempted to detect possible trends in the contribution of these techniques to the study of biodiversity.

We also recorded the biota studied. From publications that referred to specific species, we kept a record of the phylum or taxonomic group and subgroup of that species. If a publication studied more than one species, we recorded the phylum and subgroup for each of them. An aquatic biodiversity publication not focusing on any specific species or taxonomic group or subgroup was not categorized.

Due to a time delay in updating the database, the total number of records after the year 2000 was considerably lower than the previous years. Therefore, the number of biodiversity related records are also expected to be severely underestimated during this period.

Conventions: in our approach the terms 'biodiversity' and 'biological diversity' will both be referred to as biodiversity. When we refer to biodiversity we mean the biodiversity of aquatic ecosystems only, unless further specifications are given.

Results

After 1992 an exponential increase in the number of publications was observed. This coincided with the time after the Convention on Biological Diversity in Rio de Janeiro was held (Figure 1). Clearly, in all years the majority of publications referring to aquatic biodiversity are reviews or policy-related texts. The second most popular category was field data. A smaller part of publications contained models or methods. Although there is a general increasing tendency with time in the number of publications of both marine and freshwater ecosystems, the majority of the publications refer to marine ecosystems (Figure 2).

Regarding the origin of the publications as indicated by the affiliation of the first author

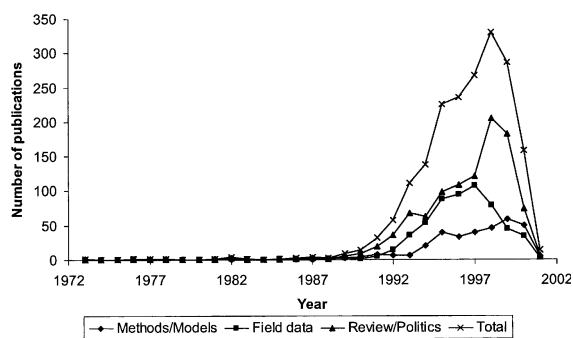


Figure 1. Occurrence of the terms 'biodiversity' or 'biological diversity' in title or abstract in ASFA database in total and in different types of papers. The decline after 2000 is due to delay in updating the database.

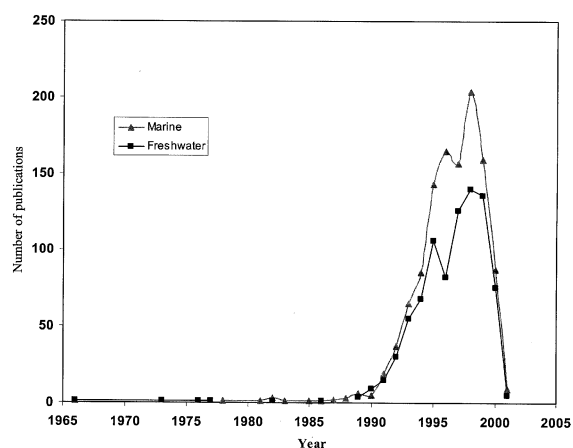


Figure 2. Number of publications referring to biodiversity in marine and freshwater ecosystems.

during the entire period investigated, (Table 1), the first 10 countries covered 56% of the publications in aquatic biodiversity and 60% of the field data published. The proportions of publications in different categories (field data, models/methods, review/politics) are similar among the first 10 countries. It is quite impressive to note that about 25% of the published research is due to one country, the US, which has 23% of the total number of publications and 21% of the publications in field data. However, the EU as a unity of 15 countries has 26% of the total number of publications and 28% of the publications in field data. The EU and the USA together have 49% of the total number of publications and 49% of the publications in field data.

We found a significant number of publications focused on the Mediterranean Sea which was unproportional to its size (Table 2). Furthermore, Antarctic regions, namely Polar Antarctic Westward, Polar Antarctic Eastward and especially Arctic regions (Polar Arctic Westward and Polar Arctic Eastward), are scientifically unexplored, since there are very few publications focusing on these regions from the appearance of the term biodiversity until today. In the North Atlantic, the EU countries (Atlantic Northeast) have considerably more publications referring to biodiversity than does the American side of USA and Canada (Atlantic Northwest). In the South Atlantic, the American side (East Latin American countries-Atlantic Southeast) is more studied in comparison

Table 1. Number of publications referring to biodiversity per country of the affiliation of the first author in the entire data base. Countries are arranged by decreasing total number of publications. Only the first 30 countries in the list are presented.

