28

Mechanisms of Ecosystem Service Production: An Outcome of Ecosystem Functions and Ecological Integrity in Coastal Lagoons

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Abstract

Coastal lagoons provide important ecosystem services, but are simultaneously highly vulnerable. We aim at a better understanding of the mechanisms of ecosystem service production in these ecosystems. Three case studies, based on results obtained during the BACOSA and SECOS projects, identify the impact of the functional organism groups bioturbating zoobenthos, phytoplankton and macrophytes on coastal lagoons. These empirical results are merged with a theoretical framework on the relations between ecological conditions and ecosystem services, consisting of an integrative matrix projection. RESPON (relative ecosystem service potential) points are estimated for the three case studies. All functional groups have an overall positive effect on ecosystem services, and a very high impact on integrity parameters such as biodiversity, trophic efficiency and nutrient retention. The highest scores are obtained for macrophytes, while

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H. Schubert, F. Müller (eds.), *Southern Baltic Coastal Systems Analysis*, Ecological Studies 246, https://doi.org/10.1007/978-3-031-13682-5_28

phytoplankton only has a slightly positive impact. For bioturbation, a major lack of knowledge was identified; bioturbating zoobenthos with high biodiversity is assumed to favour "seafloor integrity". Despite major difficulties such as lack of knowledge and highly different approaches, our analysis results in specific recommendations for management and future research. Management must consider the high connectivity of coastal lagoons with other ecosystems. Harsh impacts destroying benthic fauna communities have to be minimized. The promotion of submerged vegetation, which is an important provider of ecosystem services, must be implemented in the management of coastal lagoons.

28.1 Introduction

Since the growth phase of the ecosystem service (ES) concept has started by the end of the last Millennium, there has been the central question *"which are the mechanisms of ecosystem service production?"*, which honestly has not been answered satisfactorily till today for many ES and ecosystem types. One reason may be the enormous complexity, which surrounds the ecosystem service idea in human-environmental systems. Also the differences between the numerous single services do not support an easy comprehension. And additionally, the distinctions between scientific concepts in different disciplines may impede fast answers to this strongly interdisciplinary question. Although the problem of understanding the interactions between ecosystem structures, functions and services has been investigated from several aspects in the past (Barbier et al. 2011; Harrison et al. 2014; Liquete et al. 2016; Maes et al. 2016; Pascual et al. 2016; Erhard et al. 2017; Roche and Campagne 2017; Rodrigues et al. 2017; Grizzetti et al. 2019; Hammerschlag et al. 2019; Rullens et al. 2019; Teixeira et al. 2019), many questions are still unanswered.

Therefore, we try to illuminate some related aspects of this problem area for the investigated marine—coastal ecosystems: How can we connect ecosystem services and the empirical, ecosystem-based results achieved during the BACOSA project (see Chaps. 11, 12, 13, 18, this volume) to better understand the complex relations between ecological conditions and ecosystem services? This demand leads to more detailed questions, which are elaborated within this chapter:

(a) How can we better understand the production of ecosystem services on the base of intensive ecosystem research activities (case studies)?
(b) Which management- and research-related recommendations can be formulated based on these results?

In order to find answers to these questions, we have carried out three evaluative "thought experiments" based on the results of the BACOSA analyses of different coastal lagoons, thereby analyzing the impacts of three functional organism groups (bioturbating zoobenthos, submerged macrophytes and phytoplankton) on ES production.

These case studies are used to discuss the focal questions on the relations between ecosystem service production and dominating organisms of coastal lagoons. Consequently, this chapter was structured into a short description of the theoretical framework, some information on the methods and explanations of the three functional case studies. Subsequently, they are merged towards the focus of the ecosystem service approach, the outcome is discussed and some conclusions are drawn, thereby considering the impact of environmental conditions on species composition. The results of empirical ecological studies in coastal water bodies of the Southern Baltic Sea are combined with the outcomes of the ecosystem service studies. Thereby, highly quantitative results are linked with rather qualitative assessment strategies. This highlights a number of conceptual uncertainties, which are discussed, but still allows to draw major conclusions for both future research and management, which are presented at the end of the chapter.

28.2 The Theoretical Framework

The methodological starting points of this exercise were (i) the basic knowledge of ecological functions in coastal ecosystems, (ii) the results of six years research in the BACOSA and SECOS projects, (iii) long-term experience in regional analyses of the research area and (iv) recent theoretical ideas on the relations between ecosystem conditions and services (see e.g. Kandziora et al. 2013; Schneiders and Müller 2017). This last point can generally be described by the concept of the ecosystem service cascade (Haines-Young and Potschin 2010). Following the Chaps. 2 and 6 of this volume, ecosystem structures and processes are aggregated to the class of ecosystem functions, which have certain capacities to provide ecosystem services. The respective contributions to human welfare—the ecosystem services themselves—support benefits to humans and are therefore valued positively by the society. Consequently, the questions of this chapter are excerpts from a comprehensive network of interrelations in human-environmental systems; they focus on the biological and ecological relations that combine biotic and abiotic processors into functions, and value procedures of deriving services from these functions. Thereby, the role of biodiversity for the provision of ecosystem services is an important question.

Figure 28.1 highlights some of these aspects following Schneiders and Müller (2017): Self-organized ecosystem interactions form ecosystemic process bundles (e.g. carbon flows, nutrient flows), which link biotic active life-supporting processes to abiotic gradient structures. These processual components are integrated at the level of functions. The single features can be indicated by ecological integrity parameters, which include ecological process bundles, reflecting important carriers of ecosystem resilience and development (Müller et al. 2016). Furthermore, these processes are the basis for ecosystem service supply capacities and often summarized by the term ecosystem condition (Maes et al. 2016, 2018; Rendon

