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Seagrass ecology at the turn of the millennium: challenges for the new century

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Abstract

A review of the literature on seagrass ecology produced over the past decade (1989–1997) showed a sustained increase in the scientific production in international journals, with a doubling of the annual publication rate every four years. This production is highly concentrated in Aquatic Botany and three other journals (>50% of papers), involving contributors from 33 countries. Research efforts are growing rapidly in W. Europe, the Mediterranean Sea, the Caribbean Sea, and Australia. Studies on seagrass ecology also increase in NW America and SE Asia. Development of research is particularly strong in themes such as disturbance of seagrass meadows, and their growth, biogeochemistry and population dynamics. Yet, seagrass ecology is a rather imbalanced science, with half of the production produced by scientists from only two countries, examining only 10% of the seagrass flora from two biogeographic areas. Seagrass ecology is dominated by descriptive research (>60% of papers), with a paucity of efforts to synthesize results and derive general relationships. These characteristics result in a present lack of predictive ability, and scientific basis for the management of seagrass ecosystems. Coordination of research efforts in seagrass ecology has been limited, such that great uncertainty arises when scaling up the knowledge produced locally to assess seagrass resources at regional and global scales. Seagrass ecology must progress from the present descriptive stage to synthesis, either through large-scale comparative analyses or the formulation of general models, yielding the power to predict the time course of seagrass decline and recovery and the role of seagrass meadows in the ecosystem. The development of a cooperative framework should contribute to expanding the scale of the research, develop the capacity to conduct new relevant research, establish a global network monitoring seagrass resources, and incorporate seagrass ecosystems into international programs examining the health and functioning of the oceans. ©1999 Elsevier Science B.V. All rights reserved.

Keywords: Seagrass; Bibliometry; Research effort; Geographical distribution; Topics; Species coverage

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1. Introduction

Seagrass ecology has evolved, as most other research programs within aquatic ecology, from a descriptive stage, focused on the distribution and biology of the plants, to a quantitative, process-oriented stage (McRoy, 1996; Phillips, 1996). In this transition, research topics have diversified and new approaches and tools have appeared (McRoy, 1996; Phillips, 1996). Research efforts over the past four decades have generated widespread awareness of the importance of seagrass meadows as marine ecosystems (e.g. Costanza et al., 1997), thereby placing seagrass ecosystems as primary targets for marine conservation and restoration programs (e.g. Wyllie-Echevarria et al., 1994). These achievements have resulted from the efforts of a growing community of seagrass ecologists, who are now publishing about 100 papers annually, through the contributions of authors from more than 33 countries around the world (1989–1997 bibliometric survey).

While expanding, the scientific studies on seagrass ecology is still limited compared to many marine ecosystem. Moreover, the increase of knowledge on the ecology of seagrass meadows does not appear to be conferring a better basis to sustainably manage these ecosystems, for seagrass meadows are still being lost from the world's coastal ocean at alarming rates (e.g. Short and Wyllie-Echevarria, 1996; Marbá et al., 1997). This situation suggests a deficiency in the relevance of the knowledge being produced. The development of seagrass ecology has either been insufficient or has left important gaps limiting our predictive power. Here I evaluate the current status of seagrass ecology to provide a diagnose of its strengths and weaknesses, with the aim of identifying the main challenges to be faced to develop a solid basis for the management and conservation of seagrass meadows.

2. Methods

I provide an overview of the current status of seagrass ecology through a bibliometric study of the literature produced over the past decade (1989–1997). The period 1989–1997 was chosen because: (1) it should provide a good description of the status of seagrass ecology at the turn of the century, (2) the scientific literature produced within this time span has been indexed in major databases, thereby rendering a thorough study of this period possible, and (3) it represents the period of activity of this author in the field, thereby allowing a more informed evaluation of the results of the study.

The bibliometric study involved a search for all papers produced on seagrass ecology between 1989 and 1997. This search was conducted from two main databases, the Marine Literature Review, and the Aquatic Sciences and Fisheries Abstracts. Search parameters were kept as wide as possible to ensure that no relevant papers included in the databases were omitted. Although the databases also index reports, in addition to papers in national and international journals and conference proceedings, their efficiency in capturing the gray literature is suspected, and many reports with restricted distribution may have escaped this search. The reliability of the bibliometric search was tested using the author and colleagues, whose curricula vitae were available to me, as test individuals, yielding a 98% success rate on papers published in national and international journals and conference proceedings. For all

