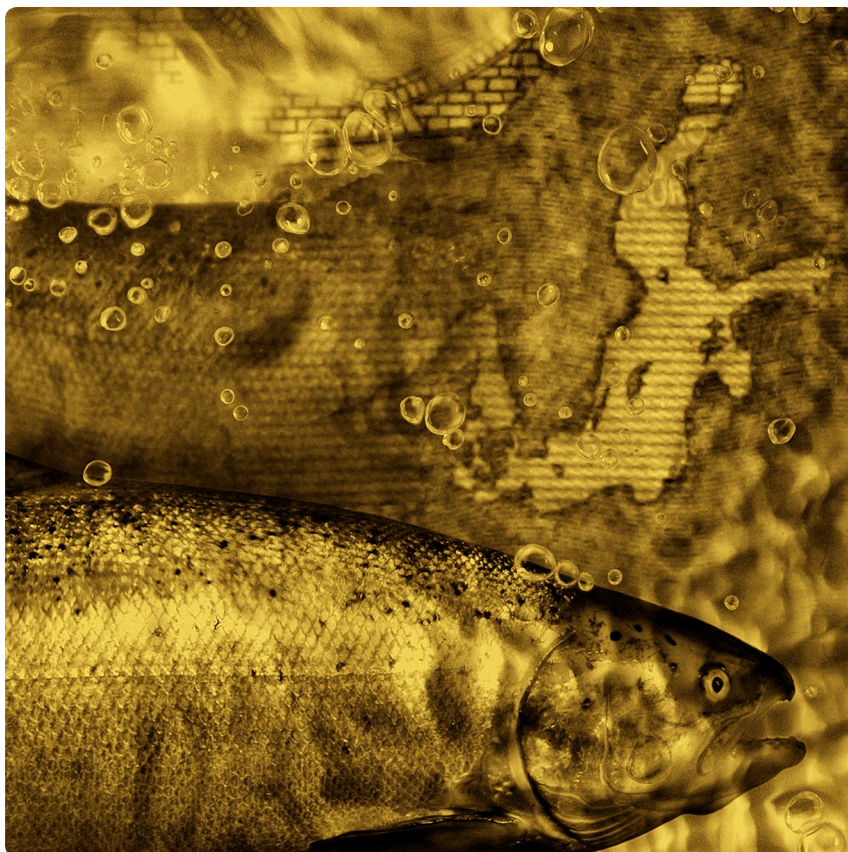
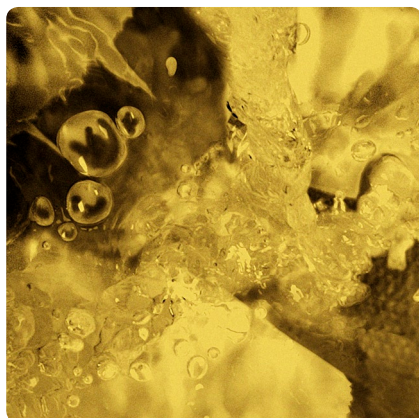


Ecosystem services provided by the Baltic Sea and Skagerrak

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Ecosystem services provided by the Baltic Sea and Skagerrak

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Preface

The Swedish Environmental Protection Agency, by assignment of the Swedish Government, has carried out a project, led by Katrin Zimmer to gather information about the economic impacts of the human influence on the Baltic Sea and the Skagerrak¹ environment. The project, based on already existing material, attempts to compare the situation if no further measures are implemented compared to if further measures are implemented. The countries around the Baltic Sea have been invited to participate in the project and the search for economic marine information has been carried out in every state that borders the Sea.

The goal of the project is to provide decision makers with the information available regarding the economic benefits of ecosystem services, the cost of measures required to protect these services, as well as the estimated costs of non-action.

The assignment was divided into different subprojects which resulted in different reports.

1. Ecosystem services provided by the Baltic Sea and Skagerrak
2. The economic value of ecosystem services provided by the Baltic Sea and Skagerrak - Existing information and gaps of knowledge
3. Trends and scenarios exemplifying the future of the Baltic Sea and Skagerrak - Ecological impacts of not taking action
4. The costs of environmental improvements in the Baltic Sea and Skagerrak - A review of the literature
5. Costs and benefits from nutrient reductions to the Baltic Sea
6. Tourism and recreation industries in the Baltic Sea area - How are they affected by the state of the marine environment? - An interview study
7. Economic information regarding fisheries - Swedish Board of Fisheries

Each of the reports 1-5 contains information on knowledge gaps and suggestions of new research or how existing information could be compiled.

All subprojects have been compiled into one synthesis report with the title What's in the Sea for me – Ecosystem Services of the Baltic Sea and Skagerrak.

This report presents the concept of ecosystem services and subsequently classifies and gives a broad review of all services obtained from the Baltic Sea and Skagerrak. By providing thorough descriptions, accompanied numerous examples, of each of 24 ecosystem services provided by coastal and marine ecosystems, the author seeks to qualitatively illuminate the importance of the various services. The ecosys-

¹ The project defines the Baltic Sea and the Skagerrak as the waters of the Bothnian Bay, the Bothnian sea, the Gulf of Finland, the Gulf of Riga, the Baltic Proper, the Danish Straits, the Kattegat and the Swedish coast of the Skagerrak.

tem service perspective is relatively recent and therefore guidelines on how to quantify the different services, remains to be developed. However, quantification and monetary valuation lies beyond this report.

Why do we need to classify processes and resources of the marine environment into ecosystem services? Although the ecosystem services provided merely constitute the consequences of living organisms natural functioning, it is important to integrate them in the topics discussed in media and politics, which often only mention the end products like fish and tourism. Defining the ecosystem processes, all their functions and all goods and services provided by them is necessary if the right political decisions to really sustainably manage the Baltic Sea and Skagerrak are to be taken. Hence the overall purpose of this report is to translate the complexity of marine biodiversity, and its prerequisites, into services or functions of economic or societal value, which can be more readily understood, for example by policy makers and non-scientists.

The report was financed by the Swedish Environmental Protection Agency. Opinions expressed in this report are those of the author and do not necessarily reflect the official view of the Swedish Environmental Protection Agency.

Stockholm, May 2008

Swedish Environmental Protection Agency

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Report in brief

Ecosystem services are benefits obtained from the environment. Ecosystem services are defined as *functions and processes through which ecosystems, and the species that they support, sustain and fulfil human life*. Ecosystem services are essential to society, both to maintain human health and economic activities. Although many of the ecosystem services are far from inexhaustible, they are typically taken for granted. Demand for certain ecosystem services, like marine food sources, often surpass the capacity of which the ecosystem supplies them.

The Millennium Ecosystem Assessment demonstrated that ecosystems have been significantly altered by anthropogenic activity. In fact our actions are already impairing the flow of ecosystem services. In the Baltic Sea and Skagerrak eutrophication and over-fishing have been the foremost cause of ecosystem deterioration. In the future global climate change and seawater acidification are likely to constitute real and daunting environmental threats.

This report classifies ecosystem services into supporting, provisioning, regulating and cultural services. Among these, the provisioning services are perhaps the most well-known, supplying goods that can be traded and consumed. Naturally, there is bias towards these more data-rich provisioning goods. However, the aim of this report is to illustrate how benefits from acknowledged services such as food and opportunities for recreation are directly dependent on a variety of less appreciated ecosystem services, which interoperate to provide the foundation for ecosystem function.

The basis of all ecosystem production is photosynthesis. By means of solar energy nutrients are converted to biomass or primary production. The two ecosystem services foremost impacting the extent of primary production are biogeochemical cycling (particularly the cycling of nutrients, water, carbon) as well as climate regulation. In fact biogeochemical cycling and climate regulation affect almost all ecosystem services, including each other, as illustrated in figure 1.

Marine primary production, in the form of phytoplankton and marine plants, is the foundation for the supporting and interacting ecosystem services of diversity, food web dynamics and habitat. Together they give rise to the various goods and services of direct benefit to humans. Diversity, food web dynamics and habitat also maintain resilience. Resilience maintains the system, ensuring flexibility and capacity to reorganize following disturbance.

In a well-functioning ecosystem, disturbances are taken care of by regulating services. In the marine ecosystem, mitigation of eutrophication, biological regulation, sediment retention and regulation of pollutants help maintain diversity, food webs, habitat and resilience. The regulating services take care of disturbances of natural, or more commonly, human origin. Meanwhile their functioning is typically related

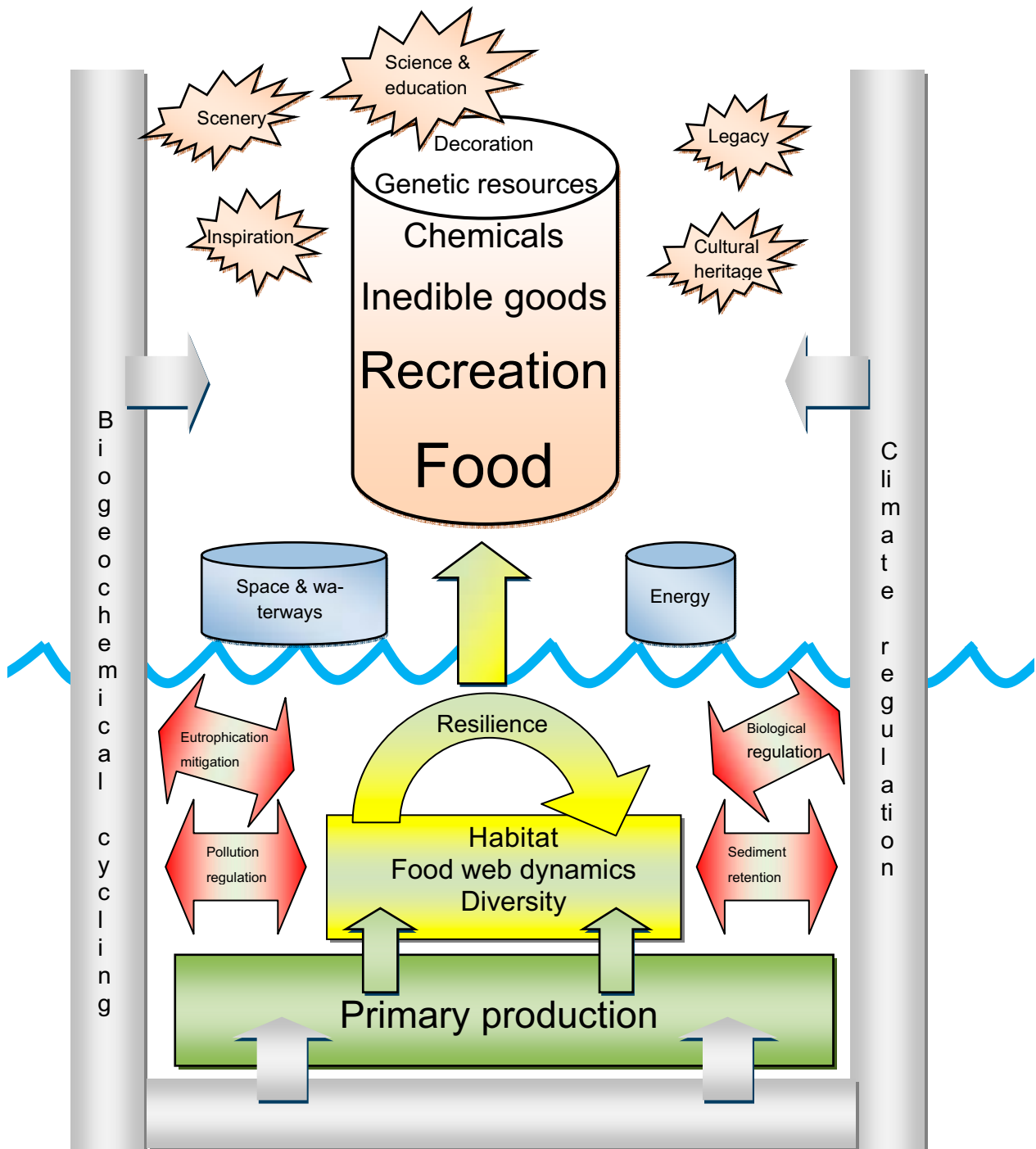


Figure 1. An illustration of how various processes interoperate below the surface to provide the economic and societal benefits included in the 'can' at the top. Unsustainable resource-use, but also human-induced environmental impact at large, will impoverish supporting and regulating ecosystem services. This will eventually diminish the goods and services directly used by humans. All ecosystem services should hence be considered in all resource management.

to other services such as maintenance of habitat (where regulation can take place) or diversity (of regulating organisms).

An ecosystem in which diversity, food web dynamics and habitat are well maintained typically provides society with a variety of cherished goods and services. Most important among the provisioning services, and of highest economic value, are food fit for consumption and recreational opportunities. In addition, inedible goods, chemical substances to promote human health or biotechnological development, and genetic resources to secure conservation and improve aquaculture are provided.

Energy and surface space for transport and development are among the few services not directly dependent on supporting and regulating ecosystem services. At the time being, it seems highly unlikely that human development will expand to the point where sea surface space is no longer available. Similarly, as long as there is space, particularly given improved technical solutions, there will be potential for energy extraction directly from the movement of seawater. Development of sea-based wind power, wave and tidal energy can reduce dependence on fossil fuels, and hence mitigate climate change. However, all use of sea surface space, particularly in coastal regions, may reduce the value of scenery as well as have adverse consequences for e.g. diversity, food web dynamics and habitat.

In addition to the traded or easily valued services, there are a number of cultural services which add benefit to human well-being. Cultural heritage, education and inspiration for art are examples of these cultural services. They can also act as triggers of interest, as their deterioration may indeed draw attention to what is happening below the surface.

Among the 24 ecosystem services revised in this report (illustrated in figure 1) only ten are considered in good condition. Both the provision of food and inedible goods are considered to be in poor condition. Seven are highly threatened, among them four of the six supporting services (food web dynamics, biodiversity, habitat and resilience). Although some services are relatively unaffected by environmental threats (like primary production and the provision of space and waterways), others seem to be impacted by many environmental threats at the same time (like biodiversity, habitat, food provisioning and enjoyment of recreation). How the most prominent disturbances of human origin threatens marine ecosystem services are presented in table 1. The table further presents some of the industries depending on each respective service. Many of these industries, in turn, impact the services that they use. It should be kept in mind that most ecosystem services are likely to be irreplaceable.

In regard to most services, there are extensive knowledge gaps. By directing research effort towards the less understood fundamental services, like food web dynamics, habitat, biodiversity and resilience, valuable information about other

SWEDISH ENVIRONMENTAL PROTECTION AGENCY
ECOSYSTEM SERVICES PROVIDED BY THE BALTIC SEA AND SKAGERRAK

Economic Marine Information

Table 1. Effects of detrimental human activity on marine ecosystem services provided by the Baltic Sea and Skagerrak. S1-6 are supporting services; R1-5 are regulating services; P1-7 are provisioning services; C1-C6 are cultural services. 🟢, documented increase in ecosystem service; 🔴, documented decrease in ecosystem service; 🔵, documented though varied impact; ⬆️, potential increase in ecosystem service; ⬇️, potential decrease in ecosystem service; ○, impact expected though not described.

