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Ecosystem accounting's potential to support coastal and marine governance

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ABSTRACT

The paper presents an exploratory assessment of ecosystem accounting's potential to support marine and coastal governance. Norwegian kelp forest management and restoration, and a series of nested case studies are used as examples. By analysing a series of institutional experiments where ecosystem accounting (EA) can potentially be applied, and by including the theoretical lens of evolutionary governance, EA is found potentially valuable. It can enhance transparency in governance, elucidate material dependencies, and link stocks and flows of natural resources with a broad spectrum of ecosystem services and values. EA nevertheless has to be considered as one tool among many others. Its use in a particular context can be best assessed when it is understood as being embedded in governance configurations which are in continuous transmutation. Different governance configurations will also shape the effectiveness of the tools. The linkages between EA, policy articulation and implementation should be considered in their complexity. It is argued that pure transparency does not exist, that neutrality of accounting tools is a fiction, and that the potential of EA is shaped by the governance context. At the same time, EA enables the discerning of new narratives about environmental and social risks, and the conservation potentials. It is argued that when assumptions and goals of EA are already shared within the governance context, the potential use of EA is even greater.

1. Introduction

This study assesses the potential of ecosystems accounting (EA) as a tool for coastal and marine governance. The assessment uses a case study of Norwegian kelp forests. Natural capital accounting systems view nature and ecosystems as assets which provide a stream of ecosystem service benefits to society [1]. Ecosystem accounting aims to transparently render the flow of services from different types of ecosystems and make them comparable over time and space. The current *System of Environmental-Economic Accounting* (SEEA) has been applied mostly on land and pilot studies have applied SEEA to coastal zones in for example Canada, Australia [2] and Mauritius [3]. They have also been planned for the Netherlands [4]. Although land and coastal ecosystems and the services they provide share many common features, they still differ from each other significantly [5].

We therefore evaluate the application of the ecosystem accounting concepts to Norwegian kelp forest management and restoration, as an example of a shallow coastal ecosystem. The kelp forest is one of the most important coastal ecosystems along the Norwegian coast. Ecosystem accounting has not been implemented yet for the Norwegian coast, but there is much information available, gained from case studies in different regimes of governance, some of them experimental, so different potential roles for accounting can be examined and discussed.

The paper is one of the first in the literature to address the role of ecosystem accounting in the context of marine governance. Theoretically, the paper deploys a selection of concepts from evolutionary governance theory, or EGT [6], to highlight the role of the new knowledge created through the accounting exercise, and to explore its potential in different regimes.

1.1. Ecosystem accounting and ecosystems services

Ecosystem accounting involves quantifying ecosystem extent, condition, physical supply and use of ecosystem services, the monetary valuation of supply and use, and the periodic revision of asset values based on changes in predicted future flows of ecosystem services [7].

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Costanza et al. [8] give an overview on ecosystem services development in the last twenty years. Braat and de Groot [9] summarize the development of ecosystem services thinking from ecological and economic roots. Gómez-Baggethun et al. [10] meanwhile provide a more thorough economic underpinning of ecosystem services perspectives. Traditional fisheries management (and the management of any other natural resource) has considered single species or ecosystems with a limited number of species in terms of changes of stocks which can increase and decrease. More recent thinking on services and accounting tries to incorporate natural capital in all its forms which has dramatically increased the number and properties of ecosystems which need to be identified, valued, and accounted for. The idea being that in such broader perspectives, the impact of human intervention, both old and new, as well as relations between interventions and between alternative courses of action can be made visible and measured [11,12]. As one is dealing then with a variety of resources, users and interests, it becomes necessary to speak of natural resource *governance* [13,14], and ecosystem accounting naturally seems to deserve a place in governance [15,16].

Ecosystem accounting aims to identify the temporal and spatial change in ecosystems' contribution to society. The ability to identify change in the economic value of ecosystems is potentially important in evaluating the aggregate effects of different combinations of policy within an accounting area [17,18]. Accounting areas are defined by governance objectives. Ecosystem accounts are potentially one of several tools in governance towards sustainable social-ecological systems [16,19]. The current state of an ecosystem or a large area consisting of various ecosystems is assessed over time. The potential effects of interventions can be scoped much more broadly as the accounting system itself already allows for evaluating many different effects (on stocks, changes in environmental assets or flows and services), while still maintaining a synthetic simplicity which can help decision-making in governance [20]. That combination of acknowledged social-ecological complexity and practical simplicity is anticipated to be attractive for decision-makers (c.f. [21]). In fact, we already know it is of interest because of the work undertaken on EA by the UN.

1.2. *SEEA as an integrated accounting system and an early synthesis*

The *System of Environmental-Economic Accounting 2012-SEEA Central Framework* was adopted in 2012 as an international standard for environmental-economic accounting by the United Nations Statistical Commission [1]. The central framework focuses on the interactions between the economy and the environment, and stocks and changes in the stocks of environmental assets. It puts statistics related to the environment at the core of official statistics [1]. The central framework helps to compile information which can be adopted to create coherent indicators to inform decision-making and to generate accounts. Building on the System of National Accounts (SNA) principles, the framework extends the System of National Accounts by including environmental assets [2,12].

In 2014 the SEEA Experimental Ecosystem Accounting (EEA) was launched [1] and three years later the SEEA EEA Technical Recommendations appeared [7]. This is the first published reference to a potential international accounting approach for ecosystems. SSEA represents a fundamental methodological development by making national accounts sensitive to spatial variation in ecosystem services flows and their value as assets (Fig. 1). Ecosystem extent, condition, physical supply and use are derived using ecosystem service mapping and modelling.

SEEA EEA is under revision until 2020, when the UN statistic division aims to present an accounting standard for approval by governments. The current technical recommendations are a touchstone for the reflections on coastal accounting and coastal governance in this paper.