Country	Field data	Models/ methods	Review/ politics	Total	Cumulative percentage of publications (%)	Cumulative percentage of field data publications (%)
USA	117	85	226	428	23	21
UK	46	26	68	140	30	29
France	48	25	35	108	34	37
Australia	25	9	64	98	40	41
Canada	24	18	51	93	45	46
Italy	24	14	26	64	48	50
India	20	8	25	53	51	53
China	19	11	8	38	53	57
Mexico	21	2	12	35	55	60
Kenya	5	2	27	34	56	61
Germany	8	8	13	29	58	63
South Africa	6	5	16	27	59	64
Spain	4	8	14	26	61	64
Sweden	6	7	13	26	62	65
Norway	5	4	14	23	63	66
Russia	7	5	11	23	65	68
Netherlands	5	7	10	22	66	68
Philippines	3	0	18	21	67	69
Japan	8	5	7	20	68	70
Belgium	7	2	9	18	69	72
Switzerland	6	3	8	17	70	73
New Zealand	8	3	2	13	71	74
China-Hong Kong	2	1	9	12	71	74
Poland	6	2	4	12	72	75
Brazil	5	3	3	11	72	76
Denmark	1	4	5	10	73	76
Israel	6	1	3	10	73	78
Latvia	5	3	1	9	74	78
Ukraine	3	5	1	9	74	79
Austria	2	4	2	8	75	79
Rest (68) countries	64	19	86	169	84	86
Unknown affiliation	54	25	212	291	100	100

Table 2. Number of publications referring to marine biodiversity per ocean zone and per year. Some of the publications in the database refer to more than one ocean zone.

Ocean zone\Year	≥1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Atlantic-Northeast	1			5	7	16	15	10	15	12	7	1	89
Atlantic-Northwest		1	1	1	3	5	6	2	7	10	1		37
Atlantic-Southeast		1			2	1			9	5			23
Atlantic-Southwest	2	3	1	10	7	30	8	9	14	8	13		105
Indian Ocean	2	1	2	5	5	10	19	16	21	20	6		107
Mediterranean	3		1	1	5	6	23	14	10	11	7		81
Pacific-Northeast		2	4	1				2	2	1	1	1	14
Pacific-Northwest	1					2	2		2	3	1		11
Pacific-Southeast			1	10	2	2	4	5	7	2	4		37
Pacific-Southwest	4		1		13	8	13	16	10	11	6	1	83
Polar-Antarctic Eastward			1		1	3		5	4	3	2		19
Polar-Antarctic Westward						3	3	2	6	5	3	1	23
Polar-Arctic Eastward				1	1	1	2	2			2		9
Polar-Arctic Westward		1				1				1	1		4

to the West African countries (Atlantic Southwest).

The published scientific effort on specific phyla (Table 3) seems to follow logarithmic distribution, having few very well studied phyla, and many phyla seldom mentioned. What is impressive is the fact that about 1/3 of all the publications which focus on the biodiversity of a particular taxon, refer to Vertebrata, usually organisms of large body size, including fish, mammals, and amphibians. Next on the list, but with considerably lower numbers are Plants, Algae, Crustaceans and Molluscs.

The published scientific focus is also uneven among subgroups of the same taxon (Table 4). Within the subphylum of Vertebrata, the most studied taxon, Pisces (fish), is the most studied subgroup. Aves and Mammalia are the second and third most mentioned subgroups of Vertebrata in publications respectively but with considerable difference from Pisces. The majority of Pisces publications either review already published work, or discuss the political necessity for conserving Pisces. The same is observed among the subgroups of Crustacea and Mollusca where the published research of the Crustacea subgroups is unevenly distributed. For example, Decapoda have almost as many publications as the rest of the Crustaceans.

After 1993 there is an exponential growth in institutions which have the term 'biodiversity' in

Table 3. Number of publications referring to biodiversity and to specific organisms of particular phyla or higher taxa. The clustering is not mutually exclusive: a publication focusing on more than one taxon is registered under all the respective taxa.