ECOSYSTEM SERVICE		IMPACT								INDUSTRIES IMPACTING & IMPACTED*		
		Eutrophication		Fishery		Hazard. subst.	Shipping	Construction & developm.	Climate change			
			Excessive exploitation & bycatch	Habitat dist. fishing	Aqua-culture		Invasive spp.	Oil spill	Physical damage	CO2	C°	Industry/ livelihood/ service
S1	Biogeochemical cycling	🔵		🔵	○		○	🔵	○	🔵	○	Supports most other services
S2	Primary production	🟢	🟢		🟢					🟢	🔵	Supports most other services
S3	Food web dynamics	🔵	🔵	🔵	🔵		🔵		🔵	🔵	🔵	Supports most other services
S4	Diversity	⬇️	🔴	🔴	🔴	○	🔵	⬇️	🔴	⬇️	⬇️	Supports most other services
S5	Habitat	🔴	⬇️	🔴	🔴	⬇️	🔴	🔴	🔴	⬇️	○	Supports most other services
S6	Resilience	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	Supports most other services
R1	Climate & atmosph. reg.	🟢								🟢	🔴	All fossil-burning activities
R2	Sediment retention	🔴		🔴					🔴			Construction, property, tourism
R3	Eutrophication mitigation			⬇️	🟢(mussels)	⬇️	⬇️		⬇️	⬇️	⬇️	Tourism, fishery, property
R4	Biological regulation			⬇️	🟢(mussels)		🔵		⬇️	⬇️	⬇️	Food industry, tourism, property
R5	Reg. of haz. subst.	🟢		⬇️	🟢(mussels)	🔴	⬇️		⬇️	⬇️	⬇️	Food industry, tourism
P1	Food	🔴	🔴	○	🟢	🔴	🔵	🔴	⬇️	⬇️	○	Fishery, health, mariculture, food, processing
P2	Inedible goods	🟢	🔴		🟢(mussels)					⬇️	○	Agriculture, livestock, petroleum
P3	Genetic resources		🔴		🔴		○	○		⬇️	○	Aquaculture
P4	Chemical resources			🔵			○	○	○	⬇️	○	Pharmaceutical, shipping, chemical, health
P5	Ornamental resources											Amber, tourism
P6	Energy										○	Wave energy
P7	Space & waterways						⬇️	⬇️				Shipping, offshore windparks
C1	Recreation	🔴	🔴		○	🔴	🔵	🔴	🔴		⬆️	Tourism, sportfish., yacht., div., health
C2	Scenery	🔴	🔴		🔵			🔴	🔴			Property, construct., tourism, health
C3	Science & education		⬇️	⬇️	⬆️		○	⬇️	⬇️	⬇️		Museums, aquaria, science, education
C4	Cultural heritage					○						Museums, festivals, health, intrinsic
C5	Inspiration					○		⬇️	⬇️			Art, ads, film, lyrics, books
C6	The legacy of the sea	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	⬇️	Intrinsic

* Though beneficiaries of the ecosystem services in question, some industries nonetheless contribute to their demise.

services may concurrently be obtained. In reality, the profit from one service is commonly obtained at the expense of another. Provided with increased knowledge about the supporting processes regulating the extent of each service, stakeholders are better prepared to make the best possible use of resources, and to avoid environmental drawback (so called greenlash).

By promoting sustainability in all resource use, the consequences for underlying supporting and regulating services will be minimized and economic value will be enhanced over the years to come. However, to be able to promote sustainability, it is necessary to take a systems' approach and to understand the interactions, flows and feedbacks of the ecosystem. From the current over-use of imperiled resources, management of marine and coastal environment should aim at achieving a resilient ecosystem, in which all ecosystem services are valued (though not necessarily equally).

Sammanfattning

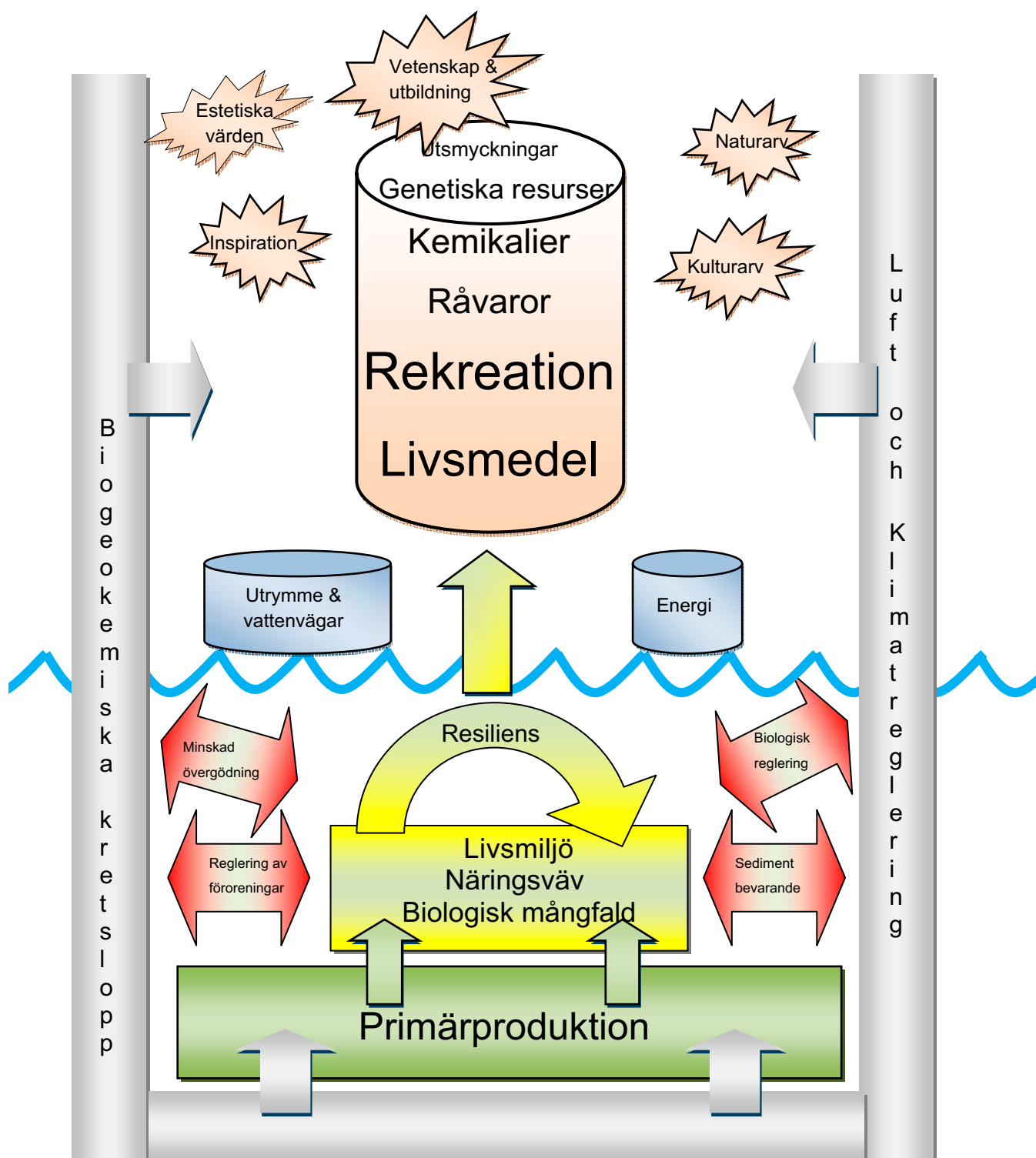
Ekosystemtjänster är vinster erhållna från miljön. Ekosystemtjänsterna definieras som de funktioner och processer genom vilka ekosystemen – och de arter som dessa stödjer – bevarar och berikar mänskligt liv. Ekosystemtjänsterna är nödvändiga för samhället, både för att bevara hälsan och för olika ekonomiska aktiviteter. Även om många av ekosystemtjänsterna är långt ifrån outtömliga tas de vanligtvis för givna. Efterfrågan på vissa ekosystemtjänster, till exempel marina livsmedel, överstiger ofta kapaciteten hos de ekosystem som levererar dem.

Millenium Ecosystem Assessment visade att ekosystemen har förändrats betydligt genom människans aktiviteter. Faktum är att våra handlingar redan håller på att skada flödet av ekosystemtjänster. I Östersjön och Skagerrak är övergödningen och överfisket de främsta orsakerna till att ekosystemen förstörs. I framtiden kommer klimatförändringen och föroreningen av havsvattnet troligtvis att utgöra allvarliga och skrämmande miljöhot.

Den här rapporten klassificerar ekosystemtjänsterna som stödjande, reglerande, producerande och kulturella. Bland dessa är de producerande tjänsterna kanske de mest välkända, då de förser oss med varor som kan köpas, säljas och konsumeras. Målet med den här rapporten är att visa hur vinsterna från erkända tjänster som livsmedel och möjligheterna till rekreation är direkt avhängiga en rad andra mindre kända ekosystemtjänster, som tillsammans ser till att ekosystemen fungerar.

Fotosyntesen är grunden för alla ekosystem. Med hjälp av solenergi omvandlas näringsämnen till biomassa eller primärproduktion. De två ekosystemtjänster som har störst inverkan på primärproduktionens omfattning är det biogeokemiska kretsloppet (i synnerhet näringsämnenas, vattnets och kolets kretslopp) liksom klimatregleringen. Faktum är att det biogeokemiska kretsloppet och klimatregleringen påverkar nästan alla andra ekosystemtjänster, inklusive varandra, vilket illustreras i figur 1.

Havens primärproduktion i form av plankton och marin växtlighet utgör grunden för de stödjande och reglerande ekosystemtjänsterna mångfald, näringsväv och livsmiljö. Tillsammans ger dessa upphov till de olika varor och tjänster som är till direkt nytta för människorna. Mångfalden, näringsväven och livsmiljön bevarar även resiliensen. Resiliensen bevarar ekosystemets funktioner och garanterar flexibiliteten och förmågan till återhämtning efter en störning.



Figur 1. Illustrationen visar hur de olika processerna samverkar under ytan för att skapa de ekonomiska och samhällsrelaterade vinsterna i "konservburken" överst. Ett ohållbart resursutnyttjande, men även mänsklig miljöpåverkan i det stora, kommer att försvaga de stödjande och reglerande ekosystemtjänsterna. Detta kommer så småningom att minska mängden av de varor och tjänster som direkt kan utnyttjas av människorna. Man bör därför ta hänsyn till samtliga ekosystemtjänster vid all resurshantering.

I ett väl fungerande ekosystem hanteras störningar av de reglerande tjänsterna. I det marina ekosystemet hjälper en mildring av övergödningen, biologisk reglering, bevarande av sediment och reglering av föroreningar till att bevara mångfalden, näringsväven, livsmiljön och resiliensen. De reglerande tjänsterna åtgärdar störningar som har ett naturligt eller ett allt oftare mänskligt ursprung. Under tiden är deras funktion huvudsakligen knuten till andra tjänster, som till exempel ett bevarande av livsmiljön (där regleringen kan äga rum) eller mångfalden (bibehållandet av arter som kan reglera andra arter).

När mångfald, näringsväv och livsmiljö upprätthålls kan ekosystemen förse samhället med en rad efterfrågade varor och tjänster. De viktigaste av produktionsfunktionerna, och som samtidigt har det största ekonomiska värdet, är livsmedel och möjligheten till rekreation. Dessutom levereras råvaror, kemiska ämnen som kan förbättra människornas hälsa eller främja den bioteknologiska utvecklingen, samt genetiska resurser som kan användas i miljövårdssyfte eller för att utveckla vattenbruket.

Energi och utrymme för transport (vattenvägar) och konstruktion hör till det fåtal tjänster som inte är direkt beroende av de stödjande och reglerande ekosystemtjänsterna. För närvarande tycks det osannolikt att den mänskliga utvecklingen kommer att expandera i sådan grad att utrymmet på havsytan inte längre räcker till. På liknande sätt kommer det att finnas en potential för energiutvinning direkt från havsvattnet så länge utrymmet finns tillgängligt, i synnerhet i beaktande av förbättrade tekniska lösningar. Utvecklingen av havsbaserad vindkraft, vågenergi och tidvat-tenenergi kan minska beroendet av fossila bränslen och därigenom dämpa klimatförändringarna. Allt bruk av utrymmet på havsytan, i synnerhet i kustregionerna, kan dock minska det estetiska värdet, förutom att det kan ge negativa följder för till exempel mångfalden, näringsväven och livsmiljön.

Förutom de tjänster som köps och säljs eller är lätta att värdera finns det ett antal kulturtjänster som ökar det mänskliga välbefinnandet. Kulturarv, utbildning och konstnärlig inspiration är exempel på dessa kulturtjänster. De kan även fungera som intresseutlösare, eftersom en försämring kan dra uppmärksamheten till det som sker under ytan.

Bland de 24 ekosystemtjänster som tas upp i rapporten (vilka illustreras i figur 1) är det bara tio som anses vara i gott skick. Bland annat är produktionen av livsmedel i dåligt skick. Sju är svårt hotade, bland dem fyra av de sex stödjande tjänsterna (näringsväv, biologisk mångfald, livsmiljö och resiliens). Även om vissa tjänster är relativt opåverkade av miljöhoten (till exempel primärproduktionen och tillgången på utrymme och farleder) ser andra ut att kunna påverkas av många miljöhot samtidigt (till exempel biologisk mångfald, livsmiljö, livsmedelsproduktion och rekreation). Hur de mest allvarliga störningarna av mänskligt ursprung hotar de marina ekosystemen visas i tabell 1. Tabellen presenterar dessutom några av de industrier som är beroende av respektive tjänst. Många av dessa industrier påverkar i sin tur de tjänster som de utnyttjar. Man bör hålla i minnet att de flesta av ekosystemtjänsterna troligen är oersättliga.

Tabell 1. Effekten av skadlig mänsklig aktivitet på de marina ekosystemtjänster som ges av Östersjön och Skagerrak. S1-6 är stödjande tjänster; R1-5 är reglerande tjänster; P1-7 är producerande tjänster; C1-C6 är kulturtjänster. , dokumenterad ökning av ekosystemtjänsten; , dokumenterad minskning av ekosystemtjänsten; , dokumenterad, men med variabel påverkan; , potentiell ökning av ekosystemtjänsten; , potentiell minskning av ekosystemtjänsten; O, förväntad påverkan, men har inte beskrivits.

EKOSYSTEMTJÄNSTER		EFFEKTER							INDUSTRIER SOM PÅVERKAR/PÅVERKAS*			
		Över- gödning		Fiske		Farliga ämnen	Sjöfart		Byggnation & utveckling	Klimat förändring		
			Överdriven exploatering & bifångst	Störningar på livsmiljön	Vattenbruk		Främmande arter	Olje utsläpp	Fysiska skador	CO ₂	C ^o	
S1	Biogeokemiska kretslopp											Stödjer de flesta andra tjänster
S2	Primärproduktion											Stödjer de flesta andra tjänster
S3	Näringsväv											Stödjer de flesta andra tjänster
S4	Biologisk mångfald											Stödjer de flesta andra tjänster
S5	Livsmiljö											Stödjer de flesta andra tjänster
S6	Resiliens											Stödjer de flesta andra tjänster
R1	Luft- och klimatreglering											All användning av fossila bränslen
R2	Sediment bevarande											Byggnation, mark, turism
R3	Minskad övergödning				(musslor)							Turism, fiske, mark
R4	Biologisk reglering				(musslor)							Livsmedelsindustrin, turism, mark
R5	Reglering av föroreningar				(musslor)							Livsmedelsindustrin, turism
P1	Livsmedel											Fiske, hälsa, vattenbruk, livsmedel
P2	Råvaror				(musslor)							Jordbruk, djurhållning, oljeindustri
P3	Genetiska resurser											Vattenbruk
P4	Kemikalier											Läkemedel, sjöfart, kemi, hälsa
P5	Utsmyckningar											Bärnsten, turism
P6	Energi											Vågenergi
P7	Utrymme och vattenvägar											Sjöfart, vindkraftverk till havs
C1	Rekreation											Turism, sportfiske, båtliv, dykning, hälsa
C2	Estetiska värden											Mark, byggnation, turism, hälsa
C3	Vetenskap och utbildning											Museer, akvarier, vetenskap, utbildning
C4	Kulturarv											Museer, festivaler, hälsa, inneb. värden
C5	Inspiration											Konst, reklam, film, lyrik, böcker
C6	Naturarv											Inneboende värden

* Samtidigt som vissa industrier drar nytta av ekosystemtjänsterna bidrar de till deras undergång

Det finns omfattande kunskapsluckor när det gäller de flesta av tjänsterna. Genom att rikta forskningen mot framför allt de grundläggande tjänsterna, som näringsväv, livsmiljö, biologisk mångfald och resiliens, kan man samtidigt få värdefull information om andra tjänster. I verkligheten är vinsten från en tjänst vanligtvis en förlust för någon annan. Med ökad kunskap om de stödjande processer som reglerar varje tjänst är berörda intressenter bättre förberedda för att kunna nyttja resurserna på bästa möjliga sätt och för att undvika negativa miljökonsekvenser (så kallad "greenlash").