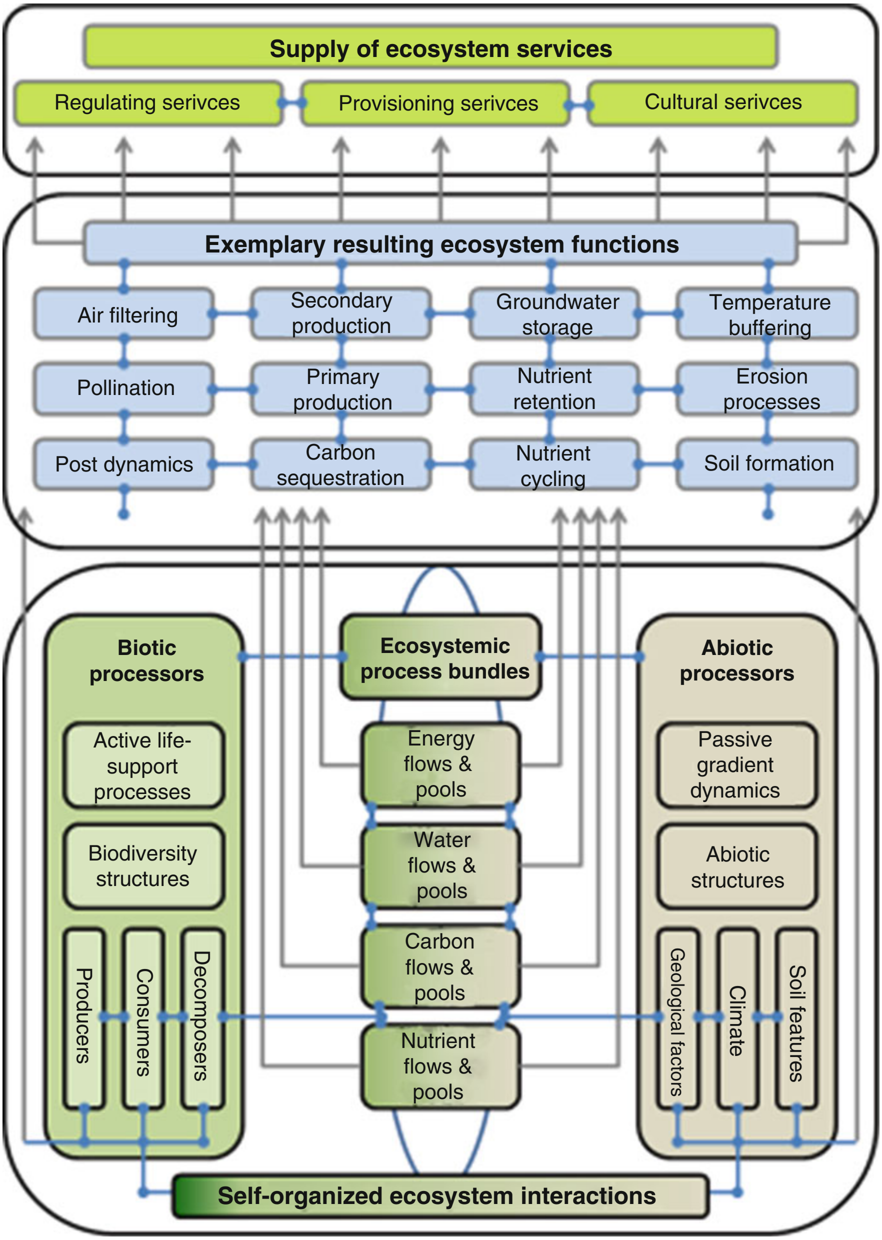

Fig. 28.1 Basic model of ecosystem service production referring to the cascade model of Haines-Young and Potschin (2010) after Kandziora et al. (2013) and Schneiders and Müller (2017)

et al. 2019). Figure 28.1 shows some of these components. On the third level of this figure, different functional components are combined with selected single processes to construct direct influence clusters towards human well-being. Thereby, each service is produced by distinct ecological components. Consequently, the ecological derivation of ecosystem service potentials turns out to be a very arbitrary, utility-focused selection mechanism. In contrast to the ecological integrity parameters, ES do not provide a holistic representation of the system, but are strongly concentrated on processes which support human welfare.

28.3 Methodological Starting Point

The following abstract assessments are based on the quantitative investigations of the projects SECOS and BACOSA as well as long-term investigations in the research area presented in this book (see Chap. 4).

Also the ecosystem service methodology was developed within the SECOS and BACOSA projects. As an outcome of multiple ecosystem service assessment approaches (see Chaps. 7 and 8 of this volume), an integrative ecosystem service matrix assessment was developed, which was applied to terrestrial, coastal and marine ecosystems (Schumacher et al. this volume; Müller et al. 2020; Bicking and Müller 2019; Burkhard et al. 2014). This matrix assesses the capacities of different ecosystem types to provide different ecosystem services. The resulting scoring system is based on an expert-guided relative assessment of ecosystem service potentials (RESPON) with basic values between 0 (no potential) and 100 (very high potential). The scores were derived from direct and indirect measurements (e.g. Kroll et al. 2012), expert assessments (e.g. Burkhard et al. 2009), regional statistics (e.g. Bicking et al. 2018), field tests (e.g. Stoll et al. 2015) and modelling results (e.g. Bicking et al. 2019), see also Chap. 24 and Müller et al. (2020).

In the following three case studies, we present the impact of three functional organism groups on the ecosystem service potentials of inner coastal ecosystems, based upon the data acquired from the investigation areas Darß-Zingst Bodden Chain (DZBC) and Vitter Bodden (VB) (see Chap. 4), long-term ecological data from the DZBC, and knowledge from a number of coastal lagoons.

28.4 The Case Studies

28.4.1 Case Study I: Bioturbation

The term “bioturbation” addresses “all transport processes carried out by animals that directly or indirectly affect sediment matrices” (Kristensen et al. 2012, p. 285), including transport of particles and solutes within the sediment and across the sediment–water interface (Fig. 28.2). This transport is mainly driven by benthic infauna activities, e.g. sorting of sediments for food particles, burrow construction

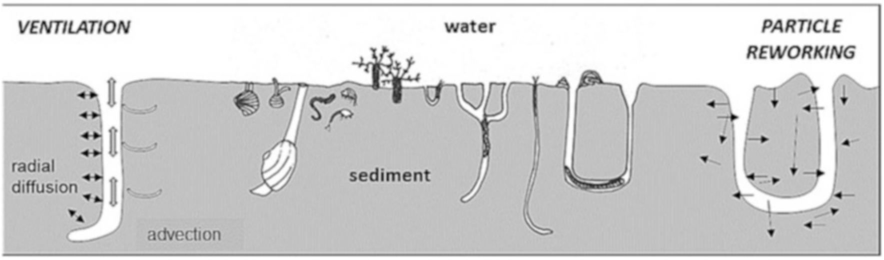

Fig. 28.2 Schematic illustration of bioturbating animals: major processes leading to fluid and particle transport in italics; arrows indicate the directions of biologically driven exchange processes. Processes illustrated: radial diffusion and pore water advection along burrows, random particle displacement during digging and maintenance of burrows. (based on an unpublished sketch by J. Renz)

and burrow ventilation. Transport by bioturbation frequently dominates over physical transport processes in marine environments shallower than 1000 m. Therefore, it is considered important for benthic–pelagic exchange and early diagenesis.

Marine scientists generally regard bioturbation as important for supporting seafloor integrity (descriptor 6 in MSFD[1]) and the well-functioning of benthic ecosystems (Smith et al. 2016). Bioturbating organisms build up structures, affect the flow of matter and energy, and therefore shape “process bundles” (compare Fig. 28.1) integral to the way soft bottom aquatic ecosystems function and supply services. An illustrative way of looking at this effect is to ask what would be different if there was no bioturbating fauna. Today some anoxic deepwater areas in, e.g. the Black Sea and the Baltic Sea, display constrained but permanently anoxic sediments. Here bacterial life thrives, but no multicellular organisms, similar to times prior to the Cambrian Explosion some 500 million years ago. Under such circumstances, the material deposited on the sea floor forms undisturbed laminated sediments, where carbon preservation tends to be higher than in situations when oxygen is available and bioturbation occurs (Canfield 1994; Bockelmann et al. 2007).

Benthic animals function as “*ecosystem engineers*” that facilitate the occurrence of other species enhancing diversity (Jones et al. 1994). Structures like burrows and tubes created in the sediment are conduits of O_2 injected into largely anoxic sediments, thereby changing redox conditions. At the sediment-water interface mounds and tubes interact with water flow to exchange solutes and particles with the overlying water (Huettel et al. 1996). Surface structures also affect erosion and deposition at the sea floor (Friedrichs et al. 2009). Thus bioturbation enhances diagenetic processes and element cycling in most soft sediment ecosystems, diversifying nitrogen cycling (Aller and Aller 1998; Laverock et al. 2013), immobilizing phosphate, and affecting sulfur-, iron- and manganese cycling (van

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[1] “Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected” according to https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-6/index_en.htm

de Velde and Meysman 2016). In this context burial of many compounds decreases, but CO_2 liberation and transfer of energy into the food chain increase.

Bioturbation, however, is not one single or uniform process, which we could relate to ecosystem services in a simple or general manner. Brittle stars move sediment grains by pushing them laterally for short distances along the sediment surface, while the sand piper *Arenicola marina* moves grains more than 20 cm vertically within the sediment. Many organisms discriminate among particles according to their size or in search of food (Wheatcroft 1992; Graf 1992; Suchanek 1985; Gebhardt and Forster 2018). This makes particle transport selective, an aspect only marginally captured by current classifications of fauna into traits of bioturbation (François et al. 1997). Time scales associated with particle reworking and fluid pumping vary considerably with major consequences for associated meiofauna and bacteria at burrows, as redox conditions in the sediment fluctuate (Aller 1994; Forster 1996; Volkenborn et al. 2010). Differences in time scales and mechanisms of bioturbation affect reactions of sediment compounds in different ways and therefore may yield different effects. The link between bioturbation (Fig. 28.2) and any particular ES function beyond “integrity of the seafloor” is therefore not easily predicted. The causal link to a specific geochemical or biological effect may be understudied at present; in any case, these links are frequently context-dependent and non-linear in their relation.