Ecosystem accounting is still in experimental stages, while natural capital accounting (not necessarily following SNA standards) has been applied mainly to terrestrial environments [22]. The most comprehensive ecosystem accounting has taken place in the Netherlands (e.g. Edens et al. [23] for Dutch water resource SEEA, Lof et al. [24] for Dutch carbon accounts). However, marine and coastal ecosystem accounting remains sparse [4]. Up to now, SEEA sectoral accounts include energy accounts, water accounts, land and ecosystem accounting and applications in agriculture, forestry, and fisheries. For marine and coastal water, aquaculture and fisheries are already mentioned as applicable areas. As a small island nation, Mauritius has carried out its first economic valuation study for marine ecosystem services for sustainable oceans, a study which paved the way for a SEEA study on coastal and marine issues in the country [3]. Marine ecosystem accounts are also being planned for the Netherlands [4] and Finland [5]. One pioneer study on marine and coastal ecosystem accounting was applied in Port Philip Bay, in Victoria Australia [2]. Current ongoing projects include the European Commission's Knowledge Innovation Project for an Integrated System for Natural Capital and Ecosystem Services Accounting (KIP INCA) which is developing experiment marine ecosystem accounts for seagrass.

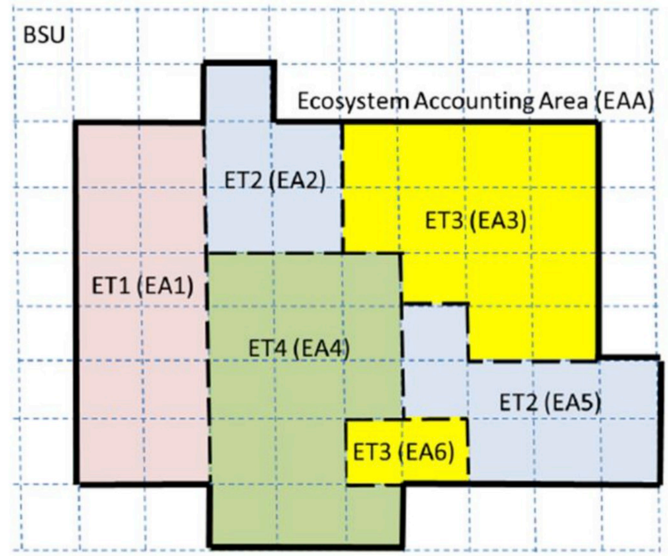

Fig. 1. The innovation of SEEA EEA is accounting for spatial variation in ecosystem services. Basic spatial units (BSU), in the form of grid squares or small polygons, support the delineation of Ecosystem Assets(EA) and Ecosystem Types (ET) and the organization of spatial data sets for ecosystem accounting. The purpose of BSUs is to provide a fine level frame to which a range of different information can be attributed [7].

The paper is structured as follows. Section 2 details the methodological approach. Section 3 develops the theoretical frame, looking at accounting in governance. Section 4 then focuses more specifically on ecosystems accounting in evolving governance. Section 5 introduces the case study and the three nested case studies of different approaches to managing the Norwegian kelp forests. Section 6 discusses several analytic issues emerge from the cases studies regarding the potentials of EA for coastal governance. Section 7 concludes.

2. Method and materials

As no EA has been implemented in Norway, the study is conducted based on existing data collected from fieldwork and survey, GIS modelling and theoretical analysis. This is a desk study using available information on kelp forests to evaluate the potential for a marine EA in Norway (e.g. Refs. [25–27]). We follow the path of [5] in exploring the potential of EA. Kelp ecosystems in Norway provide the case study to do this exploration, because of the availability of data and the relevance for the topic (different stressors, services, benefits). Moreover, within the

Norwegian case we can identify three nested case studies, sharing the general Norwegian governance framework but representing different local/regional governance configurations and marine regions. This diversity of contexts helps with the identification of different potential roles of EA.

Following the SEEA EEA Technical Recommendations [7] and the KIP INCA EEA protocol draft on experimental seagrass ecosystem accounts [28], we construct and develop the kelp EA accounts for Norway. The construction follows the steps adjusted from the SEEA EEA Technical Recommendations [7]: construction of ecosystem extent account, construction of condition account, choosing ecosystems services, and valuation of those services.

The analysis of potential governance implications of and roles for EA is based on a theoretical analysis and on analysis of the case studies, where different issues and governance regimes conspired to suggest several roles and limitations of EA depending on context. One governance regime is chosen in each regional sea area along the Norwegian coast. We mapped the main ecological and economic issues, the existing governance configuration (i.e. the pattern of actors, institutions, power and knowledge per case [29]), the expectations of EA, the results of initial studies, and extrapolated from there to delineate potential roles and limitations of EA.

3. Accounting in governance

Accounting is a powerful management technique, which renders an organization more transparent for itself, and can guide continuous adaptation and strategic orientation ([30–32]). One can observe since the 1980's a double movement in public sector governance. The first refers to the introduction of more private sector management techniques to public sector organizations. The second involves bringing these techniques to governance. Therefore, the configurations of private and public actors together articulate collectively binding decisions [33–35].

Under the influence of this so-called New Public Management (NPM), accountability of public sector organizations became more emphasized and simultaneously reduced to accounting [12,36,37]. Efficiency and effectiveness of public sector organizations and of governance was thus expected to become more measurable and accountable [18,38]. While indicators themselves could be very synthetic, i.e. relying on a wide variety of underlying data and interpretations to capture broad concepts, they also promised to enable or enhance policy integration [16,39]. The increased transparency can help to coordinate the different policies aiming at the same goal.

Accounting concepts were stretched in the process of proliferation of indicators [16,40]. They were used as if they were similar enough to more traditional accounting techniques, measuring inputs of something, outputs of either the same item or a product (to be translated back to the original unit, i.e. monetary value/currency), in a process that took time, labor, and other resources [41,42]. This ideally could be translated back again to monetary value. The influence of NPM then engendered a *metaphorical use of accounting*, with a distance sometimes being taken from the idea of changing stocks of capital, from savings and investments to viewing nature as capital.

Which forms of accounting work well in governance, hinges on the form of governance and the particular history of governance (the governance path) in a particular area [37,40,43]. Indicators can bring actors closer together, but they can also spark dissension [42,44]. Reduction of governance activities, inputs and results to numbers can be more acceptable under certain circumstances, less so in others [45,46]. When it comes to the results of governance in an exterior environment (e.g. the management of fish stocks), the impact of the policy itself might be hard to discern. The bundle of factors and set of feedback loops affecting the numbers are not always grasped by the accounting system and need to be analyzed separately [47].