Genom att verka för hållbarhet vid all resursanvändning kommer följderna för de bakomliggande stödjande och reglerande tjänsterna att minimeras, varför det ekonomiska värdet kommer att förstärkas under de kommande åren. Men för att kunna verka för hållbarhet är det nödvändigt att ha ett systemtänkande och att man förstår ekosystemens interaktion, flöden och återkopplingar. Från det nuvarande överutnyttjandet av hotade resurser bör hanteringen av havs- och kustmiljöerna inriktas på att uppnå ett motståndskraftigt ekosystem i vilket alla ekosystemtjänster är uppskattade (men att uppskattningen inte nödvändigtvis är jämnt fördelad).

Introduction

The marine environment provides humanity with numerous benefits. Some of these benefits are life-supporting; others create major economic opportunities for vast numbers of people. Least recognised are those, not readily quantified, which add to our sense of place, our health and our cultural identity. Many of us do not even know about their existence, let alone their value or the extent to which we use them. Yet, most of us contribute to their deterioration, unaware what consequences this may bring about for our personal well-being as well as for economic development in our respective region or country. The following chapters present an overview of the so called ecosystem services provided by the Baltic Sea (including the Belt and Kattegat) and Skagerrak. The importance of these services will be illustrated and their current status will be summarized.

In Europe, approximately two thirds of the inhabitants prefer coastal holidays. In Sweden, almost 90 % of the population live within 100 km of the coastline. 30 % of all vacation homes are situated within 100 m of the coastline (1). The enjoyment as well as the price tag on our seaside homes is directly dependent on the quality of the water, and so are our holidays at sea. More than half of the Swedish population regularly swim in the Baltic Sea (2) and more than one fourth regularly engage in recreational boating activity (3). Sailing, swimming or living by the sea would not be the same, were the sea a lifeless dump or a stinking soup of poisonous algae. These benefits obtained by the sea all constitute examples of environmental or ecosystem services. Before describing the various ecosystem services, some important concepts of ecology and conservation will be introduced, and their effect on ecosystem services discussed.

What are ecosystem services?

The term **ecosystem** describes a community of animals and plants interacting with each other and with their physical environment. The ecosystem includes various components such as soils, water, nutrients and living organisms. Organisms range from bacteria to trees and large animals, including humans. **Ecosystem services** are defined as the functions and processes through which ecosystems, and the species that they support, sustain and fulfil human life. Healthy ecosystems perform a multitude of essential functions. The use of these services goes back to the dawn of mankind, though their definition is recent. Linnaeus repeatedly emphasized the use and benefit of nature, but it is not until now, that this awareness is gaining ground as an argument for conservation and sustainable management.

Ecosystem services are sometimes divided into *goods*, referring to items given monetary value, and *services*, which are valued but rarely bought and sold. In the discussion which is to follow, the term ecosystem service will cover both goods

and services. It should perhaps be pointed out that the ecosystem service concept does not challenge already established ecological concepts; it merely looks at ecosystems from a utilitarian perspective.

A variety of benefits free of charge

Conservation is the act of preserving our ecosystems as well as their functions and processes. There are several reasons for environmental conservation. When species, populations, ecosystems or their associated services are life-supporting we really have no choice other than to preserve them. When economically important, incentives are strong, and yet not always sufficient. When nature is merely attractive, conservation is usually in the hand of public opinion. Finally, when a species or a service just *is*, far from spectacular and without price tag, conservation measures are rarely taken at all.

Historically, nature and its values have largely been ignored until malfunction or loss has drawn the attention to their importance. Although the wealth of prosperous nations has originated in natural resources, little has been done to safeguard them. Although often taken for granted, and in many cases inadequately managed, ecosystem services are, no doubt, the foundation for human life and development. The links between ecosystem services and various aspects of human well-being are many (4). Certain services such as the production of food for harvest are well documented. Less appreciated are life-supporting services such as atmospheric and climate regulation, detoxification of waste and the maintenance of **biodiversity**, from which key ingredients for e.g. our industrial, pharmaceutical and chemical enterprises are derived.

Ecosystem services have been categorised in various ways (5-10). The classification used in this report follows the Millennium Ecosystem Assessment; dividing goods and services into four categories according to the type of service they provide (Fig. 2). The categorisation does not in itself explain how the ecosystem services interact. Interactions between services as well as their relative importance to human society will be discussed for each of the services in the coming chapters and are summarised in the beginning of the report (p. 13).

In the marine environment, the most readily understood services include those that are labelled **goods** or **provisioning services**, meaning resources used by humans, originating in the sea. Among these, production of food for harvest is perhaps the most obvious, but this category also includes the production of genetic, pharmaceutical and chemical resources, as well as fertilizer, fodder, and energy.

Less attention has been given to the **regulating services**, among which we find many services vital to mankind including gas- or atmospheric regulation. The ocean provides the oxygen (O₂) that we breathe and represents the largest natural sink for carbon dioxide (CO₂) on Earth. Without the carbon sequestration of our

seas, CO₂ content in the atmosphere would be substantially greater with severe consequences for global climate change. Other regulating services provided by our seas include the regulation of local climate, protection against extreme weather, nutrient regulation, sediment retention, and waste storage as well as the regulation of unwanted pests such as toxic algal blooms.

Ecosystem services of importance for human culture, information and education will be gathered under the heading **cultural services**. First and most valued among these, are recreational services. They are easy to relate to. Who does not want to swim, sunbathe or rent a house by a clean, beautiful beach, ideally full of pretty shells and with the local seal colony within sight? Less known among the cultural services are the more abstract ones such as spiritual and historic services and services of importance for cultural identity. Other cultural services include scenery, education and inspiration for art and advertisement. Finally, and perhaps most difficult to value, and in no way important to all of us, is the sense of passing what we have on to future generations.

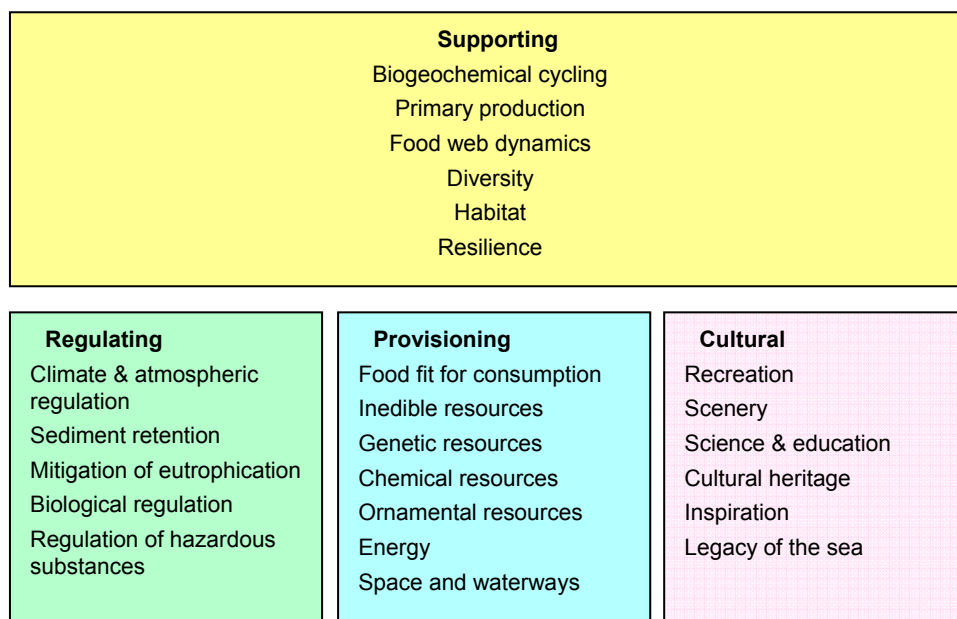


Figure 2. Nature provides us with these services – free of charge.

The wide array of ecosystem services is operating across a wide range of spatial and temporal scales. Their existence, **sustainability** and future capacity to fill human needs is closely interlinked with various ecological processes, some of which are essential to all ecosystem services. All the aforementioned services are dependent on a number of **supporting ecosystem services**. These are the least appreciated, simply because they are not used directly. Examples of supporting services include biogeochemical cycles (pathways by which chemical elements move through **abiotic** and **biotic** compartments), **primary production** (the conversion of solar energy to biomass), **food web dynamics** (all processes by which nutrients are transferred from one organism to another in an ecosystem), biodiversity (the multitude of genes, organisms and ecosystems), **habitat** availability (the availability of

an environment suitable for spawning, breeding, feeding and growth to maturity) and **resilience**, which is the amount of disturbance or stress that an ecosystem can absorb and still remain capable of returning to its pre-disturbance state. Resilience should be viewed as an insurance against irreversible change. Supporting ecosystem services are closely interlinked and can be seen as **umbrella services**, in the sense that the protection of one, secures the maintenance of numerous others among the provisioning, regulating and cultural services. This interdependency is particularly obvious for biodiversity, habitat availability and resilience. High marine diversity is directly contributing to stability and capacity to recover (resilience) in marine ecosystems (11), meanwhile providing favourable conditions for e.g. marine food harvest and bioprospecting.

The value of ecosystem services

In order to make a fair valuation of the services obtained, we need to get a good understanding of which they are and to what extent we use them. A brief example of their importance and value of ecosystem services in general is provided by the Biosphere 2 in Arizona, US, where a technologically produced, artificial biosphere was developed. Despite an approximate cost of \$150 millions (excluding the \$800 000 per year to run the climate control) (12), Biosphere 2 did not manage to support an environment hospitable for humans for more than a few months. Among other problems, lack of oxygen and low food supply compromised the project. It is easy to see that, in comparison, our original world (Biosphere 1) is both valuable and cost-efficient.

Humans have altered virtually all of Earth's natural ecosystems. Without considering the consequences, centuries of resource extraction, commonly at the expense of less obvious regulating and supporting services, have contributed to substantial gains in human well-being and economic prosperity. The key difference between the degradation of ecosystems and the depreciation of capital is related to the perception that the benefits obtained from nature is for free – in the sense that no one owns them or pays for them. With this misconception comes the threat of underestimating and over-using natural resources in a careless manner. All the same, current economic prosperity, based on natural resource use, has been achieved at a dear cost. The Millennium Ecosystem Assessment (13), presented in 2005, was an inventory of the state of the world's ecosystems. More than 1300 researches and experts from 95 countries reached the conclusion that 60 % of our ecosystem services are deteriorating due to human activity. The consequences of degradation and over-use include loss **ecological integrity** and resilience, which in turn increases the risk of **ecological surprises**. It is important to keep in mind that ecosystem dynamics are not necessarily continuous; instead they may suddenly surpass a threshold causing irreversible ecosystem changes and **greenlash**, the loss of valuable services. To halt this development, human society has to acknowledge that it is part of nature. We have to be aware of what we use so that we reduce the abuse

of the foundation for our existence. The degradation of nature is for some enough to cause action. For the majority of us, however, conservation only becomes meaningful when there is a personal benefit. Sustainable use of our natural capital or ecosystem services can only be obtained if we:

- Use resources no faster than they regenerate
- Replace the use of exhaustible resources with renewable
- Do not produce more waste than nature can absorb and circulate in biogeochemical cycles

A global paradigm shift in marine ecosystem management is currently underway. It shifts focus from species to ecosystems. New and central to this paradigm is the appreciation of humans as an integral part of the ecosystem. The **ecosystem approach** stresses the importance of ecosystems for socioeconomic development and strives to maintain long-term capacity of ecosystems to produce goods and services for human use. Instead of focusing on how to protect ecosystems *from* development, the ecosystem approach aims to manage ecosystems *for* development (4). Overall, resource management shall be evaluated from a perspective of ecosystem function and the concept of ecosystem services should be incorporated into all decision making. Exploitation of provisioning ecosystem services should not be carried out at the expense of regulating, cultural and supporting services. Further, local resource users shall be a natural part of the decision-making process (12 principles of the ecosystem approach). The MA stressed that given major political and constitutional reforms, we can indeed halt current degradation, without negatively affecting human welfare and economic development. Whether this will happen or not, remains to be seen. UNEP (United Nations Environmental Programme) and UNDP (United Nations Development Programme) have in early 2008 initiated a follow-up of the 2005 MA, within which Stockholm Resilience Centre is to participate actively, for example by taking the lead as one of the key scientific reference points within sustainable development.

Our marine environment

The scope of this report is limited to describing ecosystem services. Thus, only a brief overview to the ecology and current environmental status of the Baltic Sea and Skagerrak is included. For a thorough review, updated status reports are available in *Change beneath the surface: an in-depth look at Sweden's marine environment* (14), *Havet 2007* (15), *Baltic Sea, GIWA Regional assessment 17* (16) as well as in publications from the Helsinki Commission (17).

Today, most land-based ecosystems in Sweden are subjected to conservation, and in some cases even restoration. The marine environment, a scene of ongoing degradation, constitutes a stark contrast, and decades of neglect still override recent attempts of conservation and management. The current status of our neighbouring

seas is generally poor. According to the Global International Waters Assessment (GIWA, 16), the Baltic Sea suffers from severe **eutrophication** and over-fishing. Of concern is also increasing shipping and the modification of habitats and communities. The fact that many species live at their environmental extremes and numerous populations are genetically unique increases their vulnerability and thus the difficulties of restoring and maintaining a healthy Baltic Sea (18).

A quick tour of our marine environment reveals that the Bothnian Bay, surrounded by Sweden and Finland, remains contaminated and certain fish species are not even fit for human consumption. The Baltic proper is surrounded by Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany and Denmark. Intensive agriculture and industry dominates the coastal areas and during the last century the originally oligotrophic Baltic Sea received a four to eightfold increase of nitrogen and phosphorus inputs, resulting in increased productivity and dramatically changed species composition and food webs (19). In 2007, the extent of permanently oxygen-depleted bottoms was greater than ever. Further, fishing is largely unsustainable, shipping is intense and pollution levels are high. Kattegat, situated between Sweden and Denmark, receives nutrient-rich water from the Baltic as well as high loads from the neighbouring countries. Both Kattegat and Skagerrak, the latter surrounded by Sweden, Denmark and Norway, are subjected to over-extraction of fish and highly trafficked by tankers and other carriers of hazardous cargo. When biodiversity and ecosystem resilience are deteriorating, so is the long-term capacity to deliver essential ecosystem services. If nothing is done to halt this unpleasant development, there is little hope neither to retain all services we once took for granted nor to achieve the environmental objectives dictated by the Swedish government (20). Finally, global climate change is continuously altering conditions for all marine life, and will continue to do so for some time, no matter what we do.