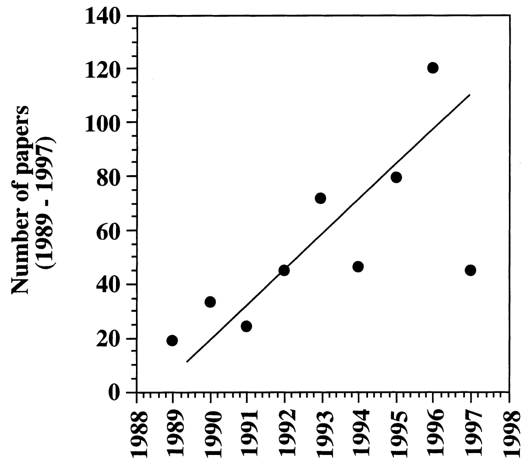

Fig. 1. The progression of the number of papers on seagrass ecology published in the period 1989–1997. The solid line represents the trend, except for 1997 for which the database was still incomplete.

studies identified, I recorded the country of affiliation of the senior author, the journal where the research was published, the location of the study, the species investigated, the approach used in the study, and its research topic. The papers published in 1997 are underestimated in this study, since not all papers have been indexed or even published at the time the search was conducted (March 1998).

3. Results

The study clearly showed a sustained increase in the scientific production in international journals, with a doubling of the annual publication rate every four years (Fig. 1). Although these papers had contributors from 33 countries, half of the scientific production originated from laboratories in two countries (USA and Australia), and authors from seven countries contributed 90% of the papers published between 1989 and 1997 (Fig. 2). Most (68%) of the papers were published in international journals (Fig. 3), but a significant proportion (32%) was published in other, more restrictive outlets, such as conference proceedings (16%), national journals (12%), and reports (2%). Although the research on seagrass ecology is distributed in 64 international journals, it is highly concentrated in a few of them. This journal (Aquatic Botany) clearly stands out as the leading journal in seagrass ecology, printing a fourth of all seagrass papers (Fig. 4). Marine Ecology Progress Series (17% of papers), and Journal of Experimental Marine Biology and Ecology (9.8%) are also major outlets of research on seagrass ecology (Fig. 4). It is striking, however, that only 10% of the papers are published in journals devoted to general ecology (Fig. 4), suggesting a poor contribution of the research on seagrass ecology to general ecological theory.

The research efforts are very skewed across the seagrass flora, with one in every four papers devoted to the study of either *Thalassia testudinum* or *Posidonia oceanica* and half of the research effort is allocated to species in the Caribbean, Mediterranean and North Atlantic

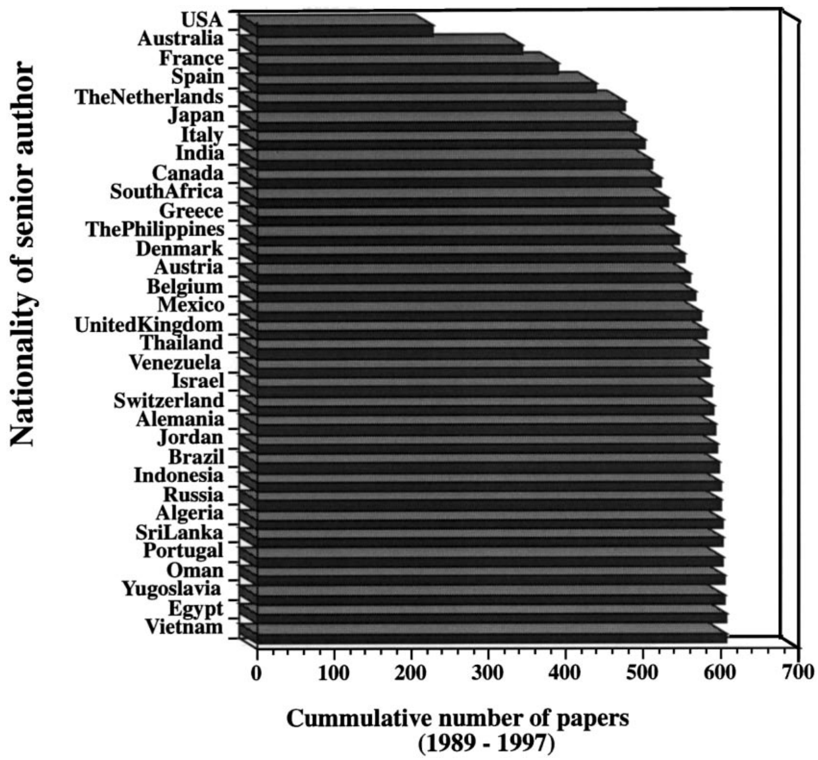

Fig. 2. The cumulative number of papers on seagrass ecology published in the period 1989–1997 by senior authors of different nationalities.