An investigation with the flame retardant BDE-99 and cadmium (Hedman et al. 2008) demonstrated how physicochemical characteristics of the pollutant, burrowing depth and burrowing type as well as sedimentary organic matter interact to generate effects of burial versus mobilization. Bioturbation may trigger opposing effects, particularly when material reaches the so-called burial depth and is removed from ecological cycles for longer periods. Mixing exposes reactive fresh particle surfaces that support the adsorption of metals and organic pollutants, but is strongly dependent on the active biological species (Kristensen et al. 2011; Banta and Andersen 2003). As a result, some sediments may become sinks for pollutants. Conversely, with oxygen transport by fauna into the sediment leading to more mobile oxidized heavy metal compounds compared to sulfidic immobilization, sediments may become pollutant sources (Kersten 1988; Förstner and Salomons 1988; Hedman et al. 2008). Mixing of fresh and refractory carbon sources stimulates overall carbon degradation (Kristensen and Holmer 2001) and therefore CO_2—liberation from the sediments. Also the degradation of oil products is more efficient when infauna pump O_2-rich water into sediments (Christensen et al. 2002, Timmermann et al. 2002, 2003; Banta and Andersen 2003; Gilbert et al. 2001, 2003).

Generally, enhanced oxidation of sediments (by bioturbation) results in immobilization of soluble phosphate (PO_4^{3-}) through adsorption to particles (Forster and Bitschofsky 2015; Bitschofsky et al. 2015; Bonaglia et al. 2013; Thoms et al. 2018; Karlson et al. 2005), which counteracts a negative feedback between hypoxia in sediments and water column primary production (Conley et al. 2002). Some investigations show, however, that phosphate may be pumped from deeper anoxic sediments to the overlying water, if sufficiently deep-burrowing tube dwelling animals are abundant (Thoms et al. 2018; Renz and Forster 2014). Similarly, tube dwellers may stimulate denitrification to gaseous N_2, a process with remediation potential counteracting eutrophication. While this is evident from modelling and laboratory experiments of mostly single species (Pelegri and Blackburn 1996; Pelegri et al. 1994; Gilbert et al. 2003), it has been infrequently found in field studies, where species composition and abundance vary (Deutsch et al. 2010; Tuominen et al. 1998). The alternative bacterial pathway leading from nitrate to ammonia (DNRA), which is largely irrigated back to the overlying water, occurs in less oxidized sediments and retains N as ammonia in the system. In this case, there is only a small abatement effect on eutrophication (Karlson et al. 2005; Bonaglia et al. 2013).

Beyond the results from many specific bioturbation studies, our current knowledge suggests that mainly the degree to which animals increase the state of oxidation of a sediment (redox state) regulates net exchanges of N and P with the water column. Apart from burrow geometry, several regulating factors and their spatial and temporal dynamics are yet insufficiently understood. Interactions with bacterial performance, species- or trait-specific effects and the dependence of ES on density and composition of macrofauna communities determine the overall effects of bioturbation. Bioturbation is important in generating functions and ES. While there is a need for more research to understand how these services emerge under specific conditions, most ecosystem functions and ecosystem service production in this context are clearly related to the integrity of the benthic ecosystem. With respect to the demands of environmental practice, we utilized the recent cognition on bioturbation processes in order to assess their potential influences on the capacity of ecosystem service supply, realizing the multiple related causes of uncertainties.

28.4.2 Case Study II: Macrophytes

Submerged macrophytes have a “key function“in shallow aquatic ecosystems. Due to a number of feedback mechanisms, they increase water clarity, retain nutrients, thereby causing a reduction of phytoplankton densities, store carbon, and offer food, substrate and shelter for a number of organisms, including microalgae, zooplankton, macroinvertebrates, fish and waterfowl (Scheffer et al. 1993; Blindow et al. 2014; see Chap. 13).

In shallow aquatic ecosystems, submerged macrophytes therefore offer a number of support mechanisms for ecosystem service production. Enhanced water clarity and lower phytoplankton densities, including a reduction of toxic cyanobacteria blooms, improve the water quality and enhance the suitability of the ecosystem for touristic utilization, especially bathing. Both high availability of plant and macroinvertebrate food increase the ecosystem’s attractiveness for waterfowl (Milberg et al. 2002). Combined with enhanced water clarity, high densities of zooplankton and macroinvertebrates in areas with dense submerged vegetation improve predation efficiency and growth rates of fish (Persson and Crowder 1998; Hargeby et al. 2005). Additionally, submerged vegetation serves as reproduction habitat for fish. In the Greifswalder Bodden, the recruitment of herring has been assumed to have decreased due to the collapse of submerged vegetation (Kanstinger et al. 2016).

Our investigations in the intensively studied shallow lagoons VB and DZBC confirm this importance of submerged macrophytes (see Chap. 13). In spite of lower nutrient concentrations in the VB, total system net photosynthesis rates are far higher. Additionally, ecological transfer rates are far higher in this macrophyte-dominated system (Paar et al. 2021). Both higher net photosynthesis and higher trophic efficiency explain that ecosystem production is far higher in all trophic levels, including organisms that are of interest for human nutrition or recreation, such as fish and waterfowl (see Table 28.1), compared to the more nutrient-rich DZBC. Such a "paradox of enrichment" has for the first time been shown for shallow coastal ecosystems (Paar et al. 2021; see Chap. 13).

Transitions from a macrophyte-dominated to a phytoplankton-dominated state are thus crucial for ecosystem services. Unfortunately, such transitions are hard to predict due to a non-linear response of shallow aquatic ecosystems to external impacts such as changes in nutrient loading. Our investigations during the BACOSA project support the assumption that the shallow coastal lagoons of the Baltic Sea occur in two possible "alternative stable states", one of which characterized by clearwater and abundant submerged vegetation, the other characterized by phytoplankton dominance and turbid water (Meyer et al. 2019; Chap. 13). While the DZBC has been in a turbid state since a decrease of the submerged vegetation in the 1970s and 1980s (Walter 1973; Behrens 1982; Chap. 12), the VB is still dominated by dense submerged vegetation. A number of factors, however, indicate that this system is close to a so-called "tipping point", where small external disturbances may cause a "switch" and therefore, have a major impact on ecosystem conditions and services.

Ecosystems dominated by macrophytes have been shown to efficiently retain nutrients and store carbon. Coastal lagoons with a rich macrophyte vegetation therefore have an important function as filters between terrestrial (mainly anthropogenic) inputs and the open Baltic Sea (Asmala et al. 2019; Carstensen et al. 2020). In the investigated region, this function has been deteriorating substantially during the last decennia, due to a decrease of submerged vegetation caused by eutrophication. The DZBC and other estuarine lagoons have already lost their former rich macrophyte vegetation. Though these lagoons still retain a major part of the external nutrient input due to geomorphological and hydrographic conditions (Lampe et al. 2013), their filtering capacity is assumed to be far lower due to the short life span, high metabolism and elemental content of phytoplankton, which enhances turnover rates of carbon and nutrients (Villnäs et al. 2019). The outer marine lagoon VB is still in a macrophyte-dominated state. A change in species composition has occurred, however, from small, "bottom-dwelling" plants such as charophytes, to tall "canopy-formers" which retain nutrients less efficiently (Blindow et al. 2014, 2016). Together with different indications of high system variability and instability (see Chap. 13), this suggests that also the filtering capacity of this ecosystem already has decreased (Fig. 28.3).