Trade in ecosystem services

In a world of escalating environmental degradation and threatened resource provision, a market for ecosystem services may create incitements to sustainable development among producers, as well as consumers. Ultimately, economic development is confined within the capacity of the worlds' ecosystems to support and provision economic activities; thus sustainable resource use is essential for continued economic growth. If users of ecosystem services, like polluters, have to pay the providers, conservation of ecosystem function may become profitable. At the same time justification for unsustainable consumption will cease. The following example illustrates how trade in ecosystem could work (21):

- Industries (agricultural and others) are not permitted to release environmental pollutants (nitrogen, phosphorus as well as others) without access to ecosystem services regulating the corresponding discharge.

- Meanwhile, providers of ecosystem services (e.g. individual or municipal owners of land/water or industries like mussel or oyster farms) are able to sell ecosystem capacity to polluters.
- Authorities establish critical loads based on scientific evidence

Trade in ecosystem services requires standardization of ecosystem services and their value, a debated subject among environmental economists (22). Specific problems characterise the marine environment, related to the lack of ownership. The question arises as to whom the naturally regulating services of the sea can be counted. If overcoming initial difficulties, trade in ecosystem services may contribute to the development of clean-tech industries that currently lack economic strength.

The scope of this report

The Swedish Environmental Protection Agency (SEPA) has the intention to illuminate the direct and indirect benefits people obtain from our neighbouring seas, Skagerrak, Kattegat as well as the Belt and Baltic Seas. Such benefits, or ecosystem services, need to be acknowledged and thoroughly monitored, as do their values need to be incorporated into decision-making processes. There are many suggestions as to how ecosystem services should be defined and classified, in order to be most correctly valued. For the most part, this report follows the classification of the MA, although being limited to the marine environment calls for a somewhat increased level of detail. Ecosystem services are essential to households, industry and economy and thus deserve rightful status. Below, marine ecosystem services used by inhabitants in Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany and Denmark will be identified, defined and extensively described and exemplified. Although most services are shared by all countries, the lion part of examples concerns the Swedish marine environment. Published literature has already identified the primary threats to marine environments in our neighbouring seas (14-16, 23); this study describes the way in which these threats imperil essential ecosystem services, both locally and globally. Finally, an attempt will be made to identify knowledge gaps. In summary, each chapter will describe the ecosystem service in question according to the following:

Extent and importance of the services to consumers, industries, society and economy

- Definition and examples of the service
- Geographic distribution of the service
- Users of the service
- The extent of use

Interdependence with other processes and services

- The processes and organisms that govern and maintain the service
- Interdependency with other services

Status, threats and consequences

- Summary of current status
- Current management of service
- Sustainability of the service
- Current threats to the service and their extent and distribution
- Consequences of any current threats to beneficiaries

Status, threats, sustainability and consequences of current threats are summarized in a table for each respective ecosystem service. Most ecosystem services operate over large scales and include various processes or resources occurring in nine countries, the table attempts to summarize the overall status, threats and consequences of current threats. Naturally, if each service were to be divided into various sub-services the outcome might differ among them.

In the table *current status* is described as *good*, *moderate*, *poor* or *unknown*, as illustrated by the colours green, yellow, red and white. An ecosystem service of poor status requires immediate attention, extended protection and careful management. Typically, as explained above, not all aspects of the service in question are in equally poor status.

The *use* of each service is described as *sustainable* or *unsustainable*, as illustrated by the colours green and red. For the supporting services sustainability of use is not applicable (white). Though e.g. habitats and diversity are crucial for all other ecosystem services, it is difficult to describe them in terms of use. As for the regulating and some of the cultural services, the characterisation of use may also be difficult to grasp. For example, the use of most regulating and cultural services are inherently sustainable – simply because our use does not affect them and because we cannot choose *how much* to use them. These ecosystem services can be affected by our action but not by our use of them.

The table subsequently states the *level of threat* to the service in question. Level of threat is described as *low*, *moderate* or *severe*, also illustrated by the colours green, yellow and red. Threats which are new and may constitute a risk in the future are dealt with in the subsequent text, but not included in the assessment presented in the table.

Finally, the table includes an estimate of the *expected consequences of current threats*. Once again, this does not take future threats into consideration. Expected consequences are described as *limited*, *moderate* or *severe*, coloured in green, yellow and red as well. For some services, the consequences remain unknown. This is typically the case if it is not known what exactly is being lost and what importance it might have as is the case with diversity, resilience and genetic resources for instance.

Ways to maintain and strengthen the service

- Alternative management
- Potential measures

Examples of knowledge gaps

- Presents knowledge gaps and potential research directions

A glossary at the end of the report explains crucial terms, marked in bold, which may be new to the reader.

All monetary values are expressed in euro (€) using the the exchange rate valid 1 January 2008 (1 EUR = 9.43 SEK). Values €have further been converted to adjust for general price level changes (inflation), using mean year values of consumer price index (obtained from Statistics Sweden).

Abbreviations are used following the initial use of the full terms in question. All abbreviations are listed at the end of the report.

Supporting ecosystem services

S1: Maintenance of biogeochemical cycling

Definition

Biogeochemical cycling refers to the cyclical movement of energy and materials within ecosystems. This cycling is essential for the provision of construction material for all living things, including the resources used and valued by society.

For example, all water, carbon and nitrogen making up the human body, as well as all other animals and our entire living world, are part of the biogeochemical cycle. Not only do these chemical elements move through living organisms, in this sense referred to as **exchange pools**. They also move through water, land and air. Hence the biogeochemical cycle is the pathway by which chemical elements move through the physical and biological compartments of all ecosystems. The cycle is a closed one and hence Earth does not receive refills of nutrients; in effect, all elements are recycled. However, some chemicals are held or accumulated for long periods of time in one place, this place being referred to as **sink** or **reservoir**. Examples of long-term storage include our coal and oil reservoirs, deposited millions of years ago.

Related processes and services

Among the many essential substances cycling the marine ecosystems, cycles of particular interest for a review of ecosystem services include:

- Oxygen cycle
- Water cycle
- Carbon cycle
- Nitrogen cycle
- Phosphorus cycle

These cycles will only be described in brief below. Thorough reviews of nutrient cycles and how they are influenced by anthropogenic activity are found elsewhere (14, 23, 24).

Oxygen cycle

Oxygen is found in the atmosphere, in the oceans, in rocks; though not all organisms need to breathe oxygen, there is definitely oxygen inside of every organism. Oxygen always bonds with other elements or with itself (as in ozone). Oxygen is bound in water molecules (H₂O) and in CO₂. There is a large amount of oxygen

forced into solution and dissolved in seawater, lakes, and streams. The main driving factor of the oxygen cycle is **photosynthesis**, which is responsible for the modern Earth's atmosphere and life as we know it. Photosynthesizing organisms use solar energy to combine CO₂ with water to create sugar (carbohydrates) and oxygen. Photosynthesis occurring in the sea (worldwide) contributes to almost half of the total free oxygen to the oxygen cycle. The oxygen is subsequently consumed by the animals and the sugars are assimilated by a variety of organisms. Through the process of metabolism, the sugars are broken down into water and CO₂. Then the cycle begins again.

Hydrological cycle

The cycling of water, or the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. The cycle is driven by solar energy. Water can change states among liquid, vapor, and ice at various places in the water cycle. In this cycle, the sea constitutes a reservoir for water and surface for evaporation. Rising air currents take the vapor up into the atmosphere, along with water from **evapotranspiration**, which is water transpired from plants and evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to condense into clouds. When precipitation falls, the water is returned to the sea, directly or via runoff from land.

Carbon cycle

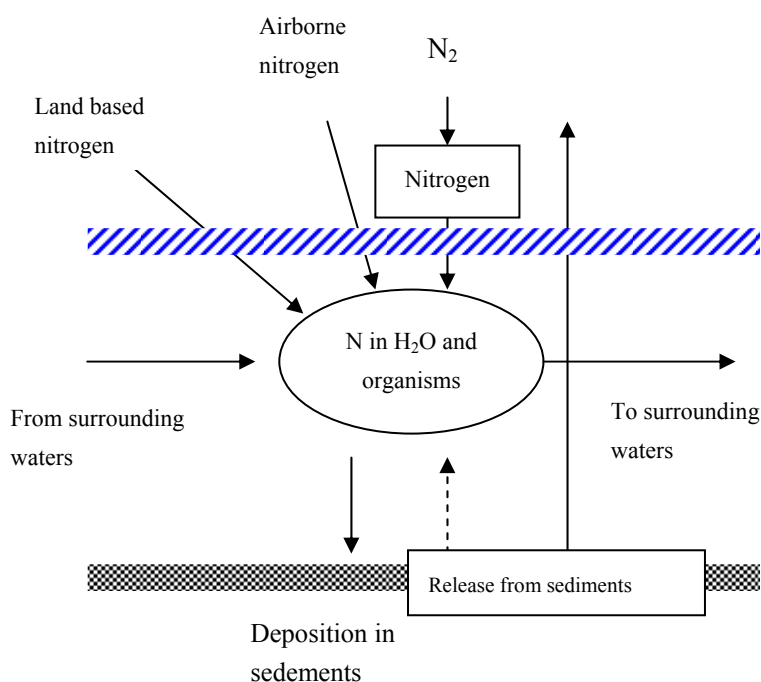
Carbon circulates through nature in various forms. It is a constituent of all organic compounds, many of which are crucial for life on Earth. Following CO₂ fixation from algae and terrestrial green plants, carbohydrates may be consumed and used to carry on metabolism, the excess being stored as fats and polysaccharides. As seen above, all animals return CO₂ directly to the atmosphere as a by-product of their respiration. What carbon is not consumed, in animal bodies and wastes, is eventually released as CO₂ by means of microbial transformation. Ancient remains of organisms have accumulated in the Earth's crust as fossil fuels (e.g. coal, gas, and petroleum), limestone, and coral. Fossil fuels, removed from the carbon cycle in prehistoric time, are now being released in vast amounts as CO₂ through industrial and agricultural processes. Part of the CO₂ is taken up by the ocean and stored as carbonic acid. The oxygen and carbon cycles are processes directly involved in climate regulation (chapter R1).

Nitrogen and phosphorus cycles

Besides oxygen, water and carbon, plants need other elements, called nutrients, albeit in smaller quantities. The most important nutrients are nitrogen (N) and phosphorus (P). Their respective cycles are relatively similar (Fig. 3). Typically, one of these nutrients is in short supply, compared to the other. This nutrient is then referred to as the being growth-limiting. In the Baltic Sea and Skagerrak, the extent to which the respective nutrients are growth-limiting varies geographically. Highest concentrations of nutrients are commonly found in shallow coastal areas where they have arrived from terrestrial runoff. Nutrients are subsequently transferred to

biomass by **phytoplankton**, sea-grass and algae, while the reverse process is taken care of in the sediments, where microbial **decomposition** converts organic matter to nutrients. Nutrients (particularly N) also originate from airborne emissions (particularly from the transportation sector). Finally, **cyanobacteria** fix atmospheric nitrogen which is subsequently supplied to the biological community. In the Baltic Sea, this fixation exceeds what is received from the atmosphere and almost equals the amount received from all rivers. On our latitudes, the nutrient cycle is largely seasonal interacting with light, temperature and primary production. Following the death of organisms, decomposition of organic matter by bacteria on the sea floor and subsequent **nitrification** leads to the release of nitrate ions into the water. Both processes require oxygen, which at times of high organic deposition, may become depleted. Finally nitrate ions may become **denitrified** and escape the water as gaseous nitrogen. In contrast to nitrogen, phosphorus never leaves the water once having entered. Following decomposition, phosphorus typically binds with iron (which is particularly abundant in the Bothnian Bay) and end up in the seabed. On seafloors devoid of oxygen (**anoxic**), this phosphorus is released and becomes once more available to the biological community.

Figure 3. The nitrogen cycle. Translated from Formas 2006 (Östersjön - hot och hopp)



Interaction with other ecosystem services

Maintenance of well-functioning biogeochemical cycling, by means of storage and recycling is a prerequisite for ecosystem productivity, which in turn affects diver-

sity and resilience and ultimately the provision of goods to society. Nutrient cycling, in turn, is dependent on the availability of nutrient storing organism. In the Baltic Sea, as well as in Skagerrak, human action has altered nutrient cycles and nutrients have become over-abundant. Eutrophication constitutes a threat to various aspects of the marine environment and under eutrophic conditions nutrient storing organisms, such as filter feeders, are of particular importance (performing the ecosystem service referred to as mitigation of eutrophication, chapter R3).

Status, threats and consequences

Status	Moderate
Sustainability of use	-
Level of threat	Moderate
Expected consequences	Severe

The status of biogeochemical cycling is considered moderate. Although there are numerous cycles in good condition, distorted nutrient cycling (N and P) as a direct effect of human action, reduces the overall status. Society has also caused major alterations in the carbon cycle due to excessive CO₂ emissions. Given that biogeochemical cycles affect all aspects of ecosystem function (Fig. 1), the expected consequences must be considered severe.

Many of our marine ecosystems are experiencing **chronic anthropogenic stress**; that is, human activities result in constant underlying impact to our marine ecosystems. Such chronic and often gradual increase of a particular disturbance does not always generate a gradual response in ecosystem function. Rather, ecosystem processes often continue as usual until a critical threshold is reached, in which case major and rather sudden change can be expected. This change, sometimes referred to as **ecosystem shift**, can be more or less permanent. A well-studied example is the clear lake which receives increasing amounts of nutrients with no obvious detrimental impacts - until one day when the lake suddenly becomes turbid. Once the sudden change has occurred, the way back typically requires more than restoring nutrient levels to what they were before the sudden shift in water quality. Sometimes restoration requires completely different actions.

According to many scientists the continuous eutrophication of the Baltic has caused this kind of shift. It may explain why decreased nutrient emissions have not significantly ameliorated the situation. Currently, alternative measures to break the deadlock are discussed, including major fish-out of planktivorous fish (25) or mechanic oxygenation of the sea floor (26). To add to the uncertainty, increasingly apparent alterations in circulation and distribution of nutrients are further to be expected as a result of climate change (27).

Maintaining biogeochemical cycles

Biogeochemical cycles are dynamic and cannot be expected to remain fixed. A fair objective is rather to avoid excessive distortion. Familiar preventive measures concerning carbon cycling include restricted burning of fossil fuels and reforestation. Regarding the excessive release of nutrients (and the consequential distortion of nutrient cycles) measures typically include improved agricultural retention, improved sewage treatment (including technical development) and the creation of wetlands.

Following the adoption of the Baltic Sea Action Plan (BSAP) in 2007, all Baltic Sea countries have committed to reduce nutrient emissions (28). In order to reach the required reductions, a number of new measures will need to be put in practise all around the Baltic Sea. In Sweden, an important step is to find the most significant sources of nutrient leakage, a task assigned to the Swedish Regional Water Authorities. In the light of the national BSAP commitments, SEPA has been assigned by the government to develop a proposal of national measures addressing excessive nutrient release. The proposal is to be presented during 2008.