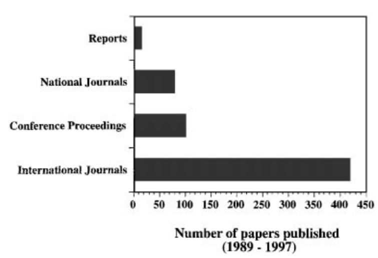

Fig. 3. The number of papers on seagrass ecology published in the period 1989–1997 in different types of publications.

(Fig. 5). Surprisingly, a large fraction (1/3) of the limited seagrass flora (<60 species) has been ignored over the past decade, since none of the studies investigated any aspect of their ecology and biology (Fig. 5). Hence, the research efforts across different biogeographic regions were highly imbalanced, with research on Caribbean and Mediterranean meadows comprising half of the studies, and with a paucity of published results on seagrasses from

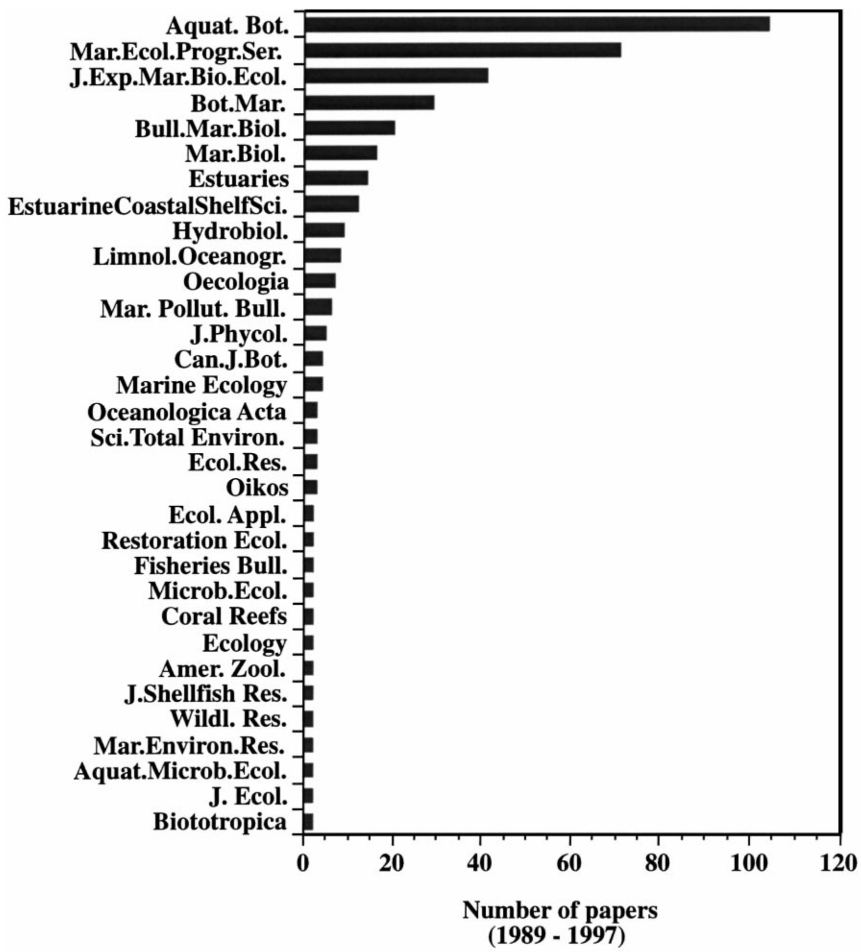

Fig. 4. The number of papers on seagrass ecology published in the period 1989–1997 in different international journals. An additional 28 journals with only one paper each are not shown.

the coasts of Africa, and the Pacific and the Indian Oceans (Fig. 6). There was, however, a rapid growth of research reports on the ecology of seagrasses in Europe (Atlantic and Mediterranean coasts), the Caribbean Sea, and Australia (Fig. 7), and an apparent increase of research efforts in NW America and SE Asia.

The vast majority (2/3) of the studies focused on descriptions of various aspects of seagrass ecology. Experimental approaches (12%), and research aimed at synthesizing available knowledge (modelling and comparative analyses, $<$10%) remained a minor fraction of the reports (Fig. 8). Moreover, there was no evidence that the high effort devoted to descriptive studies is declining (Fig. 9). In contrast, there was a sharp increase in the percentage of descriptive studies (50 to 70% of the papers) in the 1990’s (Fig. 9). The main effort (33%) was allocated to investigate the role of seagrass meadows as habitats for fauna, with a substantial