Phylum/group	Total	Field data	Models/ methods	Reviews/ politics
Vertebrata	666	185	106	375
Plants	150	53	25	72
Algae	136	63	27	46
Crustacea	126	60	34	32
Mollusca	107	39	32	36
Cnidaria	73	27	14	32
Arthropoda	63	35	18	10
Bacteria	54	18	14	22
Protista	23	14	3	6
Annelida	22	12	7	3
Echinodermata	20	12	2	6
Porifera	17	12	1	4
Fungi	16	5	3	8
Cyanobacteria	15	5	3	7
Nematoda	15	7	7	1
Bryozoa	9	6	3	0
Rotifera	5	3	1	1
Other chordata	5	4	1	0
Virus	3	1	1	1
Platyhelminthes	2	2	0	0
Archaea	2	1	1	0
Sipunculida	2	0	2	0
Tardigrada	1	0	1	0
Brachiopoda	1	0	1	0
Gastrotrichs	1	1	0	0
Lichens	1	1	0	0
Nemertinea	1	0	1	0

Table 4. Number of publications referring specifically to subgroups of the 3 most studied animal taxa. The clustering is not mutually exclusive: a publication focusing on more than one subgroup is registered under all the respective subgroups.

Taxon	Sub-taxon	Total	Field data	Models/methods	Reviews/politics
Vertebrata	Pisces	572	156	85	331
	Aves	52	13	11	28
	Mammalia	38	13	6	19
	Reptilia	27	8	6	13
Crustacea	Decapoda	47	25	8	14
	Amphipoda	18	11	3	4
	Copepoda	16	6	4	6
	Ostracoda	8	1	7	0
	Isopoda	7	3	3	1
Mollusca	Bivalvia	40	14	11	15
	Gastropoda	23	9	6	8
	Cephalopoda	9	1	3	5

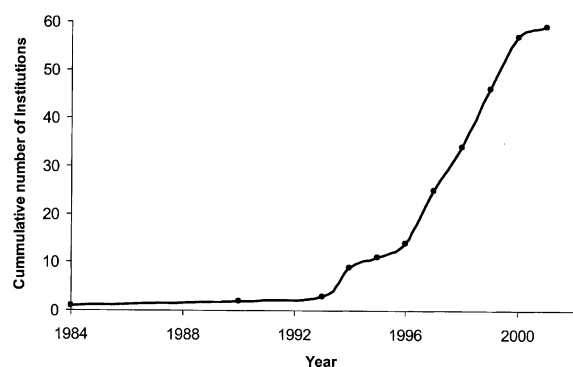


Figure 3. Cumulative number of scientific institutions (institutes, museums, labs, departments etc) using the term 'biodiversity' in their title as a function of their first appearance in bibliography (first publication).

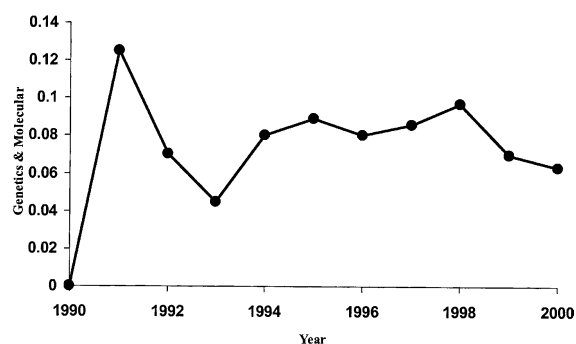


Figure 4. Annual percentage of publications referring to biodiversity using genetics or molecular techniques in their analysis over the total number of publications referring to biodiversity in the respective year.

their title (Figure 3). It seems that after the CBD was held in 1992, many institutions considered the necessity not only of studying biodiversity but also of adopting special organization structures dedicated to this task.

Generally, no trend in increasing contribution of genetics or molecular techniques in the study of biodiversity was detected (Figure 4).

Discussion

There was a significant increase in the total number of publications using the term biodiversity after the CBD in Rio de Janeiro (1992). The published research increases at a pace that seems exponential after 1992. Biodiversity always was one of the main focuses in biological research (Gaston 1996). The appearance however of the term 'biodiversity' has formed a new field of research, defined in several different ways (Margalef 1997). As a result, even in publications where biodiversity is not the center of the research interest, author(s) feel the necessity to refer to it. So, in practice, many publications did study the biodiversity of an area even before 1992, but the term would not necessarily appear in the abstract or in the keywords of the publication. After 1992, however, the term did appear in the abstract and keywords. A considerably important factor for the increase of the number of publications after 1992 is that the CBD in Rio set the priorities for getting funding in research that deals with this topic. Therefore research that lies in that area

was more likely to get funded after 1992 than before.