The results obtained during the BACOSA project support earlier investigations which show that submerged macrophytes have a substantial positive impact on all

Table 28.1 Expert valuations (I) of the ecosystem service potentials (RESPON values) and spans of the expert assessments (II) of bioturbation, macrophytes and phytoplankton

		(I) Mean relative RESPON scores due to the impacts of (A), (B) and (C)			(II) Wingspan between minimum and maximum assessments of experts in (I)		
	Indicators	(A) Bioturbation	(B) Macrophytes	(C) Phytoplankton	(D) Bio-turbation	(E) Macro-phytes	(F) Phyto-plankton
Integrity attributes	Abiotic heterogeneity	24	25	3	10	10	20
	Biodiversity	25	29	2	5	5	25
	Ecosystem net primary production	-1	20	14	25	15	20
	Nutrient retention	13	18	9	20	20	40
	Trophic efficiency	17	22	4	20	15	40
	Storage capacity	8	18	6	40	20	10
Provisioning services	Crops (human nutrition)	3	3	0	10	10	10
	Biomass for energy	1	7	2	5	10	10
	Crops (fodder), aquaculture	3	4	0	5	10	0
	Livestock	4	3	2	5	10	10
	Fibres	1	2	0	5	20	0
	Wild food	11	8	7	20	25	15
	Fish and Seafood	12	16	6	25	30	10
	Flotsam	0	7	1	1	45	20
	Ornamentals	0	2	0	0	10	0
	Abiotic energy	0	0	0	0	0	0
	Minerals	0	0	0	0	0	0
Regulating services	Local climate regulation	0	2	0	0	10	0
	Global climate regulation	1	13	13	45	30	15

	Flood protection	-2	7	0	10	30	0
	Air quality regulation	0	0	0	0	0	0
	Erosion regulation, water	1	17	1	25	10	5
	Nutrient regulation	26	20	1	10	20	15
	Water purification	6	15	2	30	30	10
	Pest and disease control	5	7	−5	10	20	20
	Pollination	0	2	0	0	10	0
Cultural services	Recreation and tourism	7	0	−14	10	40	25
	Seascape aesthetics	7	11	−5	10	20	10
	Knowledge systems	7	6	5	10	20	10
	Cultural heritage	2	6	5	10	10	10
	Regional identity	2	6	0	10	20	0
	Natural heritage	14	14	2	10	20	10
	Sums:	197	308	60	386	535	360
	Average values:	6,2	9,6	1,9	13,1	16,7	11,8

The highest RESPON scores for every parameter are marked blue

Values indicate the size of deviation for the case studies A, B, C from the average values in the original assessment matrix (see Müller et al. 2020; Schuhmacher, this volume), where the overall potential has been characterized by scores between 0 and 100. A value of 20 means that the average value for coastal aquatic systems is enlarged by 20 points under the respective scenario conditions

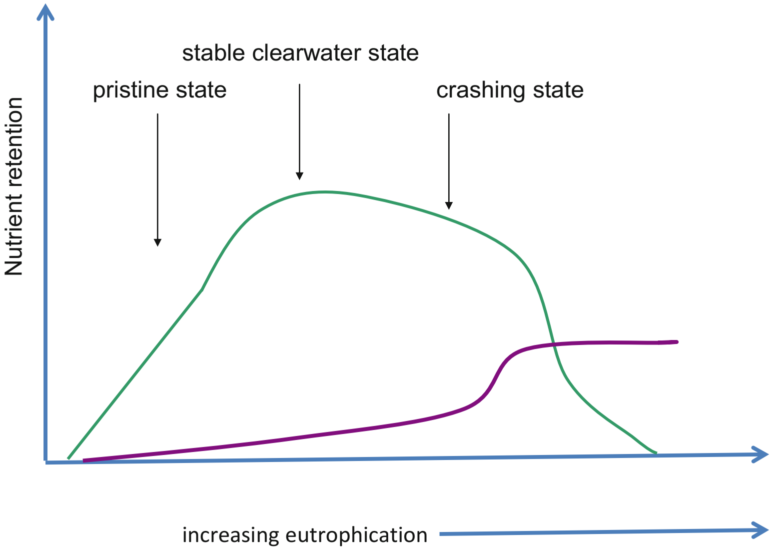

Fig. 28.3 Assumed nutrient retention by macrophytes (green line) and phytoplankton (violet line) in a eutrophication gradient. Note that in the crashing state, macrophyte biomasses are high, but the vegetation period is shortened causing a decrease in nutrient retention

integrity attributes. They provide a complex, three-dimensional structure with high biomass and abiotic heterogeneity, which stores substantial amounts of nutrients and carbon and forms the basis of a complex, species-rich food web with high trophic efficiency. We assume a positive impact on the provisioning ecosystem service "fish and seafood production". Results obtained during the BACOSA project show higher trophic efficiency in all trophic levels in the macrophyte-dominated system, and higher growth rates of perch, a commercially important piscivorous fish. Among regulating services, strong impact is assumed on nutrient regulation and water purification. Contrasting impacts are assumed on the cultural service "recreation": While submerged vegetation has a distinct positive effect on water quality, dense vegetation may impede activities such as boating, wind-surfing and bathing. A positive effect is expected on bird-watching.

28.4.3 Case Study III: Phytoplankton

Phytoplankton supports and generates many ecosystem services. As the main contributor to primary production in most aquatic ecosystems, phytoplankton produces oxygen and provides food for zooplankton and zoobenthos. Phytoplankton stores and retains nutrients, and increases energy transfer to higher trophic levels (Schubert 1984).

While these positive effects of phytoplankton are mainly observed/described at low or moderate nutrient conditions, eutrophication causes an increase in

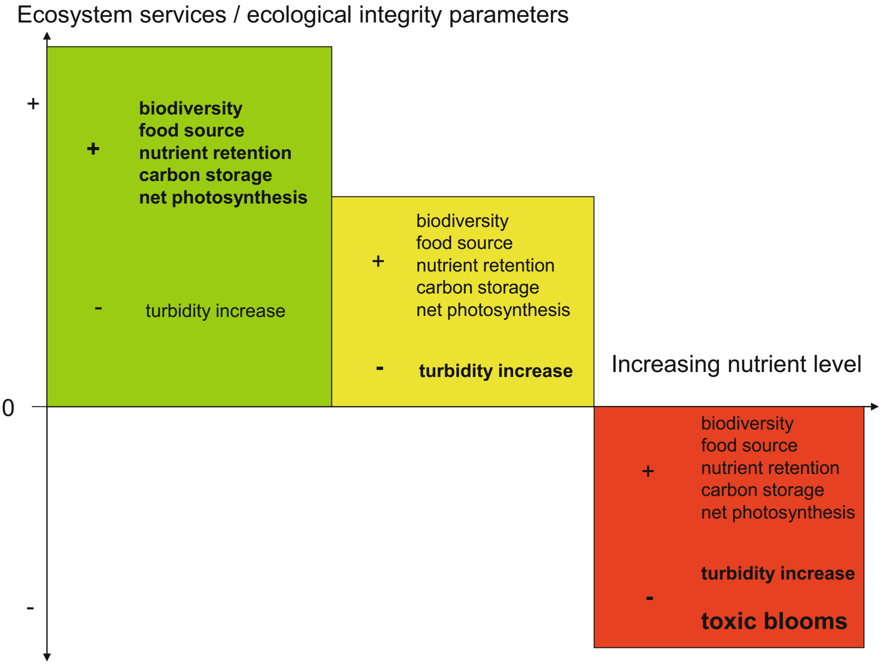

Fig. 28.4 Impact (relative scale) of phytoplankton on ecosystem services and integrity parameters along a eutrophication gradient. Strong impacts are indicated in bold. Note that two different phytoplankton conditions can be distinguished in highly eutrophicated ecosystems depending on absence/presence of toxic species

phytoplankton biomass, but often dominance of one or few taxa and thus a decrease of phytoplankton species richness (e.g. Bužančić et al. 2016). Eutrophication is also accompanied by an increase of negative effects from phytoplankton on ecosystem services and integrity parameters, which therefore can become negative in highly eutrophicated ecosystems (Fig. 28.4) Such “disservices” have also been described for other ecosystems (Dunn 2010; Schaubroeck 2017). Higher turbidity causes a decline of submerged vegetation (see Chap. 13; Fig. 28.3), which reduces the ecosystem services provided by this vegetation (see above). Additional negative effects of increasing phytoplankton biomass may be a reduction of food web structures and decrease of niches, overall lower species richness and a lower nutrient retention, coupled with increasing self-shading (Paar et al. 2021).

Upon strong eutrophication, phytoplankton blooms develop, which can be toxic at dominance of certain species of cyanobacteria and dinoflagellates. These blooms are harmful to humans, directly by poisoned food sources, and by indirect negative impacts (Karjalainen et al. 2008). Toxic blooms can occur in almost all aquatic ecosystems. Blooms also cause a self-limitation of the depth-integrated phytoplankton production. The negative impact of this situation on the ecosystem depends on the specific conditions, ratios between phytoplankton and macrophytes, and the respective food web structures (see Chap. 13).