Moreover, the knowledge and infrastructures necessary to measure, monitor, discuss and integrate various flows of information needed for achieving synthetic and quantifiable goals, are not always present [20,48]. In addition, many critics of governance by numbers have noted that each form of accounting exercise and each set of indicators creates a unique form of transparency (not a generalized form of transparency) [49] while it also comes with new and unique forms of opacity [21,50,51].

This is not surprising, as the more synthetic an accounting system becomes, the more steps and forms of interpretation are required, to condense a variety of phenomena into a number [47,52]. This means that some parts are made visible, others made invisible and some new entities are constructed in the process, while pre-existing entities (recognized outside governance and their academics) might be forgotten or blurred [37,41,43].

4. Ecosystems accounting in evolving governance

If we follow the resilience school of thought and consider governance to be part of social-ecological systems, as managing the linkage of social and ecological systems, then the evolution of governance is relevant for the state of ecosystems [14,49]. Actors push their interpretation and bring their knowledge to bear on the construction of indicators and accounting values and entities [53]. Once the numbers are produced, different actors accept or dispute them, using them for their own purposes, interpreting and drawing different conclusions in terms of linkage with institutions (plans, policies, laws) where they could play a role [54].

In the case of ecosystems accounting, the complexity of observations and monitoring required to build the accounting systems offers more possibilities for interpretation, and for selectivity, i.e. the selection of objectives, areas and features to monitor, how often to repeat the monitoring and where to place them in the context of the construction of the accounting parameters [16,55]. In particular, the definition of services, linked to value in one direction, and to measurable indicators of those services in the other direction (in the construction process of the accounting system), plus the need to bring in different ecosystems and their services on the same footing, to make them fit the accounting system, offers many spaces for interpretation and for power/knowledge interaction (c.f. [14,18,50]).

For EGT, each governance path is marked with *dependencies,* i.e. rigidities which render certain developments more likely than others. Either building in new forms of accounting in governance or importing the results of such accounting systems in governance will alter the governance configuration. Such change will be subjected to the unique sets of pressures stemming from unique sets of dependencies [14]. A new accounting system will be subjected to and alter the *interdependencies* between actors, between institutions and between actors and institutions The requirements of the new system will alter the relations. Relations based on old flows of information and old chains of decision-making are likely to shift, while in the other direction, entrenched relationships are likely to shape the form and use of the accounting system [56].

Path dependencies, as legacies from the past in the governance path, similarly affect form, functioning and effect of the accounting systems; if a particular type of information was never cherished, if policies based on that information easily disappeared on to a shelf, these legacies present obstacles to overcome, for ecosystems accounting systems [6,14,57]. Each governance path is also marked w *goal dependencies*; effects of visions of the future on the current reproduction of governance [29]. That means that an assumed link between accounting results and corrective interventions cannot be simply assumed (c.f. [58,59]). The link can be weak or strong and take many forms.

EGT further distinguishes *material dependencies* where a particular governance system might be particularly affected by materiality, both man-made and of natural origin [14,60]. For ecosystems accounting, this can make a big difference, as not the mere numbers but the numbers *in the context of heightened sensitivity for a particular ecosystem*, because of material dependencies, can inspire collective action through governance [16,38,61]. Such sensitivity to a particular environment cannot be read simply as literal dependence on a resource, a place or a living environment. Stories about the resource, entrenched in governance and assigning value to place, resource, and coordinated action with regards to the resource, *can create links between accounting results, governance deliberation, and action* [33,51]. In other words, the numbers in stories make a difference. This leaves space for a variety of potential roles for EA.

It is acknowledged here that changes in the physical environment (which could be called 'material events', see Ref. [62]) can seep through governance systems, slowly or quickly, dramatically or marginally. Therefor their effects on governance, the path and goal dependencies engendered, will differ. This is a process which hinges on the features of the governance system, the physical environment, and the material affordances of the resources for a particular use [14]. It is further acknowledged that (c.f. [63]) the boundary between social system (including governance system) and ecological system (in its static materiality and its processual nature) never vanishes through any form of management, and that it never altogether stabilizes. New tools of observation and organization create new blind spots also for this reason, while old tools lose their grip for reasons never fully understood.

In the following section, we present a marine ecosystem accounting case study for kelp forest from Norway to elaborate on the challenges and prospects for ecosystem accounting. We draw conclusions in terms of appropriate governance models and roles of SEEA where this could lead to appropriate action. From this exploratory case study, we will derive insights regarding ecosystem accounting for coastal areas and their governance, through an EGT lens.

5. A case study: Norwegian kelp forest

5.1. Kelp forest habitat: extent and condition along the Norwegian coast

There are two major kelp species, *Laminaria hyperborea* and *Saccharina latissima*, along the coast of Norway. Both species of kelp forests have been lost for different reasons since 1970, mainly due to the sea urchin grazing along the Northern coast and eutrophication along the Southern coast. Kelp forests are highly diverse and productive ecosystems [64] providing extensive ecosystem services locally and for adjacent systems [65,66]. Therefore, kelp forests are very important natural capital assets.

Fig. 2 shows the coverage/extent of the major kelp species, *Laminaria hyperborea* and *Saccharina latissima*, along the coast of Norway. The orange area indicates the coverage has been reduced comparing to the period before the 1970s. Both *L. hyperborea* and *S. latissima* forests have been dramatically reduced in the Barents Sea and the northern part of the Norwegian Sea, where sea urchins (*Strongylocentrotus droebachiensis*) have destructively grazed the kelp forest [67]. For almost fifty years, dense sea urchin populations have resulted in desert-like barren grounds, meaning that the seabed is entirely covered with sea urchins. Kelp, particularly *L. hyperborean,* has prevailed only in the outer and most wave exposed areas. Kelp forests and sea urchin barrens are believed to be two stable states of the same ecosystem [68]. In contrast to kelp forest, sea urchin barrens are ecosystems with low productivity, supporting few other organisms other than the urchins themselves [69,70]. Biologists suspect that rising water temperatures and increased crab abundances will contribute to sea urchin decline, enhancing the recovery of the kelp forests [69,71].

In the southern part of the Norwegian Sea, the North Sea and in Skagerrak, *L. hyperborea* kelp remains at the same coverage as what was the case in the period before the 1970s, as sea urchin grazing has not been taking place here. However, the *S. latissima* kelp is reduced in the North Sea and, to an even larger extent, Skagerrak. The deteriorated condition is found in the wave sheltered parts of the North Sea and in Skagerrak, mainly due to increased levels of nutrient [72,73].