Examples of knowledge gaps

The nitrogen and phosphorus cycles are inherently complicated. Despite considerable research effort, understanding of some of the fundamental involved remains limited. To further complicate the situation, implications of recent findings regarding such processes remain debated (23). And new questions keep arising. With the spreading of anoxic seafloors, precipitated phosphorus becomes resuspended, which aggravates the situation of eutrophication. Hence, one pressing task is to find out more about this process by which phosphorus leaks from anoxic bottom sediments. To which extent does it leak and can it be prevented? That is, what other factors, apart from oxygen, may increase or decrease the return of phosphorus to the water column?

Supporting ecosystem services

S2: Primary production

Definition

Primary producers use solar energy to convert dead material (inorganic) to living material (organic) by means of photosynthesis. There are three main types of primary producers in our marine environment:

- 1) Phytoplankton in the water column
- 2) **Benthic** algae and sea-grass
- 3) Coastal vegetation (e.g. reed)

Related processes and services

The process of primary production per se, or photosynthesis, goes largely unnoticed. Nonetheless, it supports most forms of life on earth, including human; its importance being global as much as local. Primary production affects most other ecosystem services by regulating levels of atmospheric oxygen and constituting the basis of the food chain. Among many other important functions, primary production affects the biogeochemical cycling and regulates global climate by using CO₂. Half of the global primary production originates from the marine realm (29). In our part of the world, marine primary production is most commonly limited by nitrogen, although in some areas, accessible phosphorus and silica may play important roles. A thorough review of how primary production is regulated is found elsewhere (24, 30).

Status, threats and consequences

Status	Good
Sustainability of use	-
Level of threat	Low
Expected consequences	Limited

Primary production is not threatened in the Baltic Sea or Skagerrak. In contrary, primary production has increased in recent years. Though increasing overall system production, excessive primary production may also cause problems for other ecosystem services.

Phytoplankton are microscopic, usually single-cell, algae which can reach concentrations of hundreds of thousands per litre water. Swedish waters are dominated by

dinoflagellates, diatoms and cyanobacteria. Phytoplankton biomass is typically higher in Skagerrak and Kattegat than in the Baltic Sea. Overall, the greatest primary production occurs in shallow coastal areas. Although measurements of primary production are not readily available, estimates from Kattegat and Skagerrak indicate production of 200 – 250 g C m⁻² (14, 31). In the Baltic Sea, primary production decreases with latitude. More commonly measured is the content of chlorophyll, a pigment present in primary producers, or the water transparency (as given by the Secchi depth). Primary production is not currently threatened although ongoing climate change may alter species composition and possibly production rates (27).

Primary production and climate change

Within the next 100 years, substantial changes in salinity, temperature, wind, ice and pH conditions may occur in the Baltic Sea and Skagerrak (27). Predicted alterations in environmental conditions include increased freshwater runoff, resulting in decreased water transparency and increased bacterial production relative to phytoplankton production (32). In the future seawater is not only getting warmer, it is becoming less **alkaline** too. Possibly counteracting these trends is a potential increase in primary production due to **seawater acidification** (33). New research has shown that phytoplankton appear to be able to increase their carbon uptake as a response to increased CO₂ levels. The resulting increase in biomass, should in turn stimulate increased sequestration. This is perhaps good news for open oceans where the organic material can be deposited deep on the ocean floor. However, in our eutrophic waters increased primary production could become detrimental and lead to extended areas of anoxic sea floors. Possibly counteracting the above are recently presented data, which indicate that if future **pH** increases more than 0.25, key steps in the chemical process of photosynthesis will become impacted (34). The most conservative decrease expected for this century is 0.2 units (chapter R1).

“Photosynthesis holds a unique position in the biosphere. Without it, the room would shut, like an abandoned hallway in space. Life on earth constitutes one single flow, one single movement of energy, originating in photosynthesis, the plug in the relationship between life and sun”

Free translation from Malm 2007 (35)

How to maintain primary production

The level of threat to primary production is still considered low. Nevertheless, certain primary producers, such as sea-grass and large macroalgae may be locally threatened, often at the expense of phytoplankton and algal mats, which increase in abundance due to eutrophication resulting and increased water turbidity and shading.

Examples of knowledge gaps

Primary production is highly variable and has to be measured repeatedly in order to get credible results. Consequently, there is limited information on the extent of primary production in the Baltic, Skagerrak and Kattegat. The assumed long-term increase in primary production has in fact not yet been demonstrated. Instead, estimates of primary production and eutrophication are typically based on measurements of water transparency, which has decreased in most Baltic basins (Fig. 4). To some extent eutrophication can also be inferred from the increased frequency of cyanobacteria blooms in recent decades. Furthermore, the response in primary production to concurrent eutrophication and aspects of climate change including seawater acidification should be further investigated.

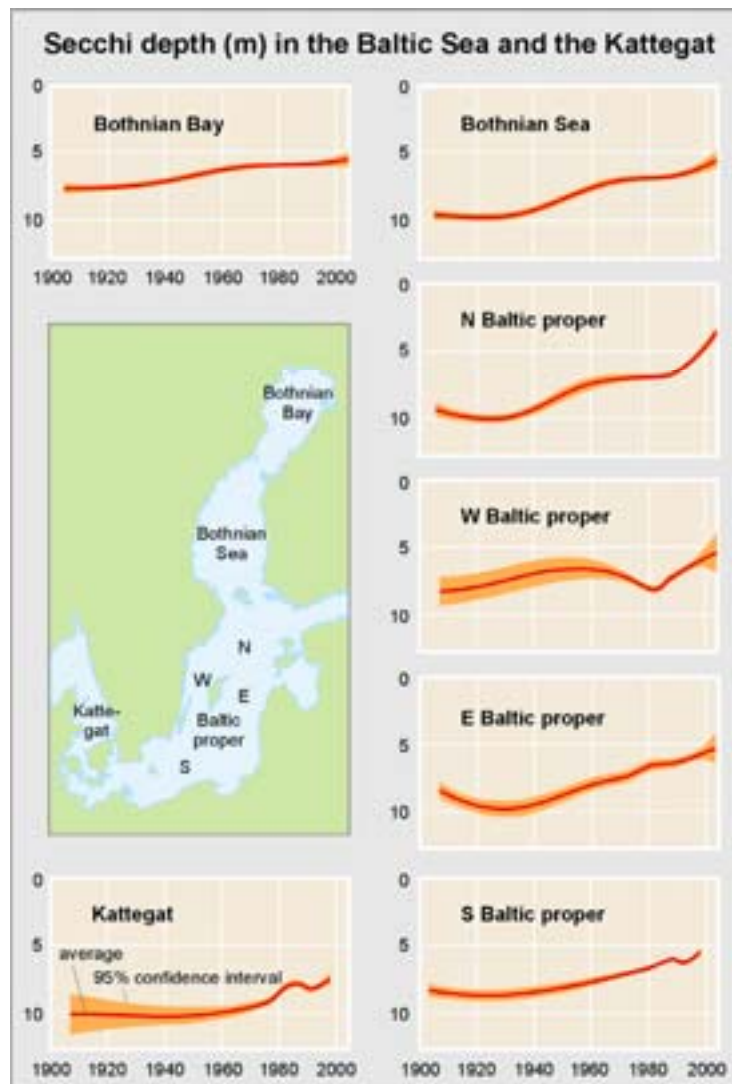


Figure 4. During the 20th century, the water of the Baltic Sea has become gradually more turbid. The diagrams show averages based on summer measurements (June-September). Source: Bernes 2005 (14).

Supporting ecosystem services

S3: Maintenance of food web dynamics

Definition

Food webs attempt to describe trophic relationships between organisms (i.e. who eats who). By means of food webs nutrients are transferred from plankton to the resources that are valued by society. An organism's position within a particular food web is defined by its function (e.g. whether it is a primary producer, feeds on animals or extracts nutrients from dead organisms).

Related processes and services

An ecosystem is made up of living as well as non-living, or inorganic components (e.g. sand, water, oxygen). A biological community, on the other hand, is composed by living organisms only. In the biological community, the organisms are linked in their need to obtain energy from food, which typically originates from the sun through primary production. At the dawn of biological communities, primary production started in cyanobacteria, or blue green algae, which are today so commonly despised. Inventing photosynthesis, they gave rise to the first trophic chain from producer to consumer. The organisms in any common food web can be divided into three groups:

1. **Producers** - photosynthesizing plants
2. **Consumers** – primary and secondary consuming animals, whether **herbivores** (plant eaters), **carnivores** (meat eaters) or **omnivores** (feeding on both plants and animals)
3. **Decomposers** and **detritivores** - consuming dead organisms and breaking down organic material

Primary production is consumed by so called herbivores, known also as primary consumers; in our seas these include zooplankton, mussels, clams, barnacles and marine isopods. These creatures, in turn, are eaten by secondary consumers, such as smaller fish, which are then consumed by larger carnivorous fish and humans. When alive, omnivores and carnivores may not constitute prey for others (thus they are **top predators**), but as they die, they become food for **detritivores**, or organisms that feed on waste matter. By consuming the remains of formerly living things, detritivores break organic material down into inorganic substances. But detritivores are not the last stop on the food web. The final trophic level, before the cycle comes back around to primary producers, contains the largest number of

organisms in the entire food web. In each handful of sediments there may be billions and billions of decomposers. Distinguished from detritivores, the decomposers break down the nutrients in decayed organic matter to a far greater extent. Typically, decomposers are bacteria and they process materials in such a way that compounds are broken down into simpler forms, or even into their basic elements, which allows for renewed photosynthesis.

Food web dynamics is dictated by species composition, which in the marine environment is typically influenced by abiotic factors such as salinity, but also by the direction and strength of local currents and winds (hydrographic conditions). Skagerrak and Kattegat, for example, are largely dominated by marine species, whereas in the Baltic, there is a mixture of marine- and freshwater species, with freshwater species becoming increasingly dominant with latitude. Species distributions may further be influenced by biotic habitat factors such as biogenic bottom substrate and local presence of conspecifics. The number of individuals in each group is regulated by the provision of food as well as by predation pressure.

Food web processes, or which organisms feed on which, play a crucial role on the flow of nutrients through the ecosystem. A functioning energy transfer from lower to higher trophic levels constitutes the foundation of an ecosystem. Consequently, food web dynamics respond to any alteration in the number of individuals in each **functional group**, with subsequent effects for ecosystem processes and services. The position in the food chain is an important factor in determining vulnerability to human activity. A large top predator, for example, consumes large volumes of smaller species and hence, the reduction in the number of species high up in the food web generally has a greater effect than the impact of a species lower in the food chain. The impact at one trophic level, which in turn sets off changes at other levels is referred to as a **trophic cascade**.

The main way in which a species affects its surrounding ecosystem is by consuming resources, or by constituting a resource for other consumers

Characterizing the food web is that there is always a loss of energy in the transfer from one trophic level to another (**2nd law of thermodynamics**). Organisms never manage to retrieve 100 % of the energy from the materials they eat; in fact, the figure is more like 10 %. A model known as the **ecological pyramid**, or **energy pyramid**, shows that as the amount of total energy decreases with each trophic level. In the top of the food web there are relatively few individuals which hold an important function controlling lower levels. Within a food web, certain species, called **keystone species**, are more important than others. In many food webs, the top predator holds such a position. In the Baltic Sea food web (Fig. 5), cod (*Gadus morhua*) constitutes a top predator and keystone species. Typically, the importance

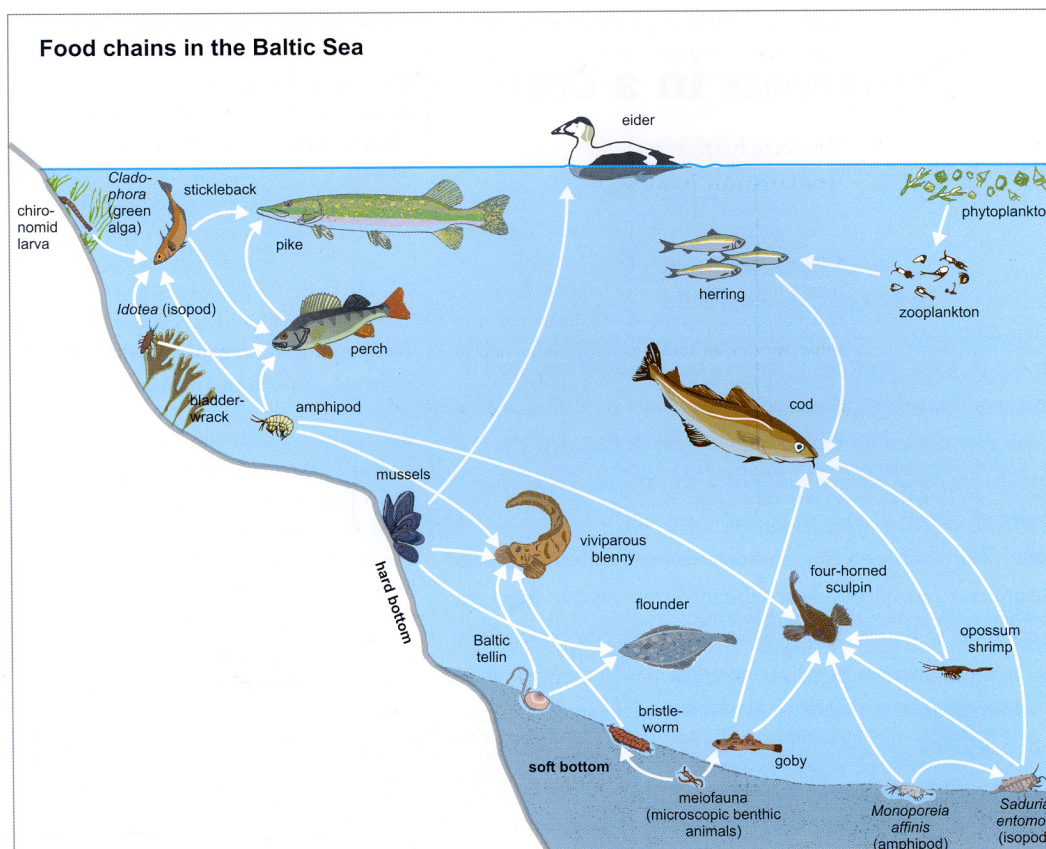


Figure 5. Illustration of Baltic food web dynamics. Source: Bernes 2005 (14)

Status, threats and consequences

Status	Poor
Sustainability of use	-
Level of threat	High
Expected consequences	Severe

Overall, food-webs in the Baltic Sea have been largely distorted, due to decades of degradation. The state of this crucial ecosystem service is considered moderate to poor. Meanwhile, levels of threats have in no way diminished and more trophic cascades may be expected in the future.

Unsustainable harvest of cod causes trophic cascades

The risk of trophic cascades appears to be greater in the sea than in the terrestrial environment. Not only does a reduction of predatory fish affect its prey, but it is also likely to influence trophic interactions further down the food chain. Presented below is perhaps the most well-known human-induced trophic cascade that has occurred in the Baltic Sea (Fig. 6).