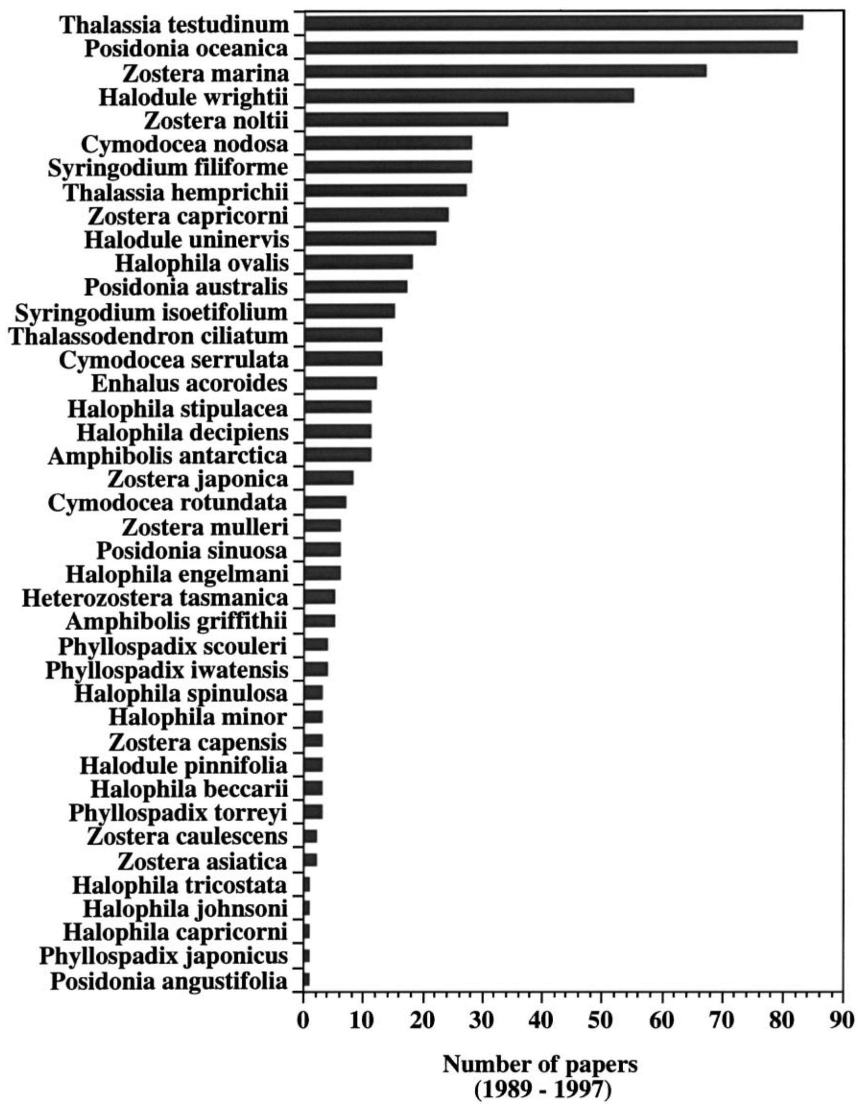

Fig. 5. The number of papers published in the period 1989–1997 on the biology and ecology of different seagrass species.

attention devoted to the distribution of seagrass meadows and their response to disturbance (1/5 of the papers, Fig. 10). The landscape dynamics of meadows, their interaction with physical processes, and, surprisingly, the management of seagrass resources have received only marginal attention in the literature published over the past decade (Fig. 10). A closer examination of the tendency reveals a rapid growth of research on the response of seagrass ecosystems to disturbance, along with research on plant growth and population dynamics, and biogeochemical processes (Fig. 11). Most of the research is performed at the ‘square

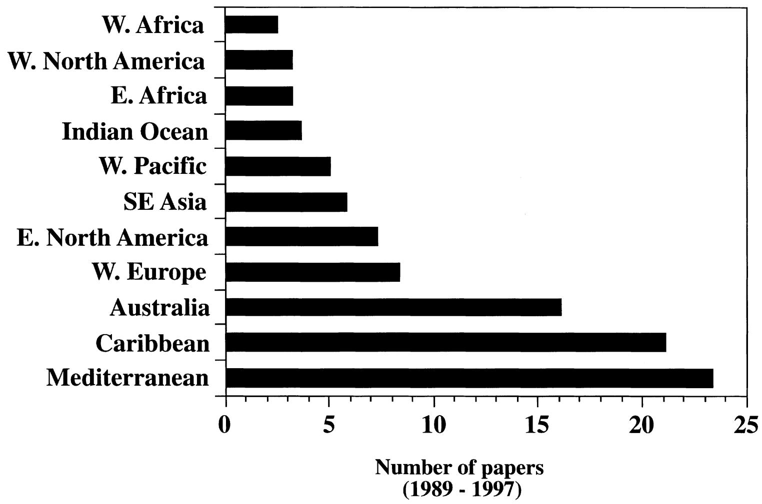

Fig. 6. The number of papers published in the period 1989–1997 on the biology and ecology of seagrasses in different biogeographical regions.

meter', quadrat scale or lower (>60%), and studies at larger scales are few, particularly those on the global role of seagrasses, which comprise less than 0.5% of the studies.