5.2. Kelp forest: ecosystem services and their values

Kelp forests provide many ecosystem services locally and for adjacent systems [65,66]. Fig. 3 shows the ecosystem services provided by kelp forests accommodating the IPBES's definition of value pluralism [75]. Kelp forests create habitat for various macroalgae, invertebrates [64] and fish [76]. They function as a nutrient source for other ecosystems [77] and in deeper areas [78]. Kelp forests provide regulating services by storing carbon in the biomass and sequestrating carbon in the sediments [79,80]. Gundersen et al. [25] estimated that the Norwegian sea urchin barrens potentially could be recovered to support more than 50 million tons of kelp forest that could provide the coast with a similar amount of biomass every year and sequester more than 30 million tons of carbon.

Kelp forests take up nutrients, serving a bioremediation function. They have been used in multi-trophic aquaculture to absorb superfluous nutrients from fish farming [81–83]. Kelp forests can also protect shorelines by dampening waves [84–86]. In addition, kelp forest provides provisioning services. Alginate extracted from *Laminaria*

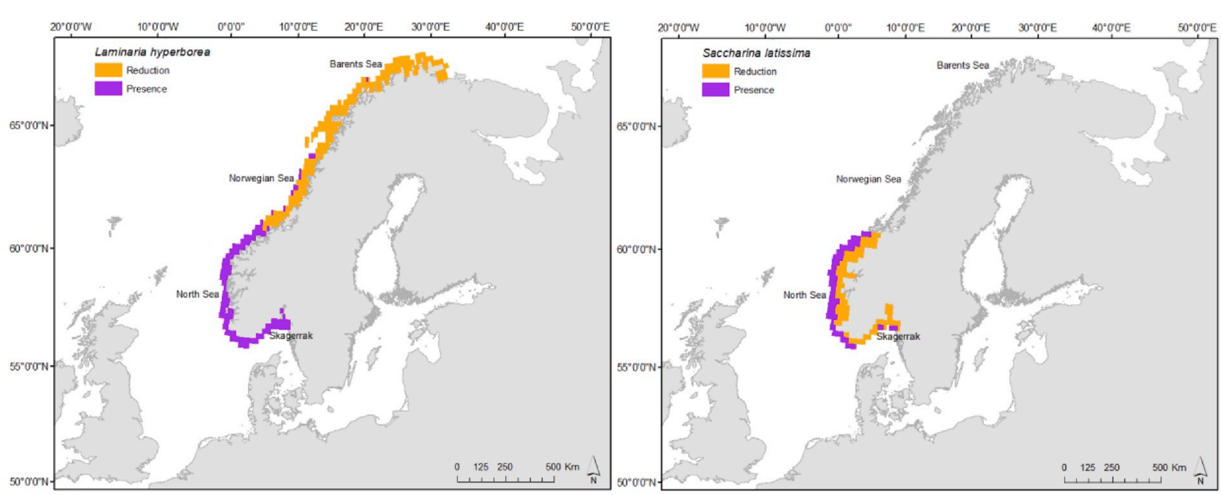

Fig. 2. Two maps showing the coverage/extent of the major kelp forest species in Norway, a map modified from Araújo et al. [74]. Left: Laminaria hyperborea, right: Saccharina latissima. Orange areas indicates that the coverage has been reduced compared to that before the1970s, purple areas indicates that the coverage remains the same as that before the 1970s. According to more recent knowledge, the S. latissima kelp forests in the Norwegian and Barents Sea are also reduced, despite this not being shown on this map. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

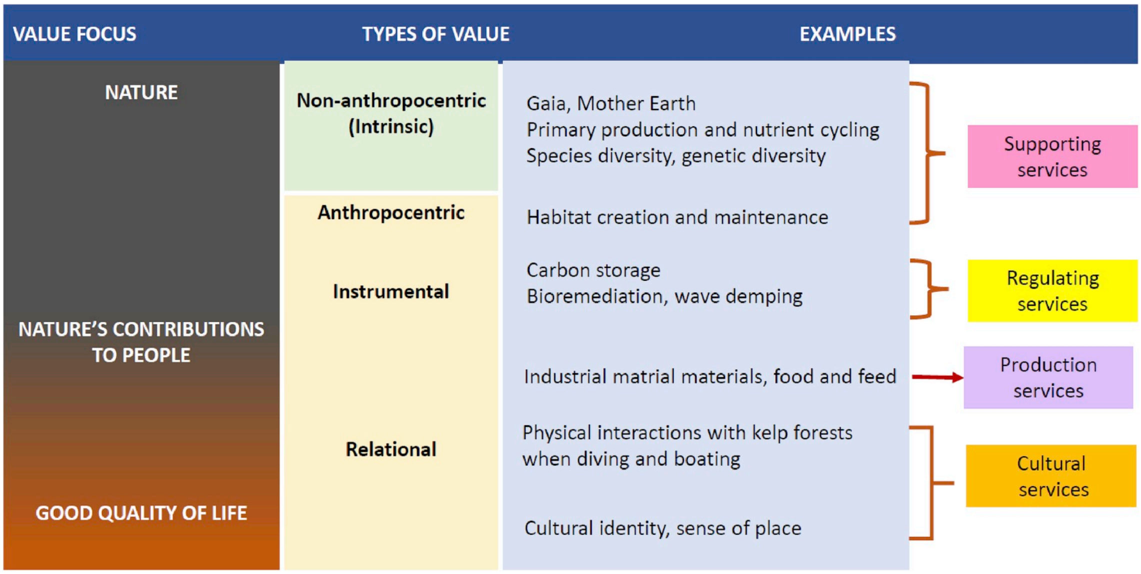

Fig. 3. Values and ecosystem services provided by kelp forests. Diverse values related to nature, nature's contributions to people and a good quality of life are adjusted for kelp forests from Pascual et al. [75].

hyperborea is important raw materials for industries [87]. Harvesting of kelp can also benefit local communities, using the seaweed for a variety of purposes, both traditional and new although large scale commercial harvesting of kelp forest is currently only allowed between Rogaland and North Trøndelag in Norway. Kelp has also been used in both animal feed and human food products. The kelp forest itself also supplies cultural recreational services as they are of major interests for diving and kayaking activities. Recovering kelp forests would attract more seabirds [88] and sea mammals [89], which would also potentially make walking along the coast more enjoyable.