Phytoplankton impact on ES is highly depending on its composition and density, which in turn is mainly influenced by eutrophication. Phytoplankton has positive impacts on all ecosystem integrity parameters, such as biodiversity, nutrient retention, trophic efficiency and carbon storage capacity, but especially on system net primary production (Paar et al. 2021; see Chap. 12). Due to this high primary productivity, phytoplankton also contributes to the provisioning service "fish and seafood production" and, due to carbon dioxide assimilation, to the regulating service "global climate regulation". At high densities and especially during blooms, however, phytoplankton has a negative impact on the cultural services "recreation and tourism" and "seascape aesthetics". Decreasing water transparency is a matter of concern especially among tourists, as the water appears as "dirty" with a low suitability for bathing. Toxic blooms, decrease of predatory fish and oxygen depletion have serious impacts on ES of shallow coastal waters. Especially cyanobacterial blooms gain high public attentions, as shown by newspaper reports in most summers.

28.5 Merging the Case Studies and the Theoretical Framework

The analysis above shows that all three functional organism groups imply important boundary conditions for the integrity of the related ecosystems (see Müller 2005; Müller and Burkhard 2010; Müller et al. 2010, 2020; Haase et al. 2018), as well as potentials to provide important ecosystem services. Following the rules of the ecosystem service matrix approach that have been described above (see Schuhmacher et al. this volume, Müller et al. 2020), the authors have searched for correction values, which should be connected to the basic matrix data, if one of the three functional groups is dominant. The maximal influence was defined by the value of 30 positive or negative RESPON points (relative ecosystem service potential, an overall span between 0 [no potential] and 100 [maximum potential]) characterizing the impact of the functional groups.

Table 28.1 shows these consequences for the three investigated case studies. Among single ecological integrity attributes, the factors heterogeneity, biodiversity and trophic efficiency receive a strong support by bioturbation and by macrophytes, while phytoplankton only has a moderate effect on these state values. Here, only the amount of energy taken up by the system (net primary production) is strongly increased. Compared to the impacts on ecological integrity, the influence on the ecosystem service classes seems to be rather low. Only wild food, fish and seafood are supported by bioturbation and macrophytes, in a smaller amount also by a phytoplankton. Among the class of regulating services, large effects have been assessed for phytoplankton and macrophytes on global climate regulation potentials due to high photosynthesis rates. Nutrient regulation is mainly affected by bioturbation and macrophytes. Finally, the cultural services are profiting from bioturbation

Table 28.2 Average RESPON scores of the expert assessments

	Average RESPON score	Average standard deviation	Average span of expert assessments	Average degree of expert uncertainty (0–3)	Average span of expert uncertainty (0–3)
Bioturbation	6,2	6,8	12,1	1,0	1,3
Macrophytes	9,7	5,3	17,0	1,2	1,9
Phytoplankton	1,9	4,9	11,3	1,0	1,2

Table 28.3 Average RESPON scores of the expert assessments related to ecosystem service and indicator classes

	Bioturbation		Macrophytes		Phytoplankton	
	AVG RESPON score	AVG Span	AVG RESPON score	AVG Span	AVG RESPON score	AVG Span
Ecological integrity	14,3	20,0	22,0	14,2	6,3	25,8
Provisioning services	3,2	6,9	4,7	15,5	1,6	6,8
Regulating services	4,1	14,4	9,2	17,8	1,4	7,2
Cultural services	6,5	10,0	7,2	21,7	−1,2	10,8

and macrophytes, while at high phytoplankton densities, the attraction for recreation and the seascape aesthetics is strongly reduced.

The right part of Table 28.1 adds the respective uncertainties by comparing the spans of the answers, which generally are high. In the bioturbation scenario, especially storage capacity, global climate regulation and water purification have high spans. They are mainly related to the question, whether the activity of the bioturbators increases the flows into the sediment, or whether releases from the sediment into the water body are dominating. This partly reflects the fact that the identity of benthic species in conjunction with the chemical matter in question may indeed generate substantially different and even opposing results. With respect to macrophytes, the uncertainties are highest on the relations with fish and seafood, floatsam, climate regulation, flood protection, water purification, and recreation. Finally, in the phytoplankton scenario, the spans are somewhat smaller, culminating in context with nutrient regulation and trophic efficiency. Overall, the largest problems for the evaluators appeared in context of crops (because in the Baltic environment the consumption of algae is a very small flow), floatsam (because the beachwrack can also be comprehended as a disservice), and knowledge systems (because one can learn from any constellation).

Tables 28.2 and 28.3 summarize these results: The highest effect on the overall ecosystem service potential can be ascribed to macrophytes, while bioturbation delivers a medium overall support. Phytoplankton gives smaller services, in a severely eutrophicated ecosystem even causing negative changes. The uncertainties of the assessing four scientists with expertise in empirical ecological investigations or ecosystem services, all familiar with the results obtained during the single case studies, are similar for the three functional groups (Table 28.2). Among the consequences for different ecosystem service types (Table 28.3), all functional groups have strongest, and the most direct influences on the ecological integrity attributes. The bioturbation scenario also supports cultural services, while the smallest influence relates to the provisions. Macrophytes have some effects on regulations. In phytoplankton, the cultural services receive negative average values, due to the severe impacts in the eutrophicated situation.

Figure 28.5 depicts the average assessments of the ecosystem service potentials (RESPON values) provided by the three functional groups in front of the respective span widths. Both values are highest in the macrophyte scenario, qualifying this functional group as the most valuable providers of ecosystem services. Bioturbation seems to support services in general on a medium level, while the phytoplankton scenario delivers the smallest service potentials.

The spider diagram of the bioturbation case study demonstrates that high potential values arise concerning ecosystem structures (e.g. heterogeneity, biodiversity), fish, and nutrient regulations. The experts' disagreements (spans) show summits referring to storage, global climate regulation and water purification. Here the outcome strongly depends on the system's situation, whether it releases sediment containments to the water body or whether it buries nutrients and carbon available in the water body into the sediment.

The overall effect of the ecosystem service potentials provided, as discussed before, becomes visible in Fig. 28.6: Here the basic values have been taken from the matrix values as described by Schuhmacher et al. (in this volume). We have chosen the evaluations for the ecosystem type "Lagoons & Estuaries (1130 & 1150), WFD type B1/B2: non-vegetated clay & mud" and have then applied our case study scenario results to this basic data set. In the Figures, the resulting data for a lagoon ecosystem are combined with the RESPON values for bioturbation, macrophyte dominance and phytoplankton dominance, respectively. For all cases studies, Fig. 28.6 shows the initial value from the Schumacher-matrix, the result obtained by combining these values and the deviation data from this study and the respective span as a measure of the inherent uncertainty of the analysis. We can find several similarities due to the original basic data, with peaks at the positions of fish and seafood provisions, global climate regulation, water purification and a relatively high valued block of cultural services. The highest values appear in the macrophyte scenario, and the lowest are again visible in the phytoplankton case study. Here the addition of the scenario conditions even reduces some of the individual service assessments.