4. Discussion

4.1. Seagrass ecology at the turn of the millennium: a diagnosis

The bibliometric study provides a clear picture of the current status of seagrass ecology, thereby identifying the main challenges to be faced. The research program can be characterized as a growing science, but one that is still descriptive in nature and suffers from considerable imbalances in the allocation of effort. Seagrass ecology is a growing science, because scientists from at least 33 countries around the globe are involved, and the publication rate is doubling every four years. Efforts in W. Europe, the Mediterranean Sea, the Caribbean Sea, and Australia are growing particularly rapidly, and the tendency for increased seagrass ecology in NW America and SE Asia are also encouraging. This growth is particularly rapid in research on disturbance of seagrass meadows as well as in studies of their growth, population dynamics and biogeochemistry. Yet, seagrass ecology is a rather imbalanced science because scientists from only two countries produce half of the publications, largely focused on only 6 species from two biogeographic areas. Moreover, the research program remains essentially descriptive, at odds with the tendency towards an increased allocation of effort towards experimental studies and synthesis (modelling and comparative analyses) in general ecology, which now encompass more than 60% of the efforts in general ecology, compared to less than 20% of efforts allocated to descriptive research (Ives et al., 1996).

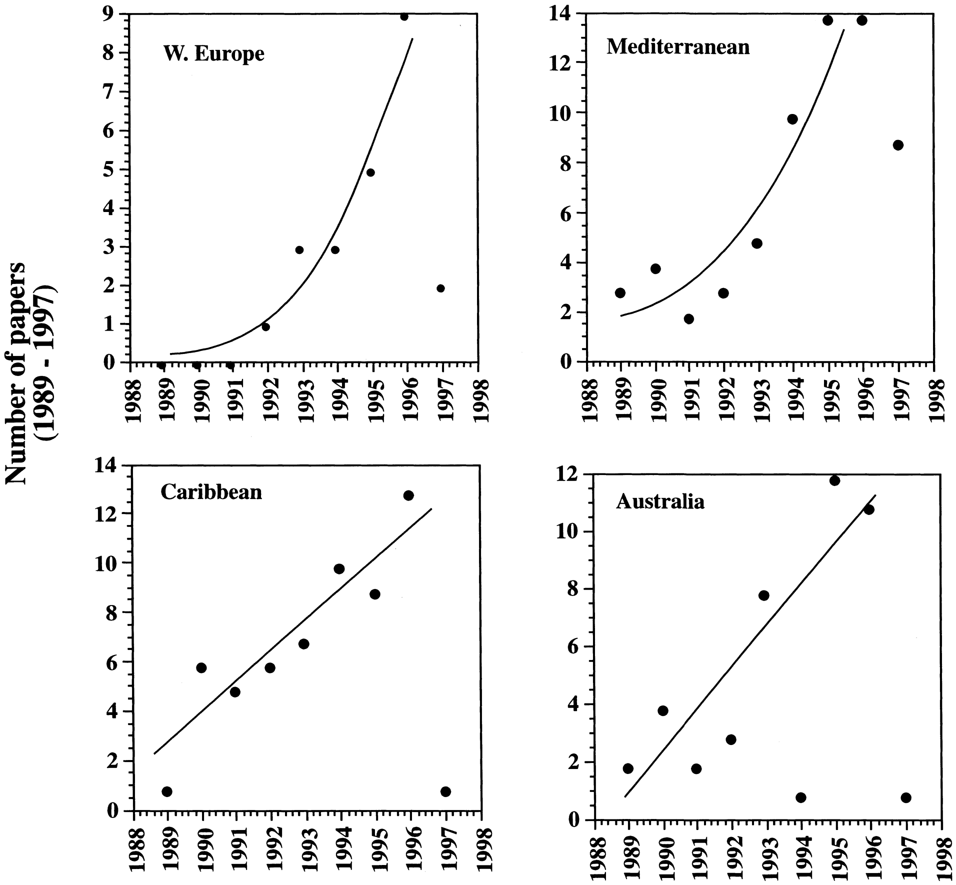

Fig. 7. The progression of the number of papers on seagrass ecology in different regions published in the period 1989–1997. The solid lines represents the trend, except for 1997, for which the database was still incomplete.