5.3. *Ecosystem accounting: extent account, condition account and monetary values of ecosystem services*

Monitoring for kelp forest extent has been carried out in Norway for the last two decades. As the monitory data does not form a time series but rather a spot data across various regions, GIS rule based modelling are adopted to estimate the existing kelp forest extent (2010). GIS rule based modelling are also applied to predict the full forest extent during the 1970s where no monitoring data is available. In such way, a kelp extent account is constructed for the four regional seas along the Norwegian coast, i.e. Skagerrak, the North Sea, the Norwegian Sea and the Barents Sea. The rules include the wave exposure and the slope of the seabed. Due to the limited data, the extent account only has two periods, 1970s with full forest extent and 2010 for the status. More details for rule based GIS modelling can be found in Gundersen et al. [25]. As there was no data for the condition of kelp forests, two possible conditions are assumed, full forest and reduced forest condition. The reduced forest condition is assumed to have 50% of the biomass of the full forest. Due to the data restriction, only the monetary value for *change* in carbon storage, supporting services and provisioning services are estimated.

Table 1 shows how management hotspots shifts when adding different ecosystem services values, namely carbon deficit, social cost of carbon, change in values for supporting services, provisioning services (i.e. kelp harvesting). Both *L. hyperborea* and *S. latissima* are considered. Average welfare loss for supporting services when kelp forest status changes from full forest to urchin barrens is estimated at €70.70 per person per year for 0.04 km^2 [27]. In Table 1, existing kelp forest in 2010 is assumed to be in the condition that is the closest to a fully developed kelp forest in our data. If we only consider the kelp extent in 2010, then Barents Sea and Skagerrak are the two regions that should be given management priority for both kelp forests (Column 4). When considering the areas lost from before 1970 to 2010 (i.e. change in the extent), the Norwegian Sea region should be the top priority area for restoration activities for both kelp species and Barents Sea listed as the second (Column 5). The reduction in nutrient load is the main measure to reduce the stressors for *S. latissima* in Skagerrak. Reducing sea urchin population i.e. grazing pressure on both kelp species, is the main measures to restore kelp forests in the Norwegian Sea and the Barents Sea (Column 12). The results therefore show the importance of looking at the changes rather than status, and how the governance measures will change.

In Table 2 we consider the condition of the kelp forest in addition to the extent. The standing biomass in 2010 for the Norwegian Sea is assumed to be in moderate condition, i.e. 50% of the biomass of the full condition. Combining insights derived from Tables 1 and 2, we illustrate how change in condition i.e. the change in biomass of standing kelp forest, will affect the management hotspots. When change in social cost of carbon and provisioning services are considered, the second priority area for *S. latissima* becomes the North Sea in Table 2 where reducing nutrients loading is the main management measures.

Another interesting point we found when comparing the change in ecosystem services values in both tables is that the supporting services value for biodiversity conservation and juvenile fish from kelp forests is the highest among all other values listed. It dwarfs the social cost of carbon as well as the kelp harvesting value. This indicates the importance to conserve and recover kelp forests in terms of social welfare rather than a short term focus on the commercial use through kelp harvesting – if we assess based on the values given to the different services. This first general application to the case demonstrates therefore the EA potential to identify management priorities, in spatial and in topical terms. It also reiterates the point that priorities in management remain choices as here the value assigned to different functions where no markets exist or where values go beyond markets (e.g. conservation) is always a matter of interpretation.

5.4. *Kelp forest EA and the current marine governance*

With some examples of Norwegian coastal and marine governance regimes, we are able to address the potential benefits and challenges for the embedding of EA in that context. The Norwegian context is also not unified, meaning that the space and the activities (c.f. services)

Table 1
Shows how the management hot spots shift when adding carbon deficit, social cost of carbon and value change for supporting service of kelp forest. We assume under this scenario that the extent of the kelp forest in 2010 is the closest we get to a fully developed kelp forest in our data set, i.e. the full forest condition as it was before 1970s.

	Coastal regions	Extent before 1970(km2)	Extent in 2010 (km2)	Change in extent (km2)	Change in biomass (mill ton)	Carbon deficit (mill ton)	Social cost of carbon (bn NOK)	Change in values for supporting services (bn NOK)	Provisioning services (bn NOK)	Stressors/cause of change	Measures to be taken
Sugar kelp (*S. latissima*)	Skagerrak	748	150	−598	−5,98	−2,19	−3	−55470	−41	Eutrophication (increased Nutrients) loads from e.g. agriculture runoffs	Pollution reduction, Reduce nutrients overloading
	North Sea	1632	979	−653	−6,62	−2,39	−3	−60572	−45	Eutrophication (increased nutrients loads from e.g. land runoffs and aquaculture	Pollution reduction, Reduce nutrients overloading
	Norwegian Sea	6338	893	−5445	−54,45	−19,96	−27	−505075	−371	Sea urchin grazing	Reduce sea urchin population, increase crab predation
	Barents Sea	1094	0	−1094	−10,94	−4,01	−5	−101479	−75	Sea urchin grazing	Reduce sea urchin population, increase crab predation
Large kelp (*L. hyperborea*)	Skagerrak	469	469	0	0	0	0	0	0		
	North Sea	884	884	0	0	0	0	0	0		
	Norwegian Sea	5507	4051	−1456	−14,56	−5,34	−7	−135058	−99	Sea urchin grazing	Reduce sea urchin population, increase crab predation
	Barents Sea	1023	500	−523	−5,23	−1,92	−3	−48513	−36	Sea urchin grazing	Reduce sea urchin population, increase crab predation

Data source: Kelp forest extent in 2010, extent before 1970 and area change are based on Gundersen et al. [25]. Social cost carbon in year 2020 based on PAGE A1B scenario is 133 EURO per tCO2 [90]. Kelp harvest value is 399USD/ton wet weight [26]. Welfare loss for supporting services is estimated at 70,7 Euro per person per year for 0.04 km2 when kelp forest status changes from full forest to urchin barrens and at 11.48 Euro per person per year for 0.04 km2 when kelp forest status changes from full forest to moderate condition with moderate biodiversity and fishery [27].

associated with the kelp forests are not governed by the same regime, the same configuration of actors or the same institutions. The following paragraphs engage with several aspects of Norwegian marine and coastal governance which could benefit from EA for the kelp forest.