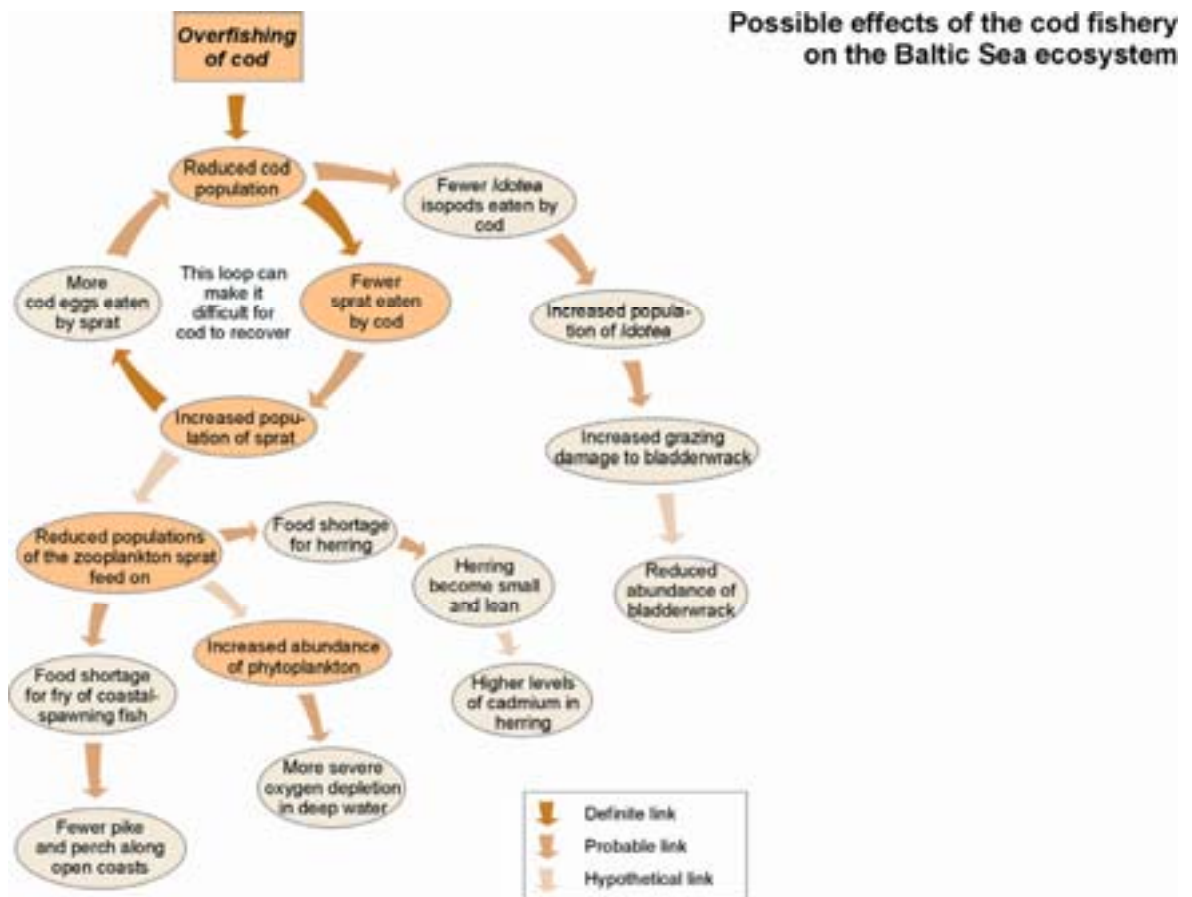


Figure 6. Possible effects of cod over-fishing. Source: Bernes 2005 (14).

The decline in cod abundance is a well-documented fact. A relationship between the two has been reported from other parts of the world where over-exploitation of cod has caused the **predatory release** of their prey, zooplankton-feeders like sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) (36). Increased sprat abundance is likely to reduce the availability of zooplanktons. In addition it may further decrease cod stocks by means of cod roe predation and food competition with juvenile cod (37). Phytoplankton, which are typically limited by nutrients and predation, may be favoured reduced predation pressure (from zooplankton); to this, add advantageous nutrient-rich conditions. Thus, the decline in cod abundance may support continuous eutrophication. We have already seen that primary production reduces oxygen, which causes yet another threat to cod, by restricting the extent of their spawning grounds. Increased abundances of sprat and herring may additionally limit the distributions of herbivorous invertebrate, causing increased epiphyte growth on macroalgae and sea-grass, with shading and limited distributions of these important habitat formers (for juvenile cod among others) as a consequence (chapter S5). Yet another trophic effect related to the reduction in cod, involves the common guillemot (*Uria aalge*), a sea bird residing in the Baltic Sea area. When breeding, the colony of common guillemots constitutes a tourism attraction on Stora and Lilla Karlsö (chapter C1). Lately, it has become evident that fledging weight among common guillemots has declined. According to current research, it

is credible that the lack of predators (cod) and limited food sources (zooplankton) have resulted in less fat content among sprat, which may in turn, contribute to reduced fledging weight among guillemots, for which sprat are staple food (38). Conclusively, these cascade effects, all offset by the decline in cod, has had deleterious impacts for various organisms and habitats and may, according to some researchers, become permanent (39).

The interconnectedness of components in the food web makes it impossible for any event or phenomenon to be truly isolated

Bioaccumulation of hazardous substances

Hazardous substances linger in the food web for extended periods of time. The following example illustrates how the effects of hazardous substances will spread in the food web (**bioaccumulation**), and increase with increasing energy requirements (**biomagnification**). Small toxic particles may stick to microalgae without causing any harm. Yet, when a small herbivore, like a zooplankton or isopod feeds on the algae, it will ingest a comparatively large quantity of the pollutant; so begins the cycle of biomagnification. By the time the toxin has passed from the zooplankton to a small fish, the amount of pollutant in a single organism might be 100 times what it was at the level of the algae. This is the unfavourable reality of food web dynamics; the higher the trophic level, the smaller the amounts of energy that the organism extracts from its food - but the higher the amount of toxic content. In top predators, the hazardous substance may appear in concentrations as great as 10 000 times their original amount. These top predators are then consumed by humans, although advice against their consumption is sometimes issued (40).

Introduced species alter food web dynamics

Increased maritime traffic is increasing the occurrence of alien species in our waters. More than three billion tonnes of ballast water are yearly exchanged between the ports of the world. This water contains e.g. fish, shellfish, algae, plankton and bacteria. The majority of introduced species found in our waters are small in appearance like microalgae and invertebrates. Though harmless in their original environment, introduced species may become invasive and cause chaos in the food web - particularly if easily adaptable with competitive advantages to local species.

In Finnish waters, 70 non-native (alien) species have been established. One of them is the American comb jelly (*Mnemiopsis leidyi*). This species was first recorded in Kattegat and southern Baltic Sea in autumn 2006. In 2007 it had spread to the northern Baltic Sea. Without natural enemies, the eradication of this species is assumed impossible. In some locations, population density can be as high as 600 individuals/ m² (41). The comb jelly feeds on zooplankton, already diminished by high sprat abundance, and juvenile fish. Given a rapid increase in numbers, significantly altering food web dynamics may occur, as have occurred in the Black Sea,

with consequences for ecosystem diversity and function, as well as for many of ecosystem services provided.

American comb jelly

The American comb jelly is a free-swimming, planktonic organism resembling jellyfish, despite not being related. It is an actively hunting carnivore, consuming zooplankton, fish eggs and larvae. Its success is the result of being a self-fertilizing hermaphrodite, which means that in theory, one individual is capable of establishing a new population. One individual can produce as much as 7000 eggs/day if conditions are right and high abundances of this species may occur in late summer and autumn. The American comb jelly originates from the eastern coast of North and South America. It lives is a very tolerant species which enables effective spreading to new areas. After the comb jelly was unintentionally introduced via the ballast water of ships to the Black Sea in 1982, it caused a dramatic decrease in the anchovy fisheries by consuming fish eggs and larvae as well as zooplankton utilized by fish as food. The reduction in income has been estimated to be over 300 million US dollars by the beginning of the 1990's. The effects have cascaded through the food web; phytoplankton has increased and the populations of piscivores and dolphins have crashed. Similar effects have been observed in other areas invaded by this unwelcome species, ranked high among the 100 worst invading species of the world.

Another alien, the round goby (*Neogobius melanostomus*) has so far reached the southern Baltic Sea. Researchers recently demonstrated that the round goby has a negative influence on the commercially important flounder (42). In addition, it is assumed to predate on fish roe. Another recently discovered alien in Swedish waters is the giant oyster (*Crassostrea gigas*), commonly cultivated in many parts of the world. Its potential effect on Swedish ecosystem function and food web remains unknown. Finally, the fishhook water flea (*Cercopagis pengoi*) has recently become established in the Baltic Sea, probably as the result of ballast water discharge (43). The water flea has a documented history as an aggressive invader. Water fleas primarily feed on zooplankton and therefore scientists are worried that high populations of water fleas will exacerbate the current decline in zooplankton abundance, as happened in Lake Michigan.

Varying response to climate change

Ongoing changes in sea surface temperature and marine chemistry may become manifested at both individual, population and community levels, with implications for food web dynamics. The following example illustrates the consequences of species-specific responses to rising temperatures. Like many other organisms, the timing of the spawning for the clam, *Macoma baltica* is dictated by temperature. As a result of recent warming trend, the clam now spawns earlier in the season (44). Meanwhile, the phytoplankton which constitute the prime food source for clam larvae have not been similarly affected by temperature. The predatory shrimp, which feed on clam larvae have adapted, however, to their resource occurring ear-

lier in the year. As a consequence, clam larvae are faced with double jeopardy; they have no access to food, yet they are still subject to predation.

How to maintain food web dynamics

In order to counteract severe disruption of food web dynamics, particularly in the light of climate change and marine acidification, the following management considerations are crucial:

- Sustainable harvest
- Application of the ecosystem approach
- Habitat protection
- Taking preventive measures against introduced species

The maintenance of food web dynamics can only be achieved through awareness and sustainable use of other more apparent ecosystem services. The most straight forward manner to restore food webs, disrupted by over-extraction, is to reduce exploitation. Where disruption requires more drastic measures, biomanipulation has been put forward as an option, albeit risky. Per definition, biomanipulation introduces considerable amounts of uncertainty into the ecosystem and the outcome in demand may be accompanied by others, less desirable impacts. Two different biomanipulation experiments have been discussed in regard to the Baltic Sea; the introduction of predatory zander (*Sander lucioperca*) and intensive fishing for sprat (25) are both aimed at reducing sprat dominance. Breaking the sprat dominance might be the only way to increase zooplankton abundance, phytoplankton control, increase water transparency and ultimately provide the conditions for improved recruitment success of Baltic cod.

Typically, the presence of non-indigenous species goes unnoticed until economic consequences become apparent. Recently, however, awareness has increased and both IMO, UN:s maritime organisation, and ICES have declared the transport of alien species as an imminent threat to marine ecosystems worldwide. AquAliens constituted a Swedish five-year research project with the objective to clarify the most important factors for the survival and establishment of alien organisms in a new environment. The final report from the AquAliens project, presented in 2008, promoted risk analyses and increased public awareness (45). Currently, in a joint project between various affected authorities (Swedish Board of Fisheries (SBF), SEPA, Swedish Species Information Centre, Swedish Board of Agriculture, Swedish Forest Agency, Swedish Customs and the Swedish Maritime Administration), a strategy and action plan for alien species are under development in Sweden and will be presented during 2008.

Examples of knowledge gaps

Food web dynamics should be a prioritized field of research, particularly in the lights of current anthropogenic impact. Without knowing the links between all species in the food web, it is difficult to grasp how e.g. resource extraction will influence ecosystem processes and services provided. There are also extensive knowledge gaps in regard to newly introduced species and their role in the Baltic Sea and Skagerrak food webs.

Supporting ecosystem services

S4: Maintenance of biodiversity

Definition

Biological diversity, or biodiversity for short, refers to the variety of life forms at all levels of organization from the molecular to the landscape level. A variety of species performing a plethora of functions are essential for most ecosystem services. Of direct benefit to society is the supply of various species for consumption. Of indirect benefit is the maintenance of resilience. Out of convenience, biodiversity typically refers to a function of the number of species and the number of individuals of each species in a given area. **Functional diversity** is an important aspect of biodiversity which refers to variation among ecological functional processes (often related to feeding patterns or interactions among species) within an ecosystem. It should be kept in mind that genes, species, ecological functions and ecosystems are not equal - some are indeed more important than others.

Three important paradigms of biodiversity

- 1) More diverse ecosystems are generally more productive and more stable (46)
- 2) Biodiversity contributes largely to goods and services of the ecosystem (47)
- 3) Biodiversity is diminishing on the high rate due to man's activity (48)

Related processes and services

The benefits of biodiversity to other ecosystem services are numerous. Biodiversity typically enables an ecosystem to perform a variety of functions, thus providing various ecosystem services, while buffering against natural and human-induced disturbance (chapter S6). The potential of diversity (particularly functional and genetic) to maintain resilience and support resource extraction may become increasingly critical in the current light of global environmental change. For example, in the event of a disturbance, functional diversity – or the existence of more than one species carrying out the same function in the ecosystem (like grazing, filtering water and bioeroding) is crucial in order to maintain ecosystem function. Similarly, the existence of genetically distinct individuals and populations promotes resistance to various environmental stressors, like drops in salinity, pH and increased temperatures (49). Also in defence against invasive alien species, diversity appears to be an important factor (50).

Maintenance of biodiversity is dependent on all supporting as well as most regulating services. It requires availability of habitat, primary production and is related to food web dynamics. It further calls for efficient biological regulation, mitigation of

unregulated eutrophication and pollution control. A recent model confirms the interactions between habitat availability, biodiversity and the provision of ecosystem services (51). The model demonstrates how the decline in the provisioning of ecosystem services due to biodiversity loss is initially slow, but then accelerates, as species from higher trophic levels are lost at faster rates. Empirical studies of ecosystem collapse support these results

Status, threats and consequences

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Unknown

The rapid loss of biodiversity is alarming, and with current levels of anthropogenic impact, the situation may become increasingly critical for a number of marine species. This is likely to have consequences for ecosystem function. Yet, due lack of knowledge about many marine species, particularly those that are rare or threatened, it is hard to determine the extent of these consequences.

Global marine biodiversity

Diversity at higher taxonomic levels (**phyla** and classes) is much greater in the sea than on land or in freshwater. Of the 82 or so **eukaryote** phyla currently recognised, around 60 have marine representatives somewhere in the world. Some 23 eukaryote phyla, of which 18 are animal phyla, are confined to marine environments. Most of these are relatively obscure and comprise few species. One major exception is the Echinodermata (including starfish, sea urchins and sea cucumbers), of which some 6000 species are known. Worldwide, only 2 % of all marine species are estimated to live in the water column, whereas the rest are associated to the sea floor. Highest diversity is found on hard substrates while soft bottoms harbour a lower number of species (52).

Marine biodiversity remains elusive

Most scientific knowledge regarding biodiversity is based on terrestrial ecosystems. Increased awareness of particularities in the marine ecosystem is however increasing. For example, the risk of cascading effects is believed to be greater in the marine environment than on land, making loss of biodiversity more severe in the marine environment (chapter S3). A typical scenario in the marine environment is that species become ecologically extinct, in the sense that they do not disappear entirely, yet they lose their importance in the local ecosystem.

A single drop of sea water can contain as much as one million bacteria, 100 unicellular flagellates, ten phytoplankton, one ciliate and 0.001 zooplankton. Because so much of the ocean is only accessible with expensive technology and remote in-

strumentation, uncovering the extent of global marine biodiversity has been - and continues to be - a slow and difficult undertaking. Consequently, scientific estimates of the number of species in the ocean vary greatly.