The characteristics of current seagrass ecology summarized above are symptomatic of an immature science. This diagnosis is based on the descriptive nature of the research, the paucity of efforts to synthesize results and derive general laws that could hold predictive power. The rapid change in the status of seagrass taxonomy is also an evidence of a certain immaturity. Despite the reduced size of the flora (48 species described in the monography by den Hartog, 1970), there has been a 20% growth of the number of species over the past two decades (e.g. Kirkman and Walker, 1989). Disparity in the count of the total number of seagrass species among authors ranges by as much as 25%, so that there is considerable disagreement even in fundamental aspects. These characteristics also reflect a relatively loose connection both within the community of seagrass scientists and with their peers in related disciplines. There is no established network of seagrass scientists, and very limited interaction between these and other marine scientists, or general ecologists. Hence, it is hardly surprising that only 10% of the papers on seagrass ecology are published in general ecology journals.

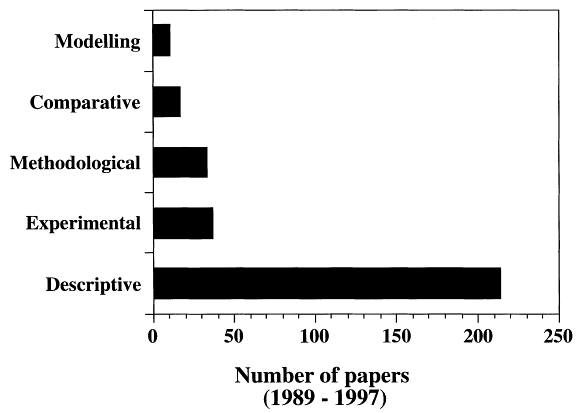

Fig. 8. The number of papers on the ecology of seagrasses published in the period 1989–1997 using different approaches.

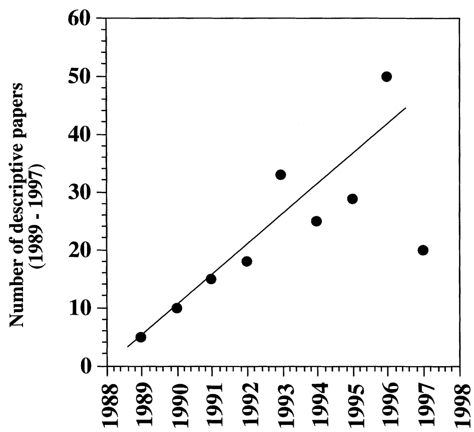

Fig. 9. The progression of the number of descriptive papers on seagrass ecology published in the period 1989–1997. The solid line represents the trend, except for 1997, for which the database was still incomplete.

4.2. Consequences

The deficiencies outlined delay progress in our knowledge of seagrass ecosystems and our capacity to conserve and manage them in a sustainable manner. The most detrimental consequence is the present lack of predictive ability, which remains largely qualitative both as to the magnitude and time scales of responses of seagrass ecosystems to particular effects (Duarte, 1995). Predictive laws are apparently restricted to the capacity to predict seagrass depth limits from water transparency (Duarte, 1991a), and to relatively coarse predictions of architectural and growth traits from allometric laws (Duarte, 1991b; Vermaat et al., 1997; Marbà and Duarte, 1998). More refined predictions, such as seagrass productivity rate

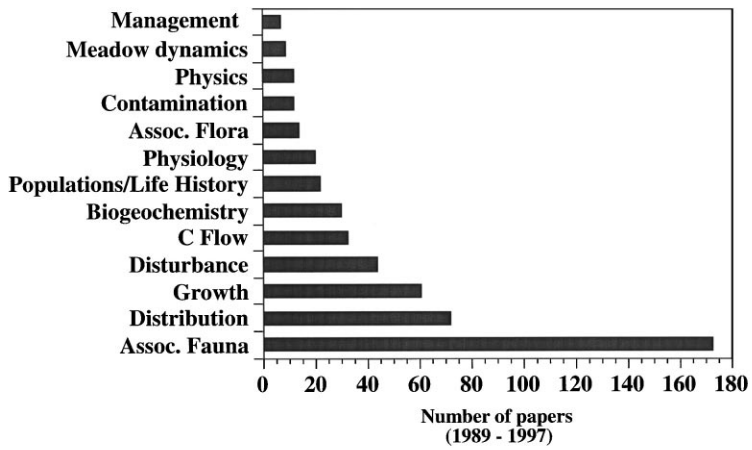

Fig. 10. The number of papers on different aspects of the ecology of seagrasses published in the period 1989–1997.