5.4.1. Case 1: Norwegian Barents Sea management plan and Skagerrak protected areas

The *Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands* was completed in 2006 and revised in 2015 [91–93]. The plan aims to achieve an integrated and ecosystem-based marine management, focusing on the impacts of climate change on the artic area including vulnerable areas like marginal ice zone and its ecosystems, the changing economic activities such as fishery, maritime transport, and petroleum activities [92]. The plan also integrates policies pertaining to the management of the Barents Sea in Northern Norway and Russia in terms of commercial fishing rights in each other's national zones and quotas for both joint fishing stock and national stocks. The plan aimed to establish a new governance regime for the area, giving place to a variety of interests, uses and users. This Northern marine ecosystem is categorized as intact (despite a long history of fisheries) and comprises diverse habitats and highly valued species of whales and seabirds. Due to climate warming, ice zones are retreating. Change in ice condition makes more areas accessible to various activities. Increasing commercial fisheries, oil and gas production and shipping put a pressure on the environment [93] and make new demands on management in the area [92]. In the context of kelp EA, the coastal areas (i.e. the shallow hard bottom areas under the water along the coast) are dominated by urchin barrens. Restoration of kelp has been carried out on a small scale basis in various research projects.

Because of the clearly delineated area and the special distribution of powers, resources and responsibilities, a more generalized marine EA might be more realistic and beneficial to governance, within which a kelp forest EA can play a circumscribed role. The governance context is more articulated and stable than usual for marine environments, the focus sharper and knowledge intensity higher, and all these governance features make it more likely for EA to work. For example, monitoring system for ecosystem and economic activities such as fishery, oil and gas exploitation and shipping activities are well stablished. This means that EA in the Arctic should have a good data base to track the physical change of ecosystem and economic value of the ecosystem services like fisheries, even if there will be new commercial activities in the future. This is more relevant when there is a shared agreement that both conservation and development are important goals of the specialized governance regime. This also cemented a place for ecological knowledge and associated actors in governance, making the application of EA and its translation into strategy more likely.

Marine protected areas are similarly promising governance regimes for the application of EA (c.f. [94]). If conservation is the main goal in a delineated area, then the listing of resources, species, and features of the environment to be protected can be expected to be easier than in most other governance regimes. Therefore, the focus of observation may also be easier to define and the accounting excise easier to carry out [14,17,20]. The number of ecosystem services to be considered might also be lower, especially if few services directly benefitting people are envisioned.

One of the Norwegian marine protected areas of interest is the Ytre Hvaler National Park, near Fredrikstad county, in the southern Skagerrak region. It covers an offshore area of 354 km^2 with diverse fauna, underwater algae and rich bird populations [95]. Within the park 32 plant species are on the red list. It also contains a 1200 m long cold water coral reef belt that is unique in Europe [96]. The area also covers a large patch of *L. Hyperborea* kelp forest but with little *S. latissima*. MPA's such as Ytre Hvaler should be promising pilot cases to use EA to track change and integrate the physical change and change in the economic values of ecosystem services and related human activities for the National Park. SEEA has been carried out successfully for the same purpose for the

Table 2
Shows how the management hot spots shift when adding carbon deficit, social cost of carbon and value change for supporting service of kelp forest. Under the scenario that the existing forest in 2010 has moderate condition with moderate biodiversity and juvenile fish abundance.

	Coastal regions	Extent before 1970 (km^2)	Extent in 2010 (km^2)	Change in extent (km^2)	Change in biomass (mill ton)	Carbon deficit (mill ton)	Social cost of carbon (bn NOK)	Change in values for supporting services (bn NOK)	Provisioning services (bn NOK)	Stressors/cause of change	Measures to be taken
Sugar kelp (*S. latissima*)	Skagerrak	748	150	−598	−6,73	−2,47	−3	−57729	−46	Eutrophication (increased nutrients loads from e.g. agriculture runoffs	Reduce nutrients overloading
	North Sea	1632	979	−653	−11,47	−4,19	−6	−75318	−78	Eutrophication (increased nutrients loads from e.g. land runoffs and aquaculture	Reduce nutrients overloading
	Norwegian Sea	6338	893	−5445	−58,92	−21,60	−29	−518526	−401	Sea urchin grazing	Reduce sea urchin population, increase crab predation
	Barents Sea	1094	0	−1094	−10,94	−4,01	−5	−101479	−75	Sea urchin grazing	Reduce sea urchin population, increase crab predation
Large kelp(L. hyperborea)	Skagerrak	469	469	0	−2,35	−0,86	−1	−7064	−16		
	North Sea	884	884	0	−4420	−1,62	−2	−13315	−30		
	Norwegian Sea	5507	4051	−1456	−34,82	−12,76	−17	−196074	−237	Sea urchin grazing	Reduce sea urchin population, increase crab predation
	Barents Sea	1023	500	−523	−7,73	−2,83	−4	−56044	−53	Sea urchin grazing	Reduce sea urchin population, increase crab predation

Data source: Kelp forest extent in 2010, extent before 1970 and area change are based on Gundersen et al. [25]. Social cost carbon in year 2020 based on PAGE A1B scenario is 133 EURO per tCO2 [90]. Kelp harvest value is 399USD/ton wet weight [26]. Welfare loss for supporting services is estimated at 70,7 Euro per person per year for 0.04 km2 when kelp forest status changes from full forest to urchin barrens and at 11.48 Euro per person per year for 0.04 km2 when kelp forest status changes from full forest to moderate condition with moderate biodiversity and fishery [27].

Great Barrier Reef in Australia [97]. This will further contribute to achieving the ecosystem based management goals for the area. A coastal and marine EA, encompassing kelp and coral, will support the monitoring and evaluation of the MPA over time.