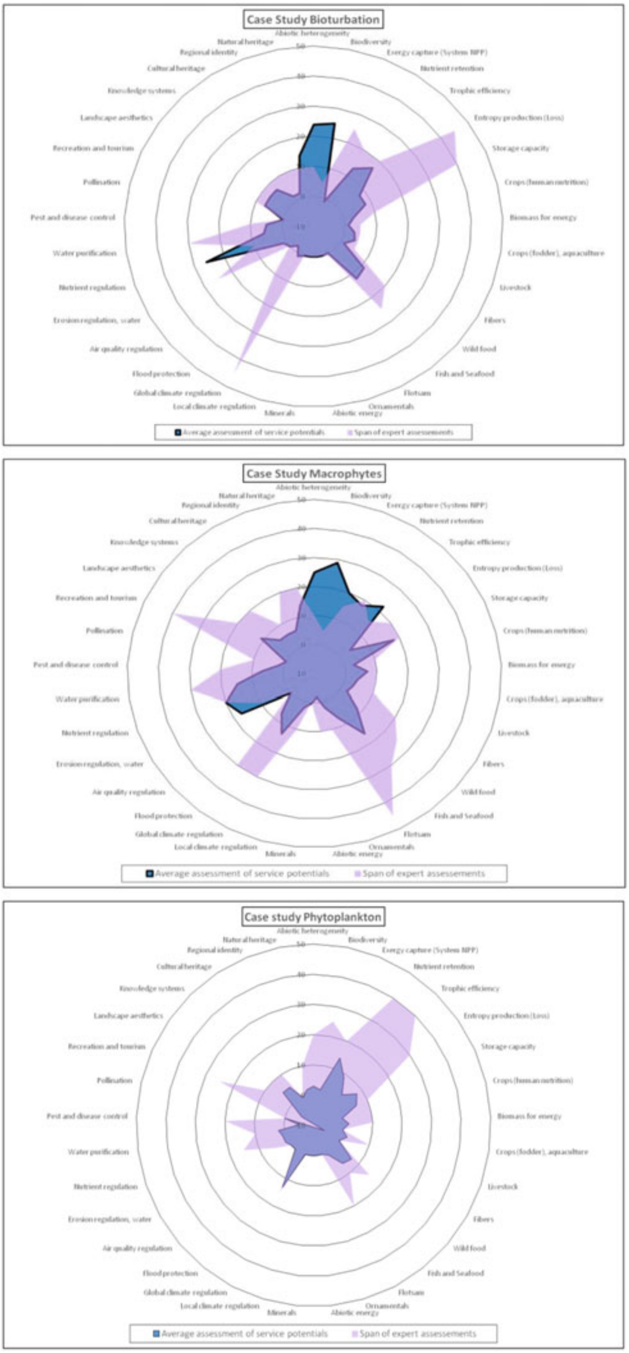

Fig. 28.5 Average relative ecosystem service potentials (RESPON values, blue) and span of expert assessments (pink) for the three case studies. The generalized influences were assessed within a data area from −30 (very strong reduction) to +30 (very strong increase)

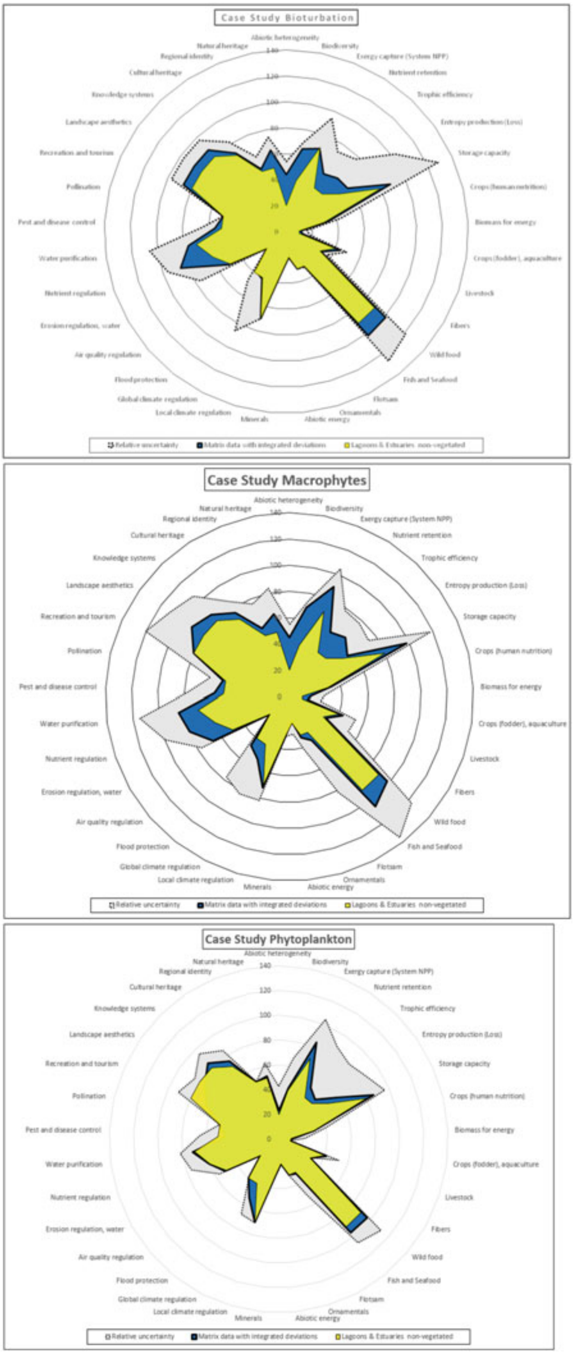

Fig. 28.6 Integrating the values for "Lagoons & Estuaries" from the matrix of Schumacher et al., (this volume, green) for non-vegetated lagoons and ecosystems with the average relative ecosystem service potentials (RESPON values, blue) and span of expert assessments (grey) for the three case studies

28.6 Discussion

28.6.1 Linking Empirical Ecologists to Ecosystem Service Specialists

In this chapter, we made an attempt to combine empirical ecosystem analysis with an expert-based ecosystem service assessment, in order to contribute to a joint understanding of ecosystem service production mechanisms. Three case studies were chosen, which had been analyzed in detail within the BACOSA and SECOS projects, as examples for intensively investigated, functionally important organism groups of coastal habitats. The necessary transformation from quantitative empirical analysis to more qualitative assessment procedures was accompanied with several productive outcomes, mainly for a better understanding of single services and for the recurring realization of complexity and locality—but also with methodological problems and interdisciplinary reservations. For the empiricist, the assessment techniques were filled up with unauthorized uncertainties on hardly walkable pathways, while the ecosystem service specialist side was wondering about the extraordinary demand for hesitations and discussions based on trifles and details. So we experienced a typical dispute between different degrees of reductionism and holism, fortunately ending in constructive emergent properties.

28.6.2 Linking Ecological Investigations to Ecosystem Service Production

All three case studies describe the intricate interactions between the environment and a “functional organism group” (bioturbating zoobenthos, submerged macrophytes and phytoplankton). As already shown in numerous investigations, all three functional groups affect the whole ecosystem to such an extent that ecosystem structure and functioning differ considerably depending on the abundance of this functional group. Such organism groups therefore have been called “key organisms” in ecological investigations (Goggina et al. 2017). Here, we present for the first time quantitative estimates of the major impact of such “key organisms” on the ES potentials in shallow coastal lagoons, supported by the high RESPON scores achieved in all three case studies.

Our investigations within the BACOSA project further show that there is not “the” coastal lagoon, but that single lagoons differ considerably in food web structure and functioning. Apart from “key organism” dominance patterns, hydrological characteristics and anthropogenic impact, especially eutrophication is responsible for these differences (see Chap. 4). Consequently, ES potentials differ considerably among single coastal lagoons.

Ecological interactions are intricate. Abiotic and biotic components are interlinked in a web-like pattern of mutual interrelationships. Anthropogenic impact has a major influence on dominance patterns of organism groups, including “key organisms”, while “key organisms” are able to modify their abiotic “frame” conditions, often to a substantial extent. Further, a direct transfer from ecological characteristics to ES is not possible. Finally, ecosystems including their "key organisms" are not only affected by anthropogenic impact, but react on and modify this impact, which has to be considered in management measures.

Thus, differences in methodologies and "languages" used by empirical ecologists and ecosystem service specialists were not the only challenge we had to face during this joint analysis—already the subject per se was all but trivial. In spite of all difficulties, we can draw some stimulating points for subsequent discussions, and finally, give some recommendations for management and future investigations of coastal lagoons.

Although data scarcity is a focal and recurrent starting point for scientific grousing and moaning, we have to realize that we are arguing from a rather luxury position. Concerning applied assessment, our case studies are good examples for interpolations within the matrix approach. The existing matrices (e.g. Burkhard et al. 2014; Müller et al. 2020; Schuhmacher et al. this volume) can depict probabilities for service supplies for a restricted number of ecosystems only. With the expert-based interpretation of the situations in the DZBC and the VB, it has become necessary to define further ecosystem types and to use variations of their structural features. In spite of several doubts, we could show that such an interpolation can be done, thereby increasing the applicability of the matrix approach extremely. This result is also valid with respect to functional units: On the one hand, we have learnt to distinguish the outcomes of bioturbation; on the other hand, the sequences and processes of eutrophication were applied to demonstrate the consequences of functional ecosystem shifts. Based on such experience, also scenarios are applicable.