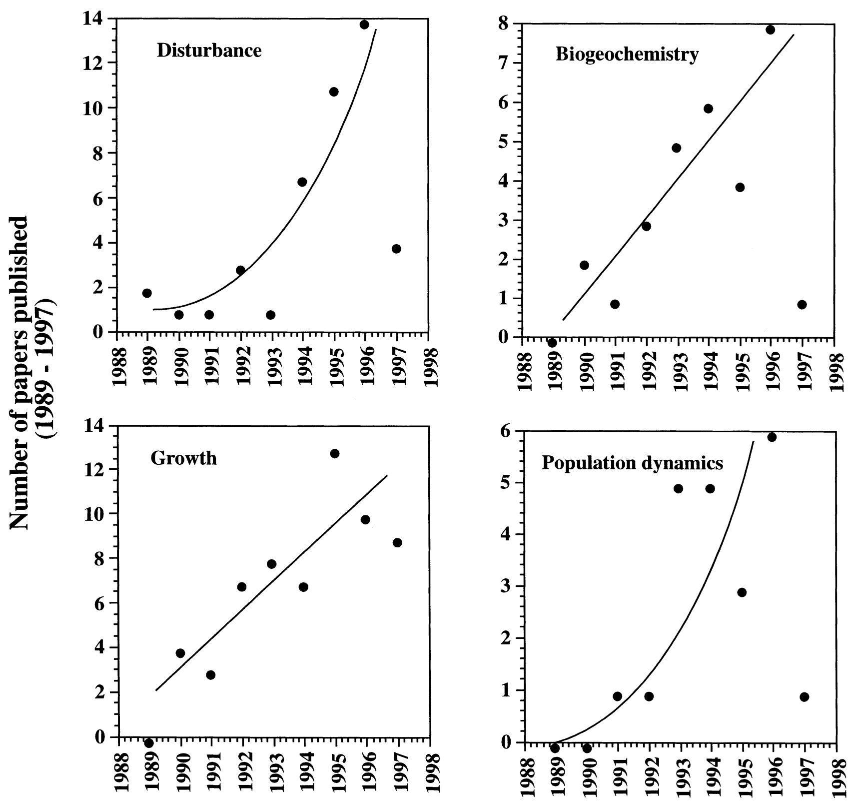

Fig. 11. The progression of the number of papers on different aspects of the ecology of seagrasses published in the period 1989–1997. The solid lines represents the trend, except for 1997, for which the database was still incomplete.

derived from the composition of stable isotopes (Grice et al., 1996), are now emerging, but their applicability remains regional at present and should be further expanded and validated. Even predictions of fundamental traits, such as the recovery time of seagrass meadows remain conjectural, and dependent on unsupported assumptions (e.g. Duarte, 1995). It is, therefore, evident that the scientific basis for the management of seagrass ecosystems is largely missing, accounting for the minimal effort (5% of papers between 1989 and 1997) devoted to this issue.

If our capacity to predict seagrass responses is limited, the capacity to predict the consequences of these responses still remains more elusive. The evidence for the role of seagrasses remains anecdotal, largely relying on historical accounts of changes, such as changes in sediment patterns in response to decline in seagrass cover (e.g. Wilson, 1949; Christian et al., 1981). We are, therefore, unable to formulate quantitative predictions on the changes in the ecosystem (e.g. sediment dynamics, biogeochemical fluxes, and faunal abundance) likely to occur from changes in seagrass cover. As a consequence, it is presently impossible to predict the rate of change in the services and products that seagrass meadows yield, valued at about US$ 19,000 ha^{-1} $year^{-1}$ (Costanza et al., 1997). This limitation poses considerable constraints on the incorporation of seagrass resources onto larger scenarios, such as integrated coastal management, where evaluation of costs and benefits provide the common framework to evaluate different components and functions.

The deficiencies outlined above largely stem from the fragmented nature of the research community studying seagrass ecology. This poor coordination of efforts often leads to redundant efforts characterized by the proliferation of exemplary research, representing models of successful research which are repeated again and again (Lakatos and Musgrave, 1968), such as leaf marking studies and nutrient addition experiments. Interactions among seagrass ecologists are few, but those with scientists working on other aspects of marine sciences are even fewer, so that the interdisciplinary approaches required to address the role of seagrasses in the ecosystem are rather limited, with some interaction occurring at the interface with biogeochemistry (e.g. Erftemeijer and Middelburg, 1995; Pedersen et al., 1997). A consequence of the lack of tradition to coordinate research efforts in seagrass ecology is that no large scale cooperative efforts, similar to initiatives on other aspects of marine sciences (e.g. IGBP program), have emerged as yet. In turn, the role of seagrass ecosystems is consistently neglected by large scale programs, despite evidence that seagrasses do play an important role in the global carbon budget (Duarte and Cebrián, 1996; Duarte and Chiscano, 1999). The fragmented nature of the community results, therefore, in great uncertainties when scaling up the knowledge produced locally, so that the assessment of seagrass resources at the regional and global scales remains cumbersome.