Biodiversity in the Baltic Sea and Skagerrak

Overall, biodiversity is highest in Skagerrak, somewhat lower in Kattegat and substantially lower in the Baltic Sea, with the number of species rarely reaching a tenth of what is found in Skagerrak. Comparing biodiversity among regions can however be problematic. Differing time scales have to be taken into account and in this respect Baltic Sea is a very recent entity. In fact, Baltic Sea biodiversity is considered not yet fully developed. The Baltic Sea harbours no **endemic** species, which means that no species are unique to the region. Due to its recent origin (ca 8000 yrs), species have not yet had sufficient time to become genetically adapted to the particular environmental conditions of the Baltic. There is a mixture of salt- and freshwater species, which commonly show genetic dissimilarities to populations living in more marine or freshwater environments respectively (53). Many species exist at their environmental limits, which may contribute to the system being particularly vulnerable. The Baltic cod is genetically unique and can therefore not be replaced by migratory or artificially introduced cod from elsewhere. As a keystone species, it is fundamental for numerous other species and possibly the whole structure of the food web (chapter S3). In summary, the Baltic Sea constitutes a marginal environment with a relatively predictable community structure, harbouring unique genes, genotypes and populations.

The Swedish Taxonomic Initiative estimates the number of animal species in Skagerrak to be 5000, and judges the flora as rich. Nonetheless, the Swedish marine realm remains largely unexplored and therefore a large-scale, three-year inventory of the west coast of Sweden was commenced in 2006. Illustrating the elusiveness of the marine environment, 88 new species were discovered in Skagerrak during a recent two-week course arranged by the **Swedish Taxonomy Initiative**. Among these species, whose existence in Swedish waters was previously unknown, 17 were, in addition, entirely new to science. In terms of fish, the **Swedish Species Information Centre** estimates that there are 100 species in Swedish waters (both Skagerrak and Baltic Sea).

Almost one third of all red-listed species in Sweden are associated with aquatic environments

Threatened species

Human activity continuous to cause biodiversity loss despite significant international agreements like the **Convention on Biological Diversity (CBD)**, the **Oslo-Paris Convention (OSPAR)**, and the **EU Habitats Directive (92/43/EEC)**. According to a recent assessment of Europe's environment, biodiversity continues to decline with consequential impoverishment of ecosystem services (54). Prospects

to stop biodiversity loss within the EU before 2010 appear practically unattainable. Among the known species in Sweden (marine and terrestrial) 5 % are threatened. Currently there are ca 216 marine species (excluding birds) on the Swedish red list (55). Monitoring of marine species, particularly if rare, may be problematic. Species that are relatively easily monitored are those restricted to near-shore habitats, especially if sedentary or attached (e.g. barnacles or sea-grass) or if spending time at the sea surface or on land (e.g. marine mammals and seabirds). SEPA and the County Administrative Boards are currently establishing action plans and promoting measures to protect all threatened species – except those subject to commercial exploitation. However, in Sweden, only a few marine species are included in the **Species Protection Ordinance** (1998:179) and thus legal protection of marine species is limited to harbour porpoises and a few non-commercial species of fish. Meanwhile, other species like cod and eel are to be protected and managed within the Fishery Ordinance (1994:1716). Although both ordinances should incorporate the EU Habitat Directive, current exploitation of threatened marine species clearly demonstrates a difference between protection of threatened species in the terrestrial, and marine environment, respectively. The major causes of biological impoverishment and loss of marine biodiversity are discussed below.

Criteria for Swedish Red List of threatened species (56)

1. Drastic reduction of population
2. Population with limited distribution, decreasing in size, becoming fragmented or is subject of extreme fluctuation
3. Small and decreasing population
4. Very small population
5. The immediate risk of extinction for the population is demonstrated through quantitative vulnerability analysis

Habitat degradation

Habitat degradation due to various factors such as eutrophication, bottom trawling, oil spills or coastal development is regularly associated with a reduction in biodiversity. While societal benefits from the exploitation of marine resources and coastal development are readily evaluated, the threats - and possibly costs – of exploitation to the environment are generally unknown or underestimated. Consequently, perceived benefits invariably outweigh perceived costs, when it comes to exploiting marine resources and environments. Many marine species depend upon long-range dispersal during motile life stages. Short-lived species, in particular, must be replenished by means of dispersal (a process called recruitment). If dispersal routes or migration are interrupted by unfavourable, or even lethal environmental conditions, populations and ranges of affected species may be reduced as a consequence. Similarly, the degradation of habitats important at one or more life stages of organisms may have deleterious consequences to the whole population. If recruitment habitats are damaged, the effect in adult populations may be delayed.

Excessive exploitation and bycatch

The pressures of fishing have given rise to a new category of species depletion: commercial extinction. Fish populations are depleted to the point that it is no longer economically feasible to fish. While not extinct, these species are certainly no longer playing their traditional roles in their ecosystems. Fishing operations, such as trawling and dragging destroy bottom habitats (with consequences discussed above) and deplete species populations; repetition of such activities delays or prevents recovery. In the Baltic and Skagerrak, over-fishing is considered one of the greatest threats to ecosystems in general and to biodiversity in particular (16). Excessive fishing has already reduced genetic diversity among Baltic cod (18) and the farming of salmon is causing impoverishment of wild salmon stocks. In addition, seals, harbour porpoises and birds are involuntarily caught in fishing gear. Current estimates of the extent of bycatch are uncertain. The fact that the Baltic population of harbour porpoises has been subject to dramatic decrease compared to historical levels makes it particularly vulnerable.

Pollution

Hazardous substances can reduce genetic diversity within a population (57). The effect may go unnoticed until environmental conditions are altered. Having been selected to withstand hazardous substances, the **intraspecific** ability to respond differently to *other* disturbances, like temperature increase and acidification, may have been reduced or lost. This illustrates the problem with various threats acting in synergy.

Alien species

Of the 168 alien species considered as threats to Swedish ecosystems, 20 are fishes. Among them we find the round goby (*Neogobius melanostomus*), which has already invaded the Polish coast, successfully outcompeting and even excluding many native species (chapter S3). Globally, invasive alien species are considered as the second leading cause of biodiversity loss after habitat alteration (58).

Climate change

With increased temperatures, the distribution and abundance of species will shift according to their thermal tolerance and ability to adapt. Not only are physiological responses to increased seawater temperatures expected, alterations in seawater pH and salinity are also expected to have major consequences for marine life. For example, the ability to navigate during migration in the red-listed eel, appears related to salinity and temperature patterns (59). A milder climate would also reduce ice conditions, which in the Baltic would specifically threaten the ringed seal (*Phoca hispida*), an endemic species that is dependent on ice surfaces in order to reproduce. Although chemical changes in the oceans are still poorly understood, it appears that acidification may cause failure to produce calcareous structures by shells, crustaceans, zooplanktons, coralline algae and corals, to mention some, as well as reduce reproductive capacity among others. According to researchers, the

effects of acidification may become apparent sooner than those of climate changes (chapter R1).

Consequences of biodiversity loss

Biodiversity loss continues despite current effort. The measurable consequences of human impact are still major. In addition, significant lag effects (i.e. sub-lethal conditions and unknown thresholds) may result in impacts of current activity becoming manifested in *future* biodiversity estimates.

There is increasing evidence that numerous marine species are already restricted to relatively small areas, which make them more vulnerable to depletion or extinction. It was once assumed that this phenomenon must be rare in the sea, since most species swim or rely upon the dispersal of reproductive cells and larvae by moving waters; in addition there are few barriers to their dissemination. Thus, it was reasoned that all marine species should be widespread. Indeed, many are, but it is now also known that many are not.

Consequences of reduced biological and genetic diversity include potential loss of marine resources harvested for food and other purposes. Due to the interdependencies among species, the demise of one can lead to the decrease or demise of others. Ecosystems become impoverished when species disappear or remain only in insignificant populations. Meanwhile, ecosystem functions are lost which can seriously threaten the integrity and stability of the ecosystem as a whole. On the whole, impoverished systems may not contain the species and genetic diversity necessary to enable them to survive major environmental changes and stresses, such as global climate change.

"We know that aquatic environments are changing due to climate change, movement of alien species, human development and other factors, and that species will need to adapt to survive - genetic diversity will help with the adaptation. If we're going to come up with the policies and management approaches required to respond to these challenges, we need more information, and we need to increase our capacity to use it"

*Devin Bartley, fish geneticist with **FAO***

How to maintain biodiversity

Marine protected areas are important tools for protecting marine biodiversity (chapter S5). All protected areas should be subject to continuous monitoring. In addition, adaptive approaches to management plans are desirable. Other important biodiversity-promoting measures include sustainable resource extraction, reduced by-catch, and decreased nutrient loads, control of hazardous substance and improved regulations and early warning systems concerning introduced species.

Examples of knowledge gaps

Protecting marine biodiversity can be problematic, in part because the status of species often cannot be assessed. It is not always clear which species are threatened and why. Improved indicators for biodiversity are needed. In addition, information about aquatic genetic resources is spotty; the application of genetics in capture fisheries and aquaculture has so far been limited, and adequate mechanisms for conserving the genetic diversity of farmed fish and their wild relatives are poorly developed. Mobility in marine animals also needs to be explored in order to understand connectivity and obtain best regional protection, with e.g. networks of marine protective areas. How climate change and acidification may affect biodiversity and how biodiversity, in turn, can provide insurance against the effects of these threats are crucial yet relatively unexplored fields. Finally, the relationship between biodiversity and resilience needs to be explored and presented in a comprehensible way. Examining how biodiversity and resilience contribute to the provision of ecosystem services is a fundamental challenge of natural resource management. It is essentially impossible to save everything at all times. Understanding more about these relationships may help managers to make correct priorities.

Supporting ecosystem services

S5: Maintenance of habitat

Definition

Marine habitat typically refers to benthic or **littoral** habitat structure and habitat forming biota. In a broader perspective, habitat is simply the environment in which an organism occurs. From this definition, it should be obvious that habitats – of all kinds - are essential to maintain ecosystem diversity and function. Nevertheless, some habitats are often highlighted as of particular value. For instance, structurally complex habitats like algal beds or biogenic reefs, as opposed to plain sand or mud, are often particularly important, as they provide refuges against predation as well as a variety of different food resources.

Related processes and services

By supporting diversity and function, essentially all ecosystem services are dependent on the maintenance of habitat directly, or indirectly. The provision of fish for consumption is dependent on presence of habitats used for spawning, feeding, breeding and growth to maturity – but not only for the fish consumed; the habitat requirements of the fish that fed the fish are just as important. This indirect dependence on a variety of habitats is illustrated by the complexity of the food web (chapter S3). Coastal habitats appear particularly important. Among both commercial and recreational fish landings, species associated with coastal habitats comprise 77 % (by weight) (60). In coastal waters, certain habitats are dominated by one species; this habitat provider is often crucial to numerous species. Key habitat builders in our marine environments include marine algae like *Fucus* and *Furcellaria*, sea-grass (*Zostera* sp.) and blue mussels (*Mytilus edulis*). The tourism industry benefits from all habitats supporting attractive wildlife such as marine mammals and birds, but also habitats that in themselves attract e.g. divers and recreational boaters. In summary, the maintenance of a multitude of habitats safeguards against ecological surprises while providing the best possible conditions for maintaining diversity, resilience and options for current or future human use.

Not only do habitats affect species distributions; various organisms, including fish, may also modify their habitat. The grazing of algae, the filtering of water, the defecating, the feeding on invertebrate that in turn feed on algae – are all examples of ways in which marine animals influence their habitat, and the habitat of others. This reciprocal influence should be considered in all aspects of e.g. monitoring, management and exploitation.

Status, threats and consequences

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Severe

In all of the Baltic Sea and Skagerrak there are numerous habitats exhibiting different status and experiencing different threat. An attempt to characterise overall status and level of threat is therefore inherently difficult. The plethora of threats must be considered alarming, and status may deteriorate further. However, awareness is increasing and various steps towards protecting and restoring marine and coastal habitats around the Baltic Sea and Skagerrak have indeed been taken.

According to the Millennium Assessment (13) many terrestrial species are stranded in small islands of nature, surrounded by human development. For long, the general belief has been that the vast appearance of the sea precludes a similar scenario. Defying this misconception, many marine habitats have become severely degraded in recent time. The extent of marine habitat destruction and fragmentation is approximating the situation on land, although causes are not always as apparent. A cocktail of threats, including eutrophication, over-fishing, pollution, development and atmospheric change is putting an ever increasing strain on marine ecosystems, sometimes acting in synergy and strengthened by positive feed-back mechanisms. Recovery from damage is typically slow and for most habitats, the potential for artificial restoration remains limited. The current states of some of our key marine habitats are described below, as well as the threats posed to them and their potential impacts.

Sea-grass meadows

Swedish sea-grass meadows are known to support a diverse and productive benthic fauna (61), providing essential nursery and feeding grounds for at least 40 species of fish (62). The loss of 60 % of all sea-grass meadows along the west coast of Sweden (63) is believed to be the result of coastal eutrophication and overfishing as well the result of development of road banks and harbours detrimental to marine environments (64). Moreover, concern has been raised that invasive non-indigenous algae may out-compete the *Zostera* sea-grass beds in a near future (65). For example, the invasive *Gracilaria vermiculophylla* often covers the sea-grass with a thick sheet, thereby decreasing its growth potential. The collapse of sea-grass habitats is likely to bring about consequences for ecosystem diversity and functions. In terms of food provisioning (chapter P1), it should be noted that an almost 100 % reduction of juvenile cod has occurred where sea-grass has disappeared (64). The cost of artificially restoring sea-grass beds are estimated at approximately 5 300 €/ ha (50).

Algal beds

Algal beds are important for marine biodiversity and primary production (66). Like sea-grass beds, they also act as a filter against high nutrient input from terrestrial sources. Algal beds are undoubtedly beneficial for the production of food by providing nursery and feeding habitat for juvenile fish of commercial importance (e.g. pike, perch and cod). In other parts of the world, and historically in Baltic Sea, large algae have been used as fertilizer and in food production. Finally, algal beds are popular sites for diving and sport fishing (chapter C1). Due to increased nutrient concentrations and reduced water transparency, erect macroalgae have in some areas been lost (67) and replaced by less productive and supportive habitats including soft bottoms, mussel beds or communities of red or filamentous algae (68). The latter often end up covering beaches, with reduced benefits and increased costs for recreational businesses (69). The effects vary with region; in the Bothnian Bay and in Skagerrak-Kattegat, macroalgae are primarily threatened in proximity to industrial discharges or sewage treatment plants (70-71). Algal beds may also become threatened by invasive alien species and climate change (72). In the Baltic Sea, *Fucus* algae are already stressed by the low salinity. To counteract loss, the restoration and replacement of algal beds have been initiated in e.g. Himmerfjärden, in the Stockholm archipelago (73) as well as in the Bay of Gdansk (74). In Himmerfjärden the majority of the plants survived transplantation and some even reproduced. In the latter region, the project failed and conditions were judged too poor to allow for continuous trials.

Mussel beds

The blue mussel is one of our most common marine species. It is a very tolerant habitat builder and considered suitable for cultivation. In Skagerrak and Kattegat mussel banks are restricted to shallow waters, whereas in the Baltic proper they dominate down to as much as 30 m depth. Blue mussels increase biodiversity (compared to bare substrate) by providing substrate for algae and refuge for small animals (75). There is a direct relationship between the size of mussel bank and species numbers. In addition to providing habitat structure to the benthic community, mussels continuously affect the habitat by increasing water transparency and removing toxic substances from the water (chapters R3-R5). The tolerance of mussels extends to most threats. Given a less saline future, they are still likely to persist, although perhaps smaller in size. How acidification may affect bivalves, however, remains largely unknown. How the development of blue mussels and oysters is affected by predicted changes in pH, is currently under scrutiny (76).