28.6.3 The Role of Biodiversity

Generally, "biotic processors" (see Fig. 28.1) strongly influence the outcome of functional interaction of ecosystem processes. Specifically, we could not only assess the important roles for ES generation of the "key organisms" investigated, but also show that these roles vary depending on the taxonomic composition and species richness of these functional traits. Thus, not only the density, but also the taxonomic composition of phytoplankton decides upon the delivery of services versus disservices (see Fig. 28.4). Bioturbating organisms can both reduce and enhance carbon sequestration and nutrient storage depending on their taxonomic composition. Different life forms of macrophytes dominate at different trophic states, including lower stability and a weakening of the ES provided by this community at higher nutrient concentrations (see Chap. 13). As a general observation, functional groups with high biodiversity have been shown to provide higher ecosystem stability (Naeem and Wright 2003; Cardinale et al. 2006). Biodiversity is playing a prominent role in ecosystem functioning and consequently, in the production of ecosystem services. Biodiversity was therefore regarded as an important ecosystem service, with some direct impact on cultural services (ecotourism, bird-watching etc.). Biodiversity further has a considerable, but indirect importance for human welfare, via its high impact on integrity indicators.

28.6.4 The Role of Dynamic Changes

As illustrated in detail in Chap. 13, ecosystems do not react linearly on external (including anthropogenic) influences. Dominating functional groups, and especially "key organisms", are able to counteract and "buffer" such impact by a number of feedback mechanisms. Along a gradual change of external conditions such as eutrophication, the ecosystem therefore first seems "unaffected" until a certain threshold is passed and it switches across its "tipping point" (see Chap. 13). Close to the "tipping point, small external disturbances can cause a major, often unexpected change in both abiotic parameters and food web composition, and a similarly substantial change in ES supply.

28.6.5 The Role of Distinct Viewpoints

ES were developed as a tool for comprehensive valuation of all aspects of human-ecosystem relations. Not only different groups of stakeholders, however, disagree in their assessment of specific services, but also experts with a comparable background differed largely in their assessment even of services directly linked to their field of expertise. For some ecology integrity components such as system net primary production or ES such as biomass for energy, quantifiable estimates can be given, but especially cultural services are notoriously difficult to quantify, though empirical values contribute to the outcome also of these ES. To get a balanced valuation, a thorough discussion of the individual aspects of each service is necessary, as experienced in this study. A specific example illustrating the disagreement among experts is flotsam, a natural component of beach ecosystems and generated mainly by macrophytes. Flotsam is often seen as a nuisance by tourists and consequently, recreation resort managers, but may be a valuable resource, an important element for coastal protection by providing nutrients for dune colonization, and enhances biodiversity by providing habitat heterogeneity.

28.6.6 The Role of Scales

A specific characteristic of the investigated coastal ecosystems is their high connectivity. Water exchange rates among the lagoons and from terrestrial ecosystems to coastal lagoons and finally, to the open Baltic Sea are high, resulting in an export of services and disservices to adjacent regions. High nutrient retention in a coastal lagoon may prevent the adjacent open Baltic Sea from eutrophication, but may be accompanied with high phytoplankton densities and therefore reduced water transparency and cultural disservices, such as the lagoon's unsuitability for bathing during an algal bloom. A rewetted coastal peatland may have improved properties, like more diverse flora and fauna, carbon storage and flood protection, but releases phosphorus for decades (Zak and Gelbrecht 2007), which is a great disservice for adjacent coastal lagoons. Unfortunately, ES assessments of rewetted peatlands focus exclusively on functions within these ecosystems (Zerbe et al. 2013). Results from the DZBC illustrate the value and necessity of data with high spatial and temporal resolution. While narrow zones within the reedbelts can release high amounts of phosphorus (Karstens et al. 2015), any phosphorus release from the sediments in the major part of the lagoon could not be shown except for high, but short and rare release events during oxygen drops under ice cover (see Chap. 12). Recent observations that anoxic conditions within the sediment locally "reach out" into the water column (Karstens et al. 2015; Bochert pers. com., Schumann unpublished) raise the question whether the lagoon system in future will retain or release nutrients. The importance of temporal scales is described in detail in Chap. 12, which illustrates short-term and long-term changes of different parameters in the Darß-Zingst Bodden chain. Like other coastal lagoons, this ecosystem is exposed to irregular, short, but drastic water level changes and exchange with the open Baltic Sea. Chapter 12 shows that extreme events such as oxygen drops or drastic water exchange rates influence a number of parameters, e.g. nutrient concentrations and transparency and finally, ecosystem services for a long time period, and illustrates the importance of high-resoluted data sets to identify and quantify the impact of such events. The question of positive or more negative effects of eutrophication or some components of the lagoon, like phytoplankton, depends also on the point of view on system borders.

Ecosystem disservices provided by the highly loaded Bodden systems thus implies a high advantage for the conditions in the open Baltic Sea. Besides these scale distinctions, we also should consider that each ES-producing process is operating on an individual spatio-temporal scale with individual developments and reaction characteristics.

28.6.7 The Role of Uncertainties

There are many causes for uncertainties in such ES assessments. Their formation and their consequences have been discussed in several papers (e.g. Hou et al. 2013; Campagne et al. 2017, 2020; Campagne and Roche 2018) and some methodological consequences have been drawn (see Chap. 24 and Müller et al. 2020). Some of these uncertainties are based on facts beyond our knowledge of structure and functioning of ecosystems, and the interactions and controls generating ecosystem services. Four scientists with different specific expertise estimated/valued changes in ES in response of bioturbation, dominance of microalgae or macrophytes for each of these three scenarios. Their professional backgrounds clearly entail deviating judgments and uncertainty in judging scenarios other than one's own field of expertise. Given that scientists would probably prefer to judge based on facts we consider the uncertainties shown in Figs. 28.5 and 28.6 quite acceptable. Moreover we do not anticipate that these uncertainties will be easily/much reduced once more data are measured in ecosystem studies.

28.6.8 Connecting Ecosystem Services and Empirical, Ecosystem-Based Results

The focal question (see introduction) was related to the connection of ecosystem services and the empirical, ecosystem-based results achieved during the BACOSA project. We have chosen the expert-based matrix approach, and as a result the authors can state that it has been suitable to better understand the complex relations between ecosystem services and ecosystem conditions. Within this experiment, we have not focussed on one or two ecosystem services with good quantitative knowledge bases, but chosen a holistic approach with comprehensive ES bundles. Thereby, we had to accept a substantial gradient between empirical, rather detailed knowledge and systems-based uncertainties; looking at the whole system was in this case, however, more significant than quantifying further details. Applying this starting point, we have to state that a direct transfer of ecological data to integrity attributes (which ARE ecological variables) is possible, but very often data are lacking and mechanisms (impacts of key organisms) still rather unknown. Due to lacking data, it is not possible to give any reliable empirical numbers for nutrient retention or carbon storage of the coastal lagoons studied. Naturally, the derived service valuations cannot be more exact than the sketchy basic data.

In our analysis, we were also able to transfer empirical data into information on ecosystem services. Thereby, the integrity attributes served as “intermediate variables”, as a direct transfer rarely was possible. Several provisioning ecosystem services, such as seafood, aquaculture production and bioenergy can be derived from empirical data such as production of different organism groups. Regulating ES can be derived and indicated basing upon the integrity indicators or ecological modelling results. Quantitative estimations are, however, encumbered with high uncertainties because of a substantial lack of empirical data. We could further estimate the impact of the “key organisms” on cultural ecosystem services, but only provide qualitative values. Summarizing, there are several methodological and strategic problems—although we have been working with an extraordinary data situation—far from the “normal” conditions of environmental decision making. Nevertheless, the answers to the initial queries of this chapter are optimistic:

(a) How can we understand the creation of ecosystem services better?
The case studies illustrate the intricate interrelationships between functional organism groups and ecosystems. In order to deduce at least (complete) ES bundles, not only individual processes should be studied. Different experimental approaches (e.g. Artificial Neural Networks, Bayesian ANOVA) may further help to analyze specific ecosystem functions. In spite of the upcoming difficulties, complex analyses are necessary. One example for such an approach is the application of various methods such as stable isotope analyses and ENA modelling to understand the functioning of the complex food webs of the DZBC and VB within the BACOSA project (see Chap. 13). Here, the expert knowledge achieved in this analysis has been used to transfer this ecological analysis into an identification and assessment of ES.