In terms of what most publications on aquatic biodiversity are actually talking about, most of them refer to the necessity of protecting or summarizing the research that already has been carried out. Secondly, scientists publish field data and then quite a few of them – as it appears from the published outcome – propose models or methods to study and predict ecosystems. As well as frequency of content, the same process can be seen in the time sequence. That is, firstly the necessity of dealing with the biodiversity seems to be published then the field research progresses and lastly methods to study or predict are proposed or models are built. It is generally accepted that there are few high quality field data available (Petchley et al. 2004). As a result, it looks like development of models will still take some time. Another observation is that the majority of the publications in aquatic biodiversity refer to marine ecosystems rather than to freshwater ones. Still the unanswered question that remains is whether the term ‘biodiversity’ is interpreted in the same way by all its users. In other words we cannot measure, at least in this study, what the authors actually mean when they use this term and if they all understand it in the same way.

As far as the geographical distribution of the derivation of research is concerned, it seems that there is a small group of countries that form our perception of aquatic biodiversity today. Judging from the country of the first author of each publication, most of the published work comes from a few developed countries which are mainly located on the Northern hemisphere. For marine ecosystems specifically, the ocean zones studied generally do increase mainly after 1993. However, there are still many scientifically unexplored areas with a very low number of publications referring to them and no clear trend of increasing scientific effort on those areas. Specifically, the Arctic and Antarctic Polar regions are still unexplored. In addition, the North Pacific Ocean (Pacific Northeast and Pacific Northwest), still has few citations in comparison to its large size. To sum up, most published aquatic biodiversity research comes from a few countries and focuses on relatively few specific regions. This limits our perception of the world’s aquatic biodiversity. Consequently we do not have sufficient information about biodiversity in most

places on earth. Even though biodiversity declines from the equator to the poles in terrestrial ecosystems (Rosenzweig 1995), this is still a hypothesis to be tested in aquatic and especially marine ecosystems where causes of this phenomenon are unclear (Clarke 1992; Rohde 1998). In addition, particularly in marine ecosystems, there are several well stated cases where diversity in higher latitudes actually increases (Gray 2002; Valdovinos et al. 2003). Therefore, the lack of information on biodiversity of Tropical and Polar Regions prevents scientific conclusions on the distribution of the world’s aquatic biodiversity.

As well, biodiversity publications seem to be unevenly focused on only a few specific phyla and the number of publications on specific phyla is disproportional to the diversity of species in each phylum. Most publications referring to one or more specific taxon deal with Vertebrata. Interestingly, even within the Vertebrata most publications deal with Pisces which are of high commercial value. Marine birds (Aves) follow with the second higher number of references within the Vertebrata. Aves belong to those species whose protection is considered to be a necessity (charismatic species). Marine mammals (Mammalia) follow in the number of citations in the Vertebrata and then aquatic reptiles (Reptilia). Consistently, within Crustacea, Decapoda are mentioned mostly because of their commercial value (shrimps, crabs etc), whereas Copepoda which are important in their role as food for juvenile fish (Fernando 1994; Peterson 1998) are mentioned only in 1% of the publications. Nematoda are seldom mentioned even though they are one of the groups with the greatest species richness (Armonies and Reise 2000; Hugot et al. 2001). Also biodiversity of microbial and monocyte organisms have a small number of citations. The study of these organisms is difficult and there is a weak relationship between morphology and diversity. This means that DNA analysis is needed to identify different species (for example, Schutyser et al. 2002). Summing up, the publications mainly refer to commercial species, then charismatic species, then species of large size and then species whose systematics (science of clustering) has evolved. Given that there is typically a 53-year lag between the last sighting of an organism and the reported date of extinction (Dulvy et al. 2003) many species might become extinct without the scientific community even noticing it.

Molecular and genetic techniques do not show any increasing trend in the study of biodiversity. The analysis of biodiversity seems to be more in an intra-population level; it deals more with species interaction on a level of individuals and species.

All the above imply that the scientific effort is largely biased in terms of geographic distribution of the studied areas, country of origin of the first author and the biota studied. These sources of bias are likely to affect the overall quality of the available information as a means for assessing the state of the global aquatic biodiversity. Furthermore, the focus on large sized or charismatic species is perhaps more compatible with traditional views of conservation of K-selection species rather than with modern views linking biodiversity to ecosystem function (Gessner et al. 2004; Giller et al. 2004; Petchley et al. 2004) where even small and not well studied organisms may play ecologically important roles.

There is a need to overcome the shortcomings of the asymmetries in research effort through a structured international science plan focusing on gaps in the present status of knowledge. This will allow the building up of a substantial knowledge-base on biodiversity that could be relevant to the goods and services provided to the human society as well as to global ecosystem services.

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