5.4.2. Case 2: kelp harvest management areas

Kelp harvest management is restricted to certain defined areas and can be considered part of the mosaic of marine and coastal governance in Norway. It comes with its own set of actors and institutions, its own set of power/knowledge relations, including its own preferential forms of institutionalized knowledge. The difference however with the previous forms of marine governance, is that the kelp areas should be considered more as overlay zoning, in planning terms, rather than a comprehensive plan [98,99]. In other words, the level of policy integration within the harvest management plans is lower than in the guiding institutions of the previously mentioned governance models, and that means that other considerations, other uses, and other users, are coordinated at lower regional level i.e. the county level, by means of other institutions such as regional regulations and in other arenas such as local hearing and demonstration (c.f. [11]). While in a coastal and marine context these arenas are not likely to proliferate (as most people and activities still live on land), this does make a difference, as there is no mandate to envision all possible and occurring activities and to balance them. The impact of EA, while eminently possible for the resource, is therefore less likely to determine the conservation outcome of the area (as distinct from the resource).

Kelp harvesting in Norway dates back several centuries. Kelp trawling for *L. Hyperborea* have been allowed since the 1970s. Kelp trawling at an industrial scale is permitted in chosen coastal areas from Rogaland to Northern Trøndelag where water depth is between 5 and 15 m [100]. The harvesting plans are detailed in each coastal county. In general, a zoning plan is implemented. In each area that is open for harvesting, one fifth of the area will be harvested each year so that kelp forest will have 5 years of recovery period [101,102]. Monitoring of the kelp forest condition is done in the harvested area each year to assure the sustainable use of the resources. Early closure of the area will be implemented if the monitoring shows degradation of the kelp forest. Kelp EA is expected to play an important role, not only by providing information on the condition and extent of the kelp habitat itself (already included in current monitoring scheme), but by providing information on the benefits to the human society via ecosystem service accounting. In other words, strong existing monitoring practices can provide a basis for extension into EA. One can speak of positive path dependencies.

EA in this context can provide a better picture of trade-offs between different stakeholders, including large international harvesters, fishers, tourists, and local communities. It takes 6–7 years for a kelp forest to recover, if one includes flora and fauna depending on it [100]. This is longer than the current 5 years' rotation period. Kelp EA could support decision-makers to find rotation schedules which can better balance various interests, depending on the local condition of the kelp forest, ecosystem services and values to the society. For example, with 5-year rotation period, the international harvesters could maximize their profits (provisioning service). With 6–7 years or even longer rotation period, the kelp forests have a better function as a habitat for juvenile fish, supporting various other species which create more values for the whole society (supporting service). In addition, fishers will benefit from increased fishing stocks. And tourists increase their enjoyment during kayaking, diving or paddling (Cultural service). However, with longer than 5-year-old rotation period, the value for provisioning service will be less while the value for supporting services and cultural services will be higher. Here ecosystem services can be either valued by physical terms or monetary terms.

It has to be said however that already this initial analysis points at the potential conflicts coming out of EA or current monitoring scheme. Current management plans may have to be rewritten and renegotiated, which is not a matter of 'implementing' the monitoring scheme or potential EA, but of altering power relations and forcing a new compromise. Negotiations among various stakeholder groups have been observed in the latest negotiation process for a new management plan for kelp harvesting in the Trøndelag area. The strong monitoring in existence, in all likelihood underpins an old compromise (as commonly observed since Burchell et al. [59], Mellemvik et al. [58], Mouritsen [43], and more recently by Virto et al. [103] and Bartelmus [16]).

5.4.3. Case 3: aquaculture zoning

EA is also expected to play a role in zoning for aquaculture. That is, the kelp forest is considered a buffer around aquaculture activities, with the kelp forest playing the role of natural asset not to be affected by the fish farming, and simultaneously as a buffer absorbing excess nutrients from those activities, protecting marine ecosystems farther away. The nutrients moreover promote the growth of certain kelp species, although one cannot go as far as to state that the overall effect is positive. Particularly *L. Hyperborea* can experience extensively increased growth near aquaculture [81–83].

If for example kelp EA is set to be institutionalized in Hardangerfjorden, Norway's largest aquaculture area, where many negative environmental effects of the industry have been observed and stirred discussion, kelp EA could help map and monitor the state of the kelp forest. Kelp EA in this case can show the multi-dimensional effects of aquaculture on its surroundings, both positive and negative. In a broader context, involving other forms of ecosystems accounting (beyond kelp EA), it is expected to assist in estimating (later balancing) tradeoffs between aquaculture and fisheries.

It should be noted that the Hardangerfjorden has not been involved in a fully-fledged zoning system, let alone comprehensive marine spatial planning. In fact, the institution at work for aquaculture is what is locally called a 'traffic light system', with red light meaning halting production expansion and green light indicating permission to expand. Beside this, conservation zones for lobster harvesting are created in the inner part of Hardangerfjorden. A general EA of natural capitals could show how well defined the basic form of zoning is, i.e. the traffic light system, is based on assessment of carrying capacity of kelp areas for adjacent fish farming. EA might also be useful to assess how the traffic light system can be coordinated with conservation zones for lobster harvesting. In other words, EA can play a role in governance by coordinating different sub-systems and governance tools (different parts of one larger area, marked by different governance approaches and tools).

6. Analytic issues and discussion

In studies and discussions on the different cases, the *accounting units can be hard to define.* As always in accounting, the question is what can be counted, how, and how the results can be translated back to monetary value. This adds to our earlier discussion on the relation between accounting rules and assumed structures, together forming a picture of a system enabling further decision-making. The accounting system is a mirror of an external system incorporates internal features of the observing system, either through reproduction of shared assumptions or through reproduction of power relations [60,104].

Many have also observed that EA comes with a risk of focusing on accounting at the expense of complete understanding of the issues (in the case studies, and in the recent more critical literature, including Bartelmus [40], Virto et al. [103,103], Schröter et al. [55]). More sophisticated accounting systems might not be better in this regard, as they are more prone to black-boxing; therefore, stopping a real discussion [19,53,54]. The mediating concept is that of *relations.* While in the accounting systems each ecosystem asset can be considered separate, the linkage between various ecosystem assets cannot be overlooked. Linkages with effects and services outside the system are also routinely under-analyzed. Envisioning the scale of a coastal area could help in establishing and monitoring links between land and sea environments relevant for the accounting exercise.