(b) Which management and research-related recommendations can be formulated based on these results?

ES provide a brilliant tool to illustrate what different aspects ecosystems have for the human society and to demonstrate the effects that human impacts may have on the provision of ES. This can be employed to prepare decisions about scenarios of ecosystem use, which balance the different stakeholders opinions. The demand for such applications of ES in management is steadily growing. Therefore, we need more information and valuation about more ecosystem types, stronger distinguished services, more experts who help to improve respective matrices, more case studies and real-life-applications, more elaborated tools. Approaches like the one described here have to be further developed. Due to the difficulties to transfer ecological characteristics to ES (see above), integrity indicators are a useful tool and indicator of ecosystem and stability. These indicators should therefore be in the focus of management recommendations, opening the door for an increased implementation of the ES approach.

Our case studies result in specific recommendations for management and future research. These recommendations also have to consider the high connectivity of coastal lagoons with other lagoons, but also terrestrial ecosystems and the open Baltic Sea. This connectivity is expressed in not only in high water exchange rates, and transport of nutrients and other abiotic matters across ecosystem boarders, but also in the migration of different organisms among the single habitats/ecosystems. Just one example is the fundamental function of coastal lagoons for recruitment of herring, one of the most important commercial fish of the Baltic Sea (Kanstinger et al. 2016). Polte et al. (2021) demonstrated that the timing of annual spawning periods has a major impact on the recruitment success of herring (*Clupea harengus*) in the western Baltic Sea. They assumed that the synergistic effect of climate change and eutrophication causes a severe pressure on fish early life stages. Our comparison between DZBC and VB shows that zooplankton densities are lower in the lagoon without macrophytes, especially in spring, and thus confirm that eutrophication of shallow lagoons might have a negative impact on fish recruitment. This emphasizes the need for cross-ecosystem management strategies (Eriksson et al. 2011; Reusch et al. 2018). If we look at our three case studies, we can summarize the following:

Bioturbation: Investigations indicate opposing impacts of bioturbation on fundamental ES such as nutrient retention and carbon storage, but many cause-effect relations are not clearly identified yet. Due to the "umbrella character" (Kristensen et al. 2012) of the term bioturbation we have difficulties inferring quantitative relations of some important processes, such as denitrification, to measured bioturbation intensity. Therefore, it is not possible to give management recommendations in these cases. It is not perceivable how technically a bioturbation community that provides positive services could be designed/created. Neither may it be desirable. Instead, a major need for future research can be identified. There should be more focus on cause-effect-relations, interactions and feedback mechanisms. There seems to be an agreement, however, that "seafloor integrity" (also an umbrella term) should be taken care of in order to allow a stable community of bioturbating zoobenthos with high biodiversity. For management this implies that harsh impacts destroying benthic fauna communities have to be minimized.

Submerged vegetation has since long been known to stabilize the clearwater state and to provide a number of ecosystem services in freshwater lakes. Lake restoration therefore aims at promoting this vegetation. The most important management tools applied are reduction of external nutrient supply, reduction of the internal nutrient pool, biomanipulation, and implementations of "wave-breakers", either as artificial structures or plantations of suitable submerged macrophytes. (Hilt et al. 2006, 2018).

For coastal lagoons, we show for the first time that submerged vegetation not only has a major impact on the whole food web, but also is an important provider of ecosystem services. We conclude that the promotion of this vegetation has to be implemented also in the management of these ecosystems. Increased nutrient loading has been identified as the reason for the disappearance of submerged vegetation in some coastal lagoons, while other lagoons still have dense submerged vegetation (see Chap. 4). A substantial reduction of these loads has been achieved since the 1990s, but has not yet caused any major re-colonization of the submerged vegetation in the DZBC and Greifswald Bodden (Munkes 2005; Paar et al. 2021). Further reductions of the nutrient loads increase the probability for a re-colonization, but the necessary amounts of reduction can not be quantified, as we do not know how close these ecosystems are to the "tipping point" (see Chap. 13). In contrast to freshwater ecosystems, only few investigations have identified and quantified the feedback mechanisms for either of the two states, and further studies are badly needed. Biomanipulation seems not to be a promising tool because of the large size of the coastal lagoons, and their openness and the high migration rates of fish along the Baltic Sea coast (Eklöf et al. 2012). Implementation of wave-breakers may be a suitable tool to increase the chances for macrophyte recovery in isolated parts of estuarine lagoons. Any plantations of submerged macrophytes, preferrably in sheltered bays and/or in sheltered enclosures, is promising only if the conditions are good enough to allow positive growth rates for these plants (Bakker et al. 2013). Because of the poor light availability, a successful colonization can be expected only in shallow (marginal) regions of the estuarine lagoons. An expansion to deeper water, which is necessary for the establishment of a clearwater state, is dependent on a longer period of favourable weather and hydrology conditions.

The VB, still in a favourable macrophyte-dominated state, may be close to the "tipping point" (see Chap. 13). Any negative impact that may cause a switch to the turbid state should be avoided, as a return to macrophyte dominance would then need major and cost-consuming actions.Most important is avoidance of any further nutrient increase. Digging and construction activities may cause increased turbidity and should be limited. Piscivorous fish, which has be shown to have a substantional impact on filamentous algae in coastal brackish lagoons (Donadi et al. 2017), is increasingly exploitated by commercial and especially, recreational fishery, and pike (*Esox lucius*) shows first signs of recruitment overfishing in our investigation area (van Gemert et al. 2021). A limitation of recreational fishery is therefore recommended.

In contrast to freshwater ecosystems, alternative state patterns in coastal lagoons are poorly investigated (see Chap. 13). Further studies are badly needed to predict regime shifts and to develop successful management strategies. Because of the non-linear response of shallow aquatic ecosystems, this is a challenging task, as large increases in the indicators only "occur once a regime shift already is initiated, often too late for management to avert it" (Biggs et al. 2009). Intensive research has recently aimed at detecting "early warning signals" of regime shifts, and identified increases in variance, increased system skewness and slow recovery after disturbances as possible indicators (van de Leemput et al. 2018).

Especially under low and moderate nutrient conditions, phytoplankton provides positive ecosystem services. In highly eutrophicated ecosystems, however, both integrity parameters and ecosystem service values decrease due to a shift in species composition to few, highly grazing-resistant taxa dominated by cyanobacteria. This causes lower trophic transfer efficiency and ultimately, an ecosystem with low production also of higher trophic levels including species used as seafood (see Chaps. 12 and 13). Apart from grazing resistance, a high nutrient efficiency causes a high stability of such cyanobacteria communities (see Chap. 12). In such ecosystems, also toxic algal blooms may develop, which can give rise even to negative ES values (see Fig. 28.4).

Management therefore should aim at controlling and reducing both internal and external nutrient loadings. Further, there is a high need for research on factors stabilizing and de-stabilizing grazing-resistent cyanobacteria communities.

28.7 Conclusions

In this chapter, we have tried to illuminate the coupling of an expert-based ecosystem service assessment and empirical, ecosystem-based knowledge to better understand the complex relations between ecosystem services and ecosystem conditions. This connection between deep processual knowledge on ecosystem structures and processes and usable, modern recipes for practical environmental management is a long bridge, whereby the connected islands can be rather distant from each other and the lanes may be quite instable, in some cases being pathways only. Nevertheless, we have to use this link in order to find long-term sustainable solutions on a suitable scientific basis. Therefore, the elaboration of applied concepts for ecosystem service management based upon ecosystem analysis will remain a very important task in future.

Acknowledgments We are grateful to J. Renz for the original sketch underlying Fig. 28.2.

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