4.3. Challenges for the new century

Seagrass ecology must progress from the present descriptive stage to synthesis. The empirical observation basis has grown exponentially, and the discipline is now ripe to attempt synthesis, whether through large-scale comparative analyses (e.g. Duarte and Chiscano, 1999) or through attempts to produce general models (e.g. Bach, 1993; Fong and Harwell, 1994; Madden and Kemp, 1996). Comparative analyses encompassing most of the seagrass flora are now possible, such as the analysis of seagrass depth limits (Duarte, 1991a), nutrient content (Duarte, 1990), stable isotope composition (Hemminga and Mateo, 1996), and clonal growth (Marbà and Duarte, 1998). Synthesis must extend to all aspects of seagrass ecology, including systematics, where comparative analyses based on molecular techniques are now yielding more parsimonious accounts of the structure and origin of the seagrass flora (Les et al., 1997). The efficient use of the empirical basis available also requires the use of new approaches to synthesize information, such as meta-analyses of experimental research (e.g. nutrient addition experiments), deriving generality from individual results (cf. Downing, 1990). Yet, synthesis can only meet partial success if stemming from loosely assembled collections of independent studies, because imbalances in the distribution of the data and methodology will limit the power of the analyses.

Attempts to provide synthesis will also lead to the development of seagrass ecology as a predictive science. In particular, the power to predict the time course of seagrass decline and recovery following perturbation is badly needed as a basis for management. The role of seagrasses in the ecosystem cannot be sustained on descriptive or circumstantial evidence alone, and seagrass ecology should strongly strive to achieve the power to formulate quantitative predictions on the roles of seagrass meadows, such as the relationship between seagrass and associated fauna, sediment conditions and biogeochemical processes. Efforts to delineate the habitat requirements of seagrasses further (e.g. Dennison et al., 1993) are likely to yield a very useful product for both scientists and coastal managers. Present knowledge on habitat requirements include knowledge on the minimum light requirements of seagrasses, set at about 11% of the incident light (Duarte, 1991a,b). Knowledge on requirements on sediment composition, such as silt content (Terrados et al., 1997), redox potential, sulfide concentrations (Terrados et al., 1999), and nutrient concentrations (Hemminga, 1998) for seagrass growth are now being developed.

Increasing the relevance of seagrass ecology requires that the scale of research be expanded, from the emphasis on the quadrat (typically $<1\,m^2$) to the study of landscapes and or meadows (e.g. Fonseca, 1996; Vidondo et al., 1997). Such studies should also incorporate interdisciplinary approaches to the study of seagrass meadows, as an avenue to acquire more reliable knowledge on their role. This role is known to be important even at the global scale (about 1% of the global marine primary production, and >15% of the excess carbon fixed through marine photosynthesis, cf. Duarte and Cebrián, 1996; Duarte and Chiscano, 1999), but the reliability of the estimates is limited by present uncertainties as to the global extent of seagrass meadows.

The need to progress towards synthesis and large scales remains elusive with the present structure of the research community. Hence, the bottle-neck for the successful elucidation of these challenges can be identified as the capacity of seagrass ecologists to establish a cooperative framework. Such cooperative framework should particularly strive to (1) build the capacity to conduct relevant research where this is still lacking, as a prerequisite to scale these aspects of seagrass ecology to the global level; (2) to establish a global network monitoring seagrass resources, with the dual role of providing a baseline and allowing the detection of change, for seagrass decline coherent across the scale of entire oceanic basins has been reported in the past (e.g. eelgrass wasting disease, cf. Cotton, 1933; den Hartog, 1987); and (3) to incorporate seagrass ecosystems into international programs addressing the health and functioning of the oceans and the sustainable use of coastal ecosystems. Positive steps towards the development of such cooperative framework are, however, emerging, with an operational electronic list (Seagrass Research Discussion List, seagrass_forum@essun1.murdoch.ed) and the establishment of a seagrass network (SEAG-NET), which has been presented at the Third International Seagrass Biology workshop (Quezon City, The Philippines, 19–26 April 1998).

In summary, the present analysis portrays seagrass ecology as a growing science, but also highlights the important imbalances in the distribution of efforts, together with a dominance of descriptive studies, as the main maladies of the discipline. Progress in seagrass ecology will be enhanced by a redistribution of efforts towards the achievement of predictive power, and an emphasis on synthesis and networking of these efforts, which would allow the scaling up of the knowledge from the local to the regional and global scales.

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