A second issue pertains to *context and scale.* Species might be migrating and ecosystems are always a human interpretation in their delineation. Effects of change may happen in one spot with one species and at the same time the effects can be spread to other places, areas, species, and ecosystems. All these effects cannot be entirely mapped or counted. This is both a practical and theoretical reality. One can also use the concept of ecosystems processes to point to the futility of defining stable frames in which to count stable units. For example, kelp forests are linked to sea bird and sea mammal populations on shore as the forests provide the fish that sea birds and sea mammals live on. Another issue of crossing boundaries is that of land-sea interactions. Human activity and natural events onshore affect coastal ecosystems and services - earlier industry discharge dramatically reduced the *S. latissima* kelp forest in the Skagerrak area for example. On the other hand, coastal ecosystems will affect terrestrial ecosystems. Kelp forests for example provide habitat and nursing ground to small fishes and coastal cod which in turn contribute to sea gull populations which makes bird watching onshore more attractive.

In addition, if we speak of ecosystems services, it is practically and theoretically impossible to map them out completely, in time and space. We do not know to what extent a small kelp area contributes to another ecosystem which connects to other ecosystems which can benefit societies far away or far into the future [18,50]. The same uncertainty clings to spatial and temporal scales. If we stay in the frame of social-ecological thinking, and include services to people and communities, then that adds more complexity, as communities redefine continuously who they are, what they want (value)and how their political and economic structures are organized [105].

Connected to the conceptual rigidity of EA and of accounting in general [36,40], and its limited ability to tackle processes and relations, is the blindness to the possibility of *radical transformation* of the ecosystem [106]. Rather than staying in a relatively stable state, an ecosystem is always changing and can shift into a qualitatively different regime. Some would speak of different ecosystems, others of different states of the same system. Indeed, we referred earlier to sea urchin barrens as a different state of the system we also called a kelp forest. If we are only counting, we may remain blind to issues of *thresholds and irreversibility* where timing of intervention is crucial before the ecosystem reach the thresholds [107].

For example, for marine protected areas, it makes a big difference whether the kelp turns into sea urchin barrens. But also for the other governance regimes, aiming at different dominant activities, such shifts are likely to be a game changer. Ecosystem assets can have thresholds above or below which irreversible degradation (or transformation, depending on your perspective) will occur. When sea urchin populations reach a certain threshold, the kelp forest spirals down into annihilation. Complex food chain interactions can generate threshold effects and thus regime change. This has already happened in many different ecosystems [108,109]. For SEEA, operating in social-ecological systems, the thresholds can be different for social and ecological systems (one can transform and the other collapse for example), and both can remain invisible [107].

The Norwegian cases also drove home the point that the potential of EA dramatically differs per type of governance, its ambitions and complexity. Where governance is sensitive to its material environment, where natural resources are at the core of governance, EA looks most promising as it shares dominant assumptions and goals with the governance configuration. EA should, therefore, never be the sole determinant of governance and should be considered together with other principles such as the precautionary principle.

7. Conclusion: ecosystems accounting in evolving coastal and marine governance

SEEA/EA has great potential to bring together the social and ecological worlds in governance, as it attempts to make what is happening and what is valued in the social and ecological system commensurable (c.f. [41,42]). It can create a transparency in two directions that is useful for decision-makers in governance, in situations of vulnerable resources and systems. Where other forms of accounting do not identify ecosystems, and especially where other sources of ecological information are also lacking, SEEA (and more broadly EA) hold great promise. We add, based on our theoretical and case analyses, that marine environments and other environments with a centrality of resource questions and a relative simple form of governance (in terms of actors, institutions, power/knowledge) make it attractive for some role of SEEA (and EA). In marine environments, the often observed governance gaps (e.g. Refs. [60,110]) are leading in many countries, as in Norway, to governance experiments and localized forms of governance, which offer new flexibilities and opportunities for path creation which can open spaces for tools such as SEEA (and EA). Under such conditions SEEA (and EA) also looks promising to further the policy integration which will be needed for comprehensive care or even restoration of habitats. Forms of governance such as Marine Spatial Planning could then likely emerge from a simpler governance configuration with SEEA (and EA) at its core. The Norwegian cases offer glimpses of different potential roles of SEEA (and EA) in such relatively simple marine/coastal governance configurations.

In EGT terms, SEEA (and EA) is tightly coupled to a material environment, and highly subjected to material dependencies. Of course, the idea is also to create new goal dependencies, with the overarching goal of conservation ideally now gaining more traction, having more influence on governance. And of course, that goal is directly tied to a material environment (protecting or reconstructing). It could also be said that where EA seems to offer most promise, is *when it is understood that material dependencies are strong* with a double emphasis on the presence of strong material dependencies and a deep understanding of those material dependencies within governance circles. If such understanding (say, the perception of a threat to a livelihood dependent on fishing) is prevalent, then it is more likely that ecological knowledge is accepted as part of decision making, and built into new institutions (policies, plans, laws), and that the added value of SEEA (and EA) is understood and linked to economic value (hence livelihoods). From there, it is more likely that the results of the accounting exercise would in some sense be 'implemented', i.e. subjected to the double transformation from knowledge to policy (institution) and from policy into practices of coordinated action ('implementation').

Many possible roles for SEEA (and EA) in governance are imaginable including testing scenarios, defining scenarios, testing goals, and finding weak spots in current regimes. SEEA (and EA) aims to link and render commensurable very diverse systems across temporal and spatial scales. No forms of accounting are neutral and this form of accounting *exists for a predefined policy goal,* i.e. better protection of environments and resources. SEEA (and EA) shows what is happening in a more synthetic way and finds new arguments for careful management in defining linkages with appreciated functions and activities.

An EGT inspired assessment of SEEA (and EA) points out not only some mythologies (e.g. neutrality, transparency) and limitations (e.g. engineering of social-ecological systems, observation of changing relations) but also engenders a new understanding of its potential. SEEA and its relatives can now be understood as persuasive storytelling [111] by players trying to push governance on a more sustainable path. If placed in and adapted to an always unique governance context, these forms of accounting can discern new stories while endowing them with a persuasive character by identifying new arguments, audiences, and allies.

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Appendix A. Supplementary data

Supplementary data to this article will be provided on request https://doi.org/10.1016/j.marpol.2019.103758.

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