Shallow soft bottoms

Soft bottom seafloors occur along all coasts of the Baltic Sea and Skagerrak, although their extent and characteristics differ regionally and locally. These nutrient-rich sediments are highly productive and diverse. Constituting a mosaic of different structures including sea-grass, sand and shells, they provide habitats and feeding grounds for numerous species, among which filter-feeders, sea birds and commer-

cial fish are found. Lately, soft-bottom habitats are gradually becoming covered by filamentous algae, an undesired development potentially resulting in reduced diversity, limited provision of food (reduced catches of plaice have already been documented) , enjoyment of recreation and aesthetic value.

Offshore banks

Offshore banks are shallow environments, often dominated by hard bottoms. The distance from shore typically makes them less impacted by human-induced stress and thus they provide unique habitats, of particular importance for organisms subjected to increasing levels of threat along human-impacted coastlines. For example, juvenile stages of some commercially important fishes are essentially restricted to offshore banks. Offshore banks also play important roles for sea birds. Offshore banks southwest of Gotland, for example, constitute the most important locality for wintering long-tailed duck (*Clangula hyemalis*). Given the recent interest in offshore banks shown by the wind power industry, SEPA has undertaken marine geological investigations of 19 offshore banks (77). As a result, three Skagerrak banks have been listed, while another seven Baltic banks have been proposed for listing, within the Natura 2000 network. Currently, the government has assigned SEPA with investigations of an additional 20 shallow offshore banks.

Cold-water coral reefs

Coral reefs in the deep waters of Skagerrak were only discovered in the last century; today most of them have succumbed to human impact. Cold-water reefs can be extensive in size and provide habitat for a multitude of species (78). However, they are susceptible to disturbance, particularly to destructive fishing methods such as trawling. As a result, only one of the six known Swedish reefs contains living colonies. Although only *Lophelia pertusa* is a true reef builder, other non-reef building corals also provide complex structures, which likewise contribute to habitat and biodiversity. Besides being affected by mechanical disturbance, like trawling, the slow-growing corals are sensitive to reduced oxygen concentration (as a result of eutrophication), invasive non-indigenous species, pollution and acidification. Despite current research in the field of reef restoration, the near-future of cold-water reefs appears grim. Restoration of cold-water corals might take 50 - 100 years and estimates of restoration costs based on current knowledge and technology are estimated to at least 53 000 € (79.).

Swedish Environmental Objective No 10 - A Balanced Marine Environment, Flourishing Coastal Areas and Archipelago

"The North Sea and the Baltic Sea must have a sustainable productive capacity, and biological diversity must be preserved. Coasts and archipelagos must be characterized by a high degree of biological diversity and a wealth of recreational, natural and cultural assets. Industry, recreation and other utilization of the seas, coasts and archipelagos must be compatible with the promotion of sustainable development. Particularly valuable areas must be protected against encroachment and other disturbance"

How to maintain habitats

Habitat requires more recognition as a contributing factor to the status of e.g. commercial fish stocks. Having established such relationship, habitat protection should be a priority for the management of marine resources and included in action plans for commercial stocks, threatened species and biodiversity. Essential for effective protection is the mapping of the marine environment. Only with good mapping, can tools for effective marine spatial planning be developed and areas of high conservation value be identified. Once identified, important habitats need to be legally protected.

Worldwide, an increasing number of valuable marine habitats are set aside as **marine protected areas**. Also in the Baltic Sea and Skagerrak, progress has been made, particularly by the designation of marine nature reserves. In 1994, 62 Baltic Sea Protected Areas (BSPAs) were designated under HELCOM Recommendation 15/5 (80). Although preference was given to areas already under some form of protection, very few of the designated areas have been finally incorporated in the BSPA network yet. There still remains the additional task to incorporate 24 offshore areas identified by experts in 1998 into the network.

Among the Baltic Sea countries, Germany leads the way when it comes to protecting the marine environment. Approximately 40 % of the marine Germany's marine environment is currently included in the **Natura 2000** network. In 2004 Germany also nominated ten NATURA 2000 areas in the offshore areas of its Exclusive Economic Zone (**EEZ**) in the North Sea and Baltic Sea to EU. Germany was thus the first EU Member State with a complete set of marine NATURA 2000 nominations. The nominated MPAs within the German EEZ account for as much as 31.5% of the total offshore German marine area.

In Sweden, almost 6 % of Sweden's territorial waters are protected as **nature reserves** or within the Natura 2000 network (Fig. 7). In the EEZ, three offshore banks have been listed as Natura 2000 areas. Natura 2000 has indeed been of great importance as a tool for marine habitat protection, not the least for the county administrative boards, and currently marine and coastal environments are included in 260 of Sweden's Natura 2000 areas. The 15 marine nature reserves are nationally protected and activities such as dredging, marine development, anchoring and habitat-destructive fishing may become restricted. In addition, Sweden has notified nine new areas for inclusion in the **HELCOM** network of valuable marine areas. This network now includes 21 Swedish areas. Moreover, six Swedish marine areas are included in the OSPAR network of marine protected areas and an area in which fishing is permanently banned has been established by SBF. Finally, preparations are under way to set aside Kosterhavet in Skagerrak as Sweden's first marine **National Park**. When opening in 2009 it will serve to protect unique environments

and species. As part of the **Swedish Environmental Goal # 10** long-term protection shall be provided for at least 50 % of marine environments of high conserva-

Marine Protected Areas

Marine Protected Areas (MPAs) are valuable tools for conserving natural and cultural marine resources as part of an ecosystem approach to management. Although the Swedish Environmental Code includes no specific instruments for the protection of marine areas, all coastal and marine areas inside the **Exclusive Economic Zones (EEZ)** are comprised by its general legislation on area protection. Outside the territorial border, in the EEZ, area protection can be achieved within the Natura 2000 network. Below is a list of protective measures available under Swedish legislation.

Nature Reserve

The establishment of nature reserves is based on criteria developed by SEPA and the county administrative boards "*for the purpose of preserving biological diversity, protecting and preserving valuable natural environments or satisfying the need of areas for outdoor recreation*" (the Environmental Code). National parks and nature reserves must have management plans that include practical steps for maintenance and monitoring. Within nature reserves, county administrative boards can regulate fishing for the purpose of habitat protection.

Natura 2000

Natura 2000 is a network of sites with high conservation interest in the EU. The aim is to prevent destruction of natural habitats and to protect animals and plants from extinction. The sites are identified for inclusion in the network under the provisions of the Birds and Habitats Directives.

National Park

National Parks are established by the Government. According to the Environmental Code the purpose of a national park is to preserve "*a large contiguous area of a certain landscape type in its natural state or essentially unchanged*". National parks must have management plans that include practical steps for maintenance and monitoring.

Biotope protection

According to the Environmental Code, biotope protection can be achieved for certain marine biotopes including cold-water coral reefs and other biogenic reefs, shallow bays and inlets as well as shores and marine habitats harbouring populations of threatened species or of particular importance for threatened species.

Fishery restrictions

Fisheries regulation such as gear restrictions and no-take areas can be issued by the Swedish Board of Fisheries (SBF).

tion value by 2010, and at least 70 % of coastal and archipelago areas with significant natural and cultural assets. All together there should be 26 marine protected areas in Swedish waters before 2010. A further three coastal and open sea areas with permanent bans will be established in the Baltic Sea and Kattegat-Skagerrak respectively by 2010 for evaluation by 2015 (81). Despite aforementioned effort, recent revision of interim targets concludes that they may not be realistic. Instead, a network of areas with favourable conservation status, comprising 15 % of Swe-

den's marine realm, should have been established. Among these, 10 % should be subjected to long-term protection (82). Additional interim targets proposed by

Skyddade områden

-  BSPA-områden
-  OSPAR-områden
-  Ramsar-områden i anslutning till hav
-  Marina naturreservat
-  Marina Natura 2000-områden



Figure 7. Marine nature reserves/ Marine Natura 2000 (red) as well as areas reported to the OSPAR (blue, striped), HELCOM (orange) and Ramsar (green). *Source: Naturvårdsverket 2007(82).*

SEPA, which may be of value for habitat maintenance, include sustainable use of the coastal environment and restoration of littoral environment.

While legislative protection of marine habitat is important, it offers little or no protection against threats such as eutrophication, pollution, invasive alien species, acidification, and climate change. One of the key concepts in ecological studies is the idea that a disturbance in one area can lead to serious consequences elsewhere. The interconnectedness of components in the environment thus makes it impossible for any event or phenomenon to be truly isolated. From this follows that no marine protected area functions as an isolated entity; in reality it is intricately connected to surrounding habitats. In this way coastal environments are affected by pelagic waters and vice versa. The introduction of the ecosystem approach as a new paradigm to achieve sound management (83), will hopefully take these complexities into account, not to mention the continuous impact by societal and economic dependence on the marine environment. Conclusively, the protection and restoration of habitats is crucial to prevent further degradation of and damage to habitats, habitat-building species and ecological processes, following the **precautionary principle**.

Examples of knowledge gaps

While currently increasing our knowledge about the distribution of marine habitats, it is important that we learn more about their particular function. Although we may have reached the conclusion that habitats and the ecosystem are interlinked, we might not know enough of the processes linking them to use this for hands on management. Some important questions to be answered are:

- Which habitats or habitat-forming species play a role in the growth and reproduction of endangered or commercially important species?
- Which habitats maintain processes essential for biodiversity and ecosystem function?
- What is the role of habitat or ecosystem diversity and how are different habitats and, on a larger scale, ecosystems connected?

Where essential habitats have already been identified, continuous research into how to best protect and restore them remains central.

Supporting ecosystem services

S6: Maintenance of resilience

Definition

A commonly used definition of ecological resilience is the extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly shifting to alternate states (84). This service is essential for maintained ecosystem function.

Related processes and services

Resilience is a function of biodiversity. High marine biodiversity increases stability and recovery potential for many ecosystems (11). The stabilizing effect of diversity is in part attributable to the existence of more than one species carrying out the same function (85) as well as to the potential for varying responses to disturbance among species (86). In contrary, if all species within a functional group respond similarly to human pressures, such as over-fishing and pollution, high species diversity is not helping; the function may nonetheless be lost. As reviewed in a previous chapter, biodiversity is maintained through a combination of biogeochemical processes, habitat availability, photosynthesis, reproduction among others (chapter S4).

The ecosystem service of resilience can be considered as an insurance against catastrophic or irreversible changes and accompanying loss of ecosystem services. Resilience is important in all systems; in those that are already subject to disturbance as well as in those which act as sources and potentially provide **ecological memory** to other more afflicted systems. When an ecosystem has been disturbed, reorganization and recovery is dependent on the organisms and organic materials that have persisted, referred to as the **internal ecological memory**. Given insufficient remnant of the original ecosystem, input is needed from elsewhere. In this context **external ecological memory** refers to plants and animals outside the disturbed area. The greater the impact, the greater is its relative dependence on external ecological memory for recovery of ecosystem function and processes.

Status, threats and consequences

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Unknown

Current loss of biodiversity, deterioration of habitat and distortion of food webs reduces resilience, although to which extent is difficult to state. Even more challenging is to foresee the consequences this might have for ecosystem function and continuous provision of services. However, it may be concluded that current deterioration of ecosystem resilience is alarming.

Ecosystems vary considerably, often in a cyclic way from over days to over years, decades and centuries. On our latitudes, for example, ecosystems typically exhibit seasonal changes. In contrast to this natural and cyclic change and as a result of human impact, ecosystems today face less desirable states of relatively stable character, usually referred to as **alternate states**. Many marine ecosystems have shifted into less productive states with resource supplies increasingly characterized by uncertainty and surprise. Today, the capacity of the marine ecosystem to generate services of importance for society has clearly diminished (13, 87-88). Concurrently, resilience has been reduced. Current threats to resilience include all chronic and acute disturbance of human origin, many of which have already been described in previous chapters (e.g. over-harvesting, eutrophication, pollution, climate change). Together, these threats are restricting the distribution of, and altering interactions between, marine species. Forecasting the consequences of human impact is not always an easy task. In the Baltic Sea, with a limited number of species and low **functional redundancy**, the ecological extinction of even one species could have severe consequences at ecosystem level. In addition, impact may not be apparent until a **threshold** is reached, in which case it can result in permanent and undesired **ecosystem shifts**, with implication for resources desired by humans – now and in the future. Examples of such shifts include the shift from coral to macroalgae on Caribbean reefs (89), the famous example of the collapse in the Newfoundland cod fishery (90), but also the shift from cod- to sprat-dominance in the Baltic (39). There is a lot to learn about resilience from the story of the Newfoundland cod fishery. This fishery had yielded an overall annual catch of about 250 000 tons for more than a century prior to the mid-1950s. At the time of the collapse, the Canadian government had for long been warned by scientists and environmentalists that the cod stocks were overexploited and that destructive fishing practises were employed (the Swedish government has received similar warnings). Yet, the Canadian government refused to significantly reduce quotas, fearing loss of jobs and other economic consequences. The cost of their short term outlook and refusal to acknowledge ecological indications turned out to be devastating. In 1992, collapse of the cod stocks off the east coast of Newfoundland forced the Canadian government to take drastic measures and close the entire fishery. Over 40 000 people lost their jobs. The communities are still struggling to recover. The marine ecosystem is still in a state of collapse; reducing the impact to pre-collapse levels was, and is, typically not enough to restore previous conditions. This calamity demonstrates that human society today have the technological capability to find and wipe out every commercial fish stock, in any sea, and do irreparable damage to entire ecosystems in the process (87, 91).

How to maintain resilience

Managing resilience may require insight into potential alternate states of the system, as well as sound understanding of the processes involved in such change. It further requires identifying and managing the critical thresholds which separate **desirable states** from **undesirable** ones. In order to avoid unwelcomed shifts of the system, which may or may not become irreversible, identifying factors pushing the system towards such critical threshold may be more important than knowing the threshold per se. Therefore, it is of utter importance to pay attention to indicators of gradual change and early warning signs. Resilience is best managed by applying the ecosystem approach, with particular focus on the maintenance of genetic, species and functional diversity, as well as the provision of high quality habitats. Equally important is to adopt the view that humans and nature are interdependent and interacting. Repeated evaluation of available management tools provides groundwork for the adaptive and efficient management of ecosystem resilience. Conservation measures could include e.g.:

- Marine protected areas
- Action programs for threatened species
- Sustainable resource use
- Restrictions on actions contributing to pollution and eutrophication
- Habitat restoration

“One of the fundamental challenges facing ecologists, is understanding how natural systems will respond to environmental conditions that have no analogue at present or in the recent past.”

Harley et al. 2006 (92)

Examples of knowledge gaps

The importance of resilience is slowly gaining recognition. However, this field remains characterized by a lack of hands on facts and clear guidelines for policy makers and managers.

Above all, the following questions need to be addressed:

- How can resilience be measured?
- How is resilience managed and protected?

Regulating ecosystem services

R1: Climate and atmospheric regulation

Definition

Chemical composition of the atmosphere and ocean is maintained through a series of biogeochemical processes. The marine environment and its living organisms are involved in the regulation of oxygen, ozone and dimethyl sulphide, as well as in the exchange and regulation of carbon. In other words, the climate regulation taking place in the marine environment provides oxygen for breathing and slows down global warming.

Extent of use and importance to society

Oxygen provision

From a global perspective, oceans are the largest producers of oxygen, larger than all land-based vegetation in the world. Through the process of photosynthesis, sea weed (multi-celled sea plants) and phytoplankton (single-celled sea plants) regulate the levels of oxygen in the air we breathe. Although smaller in size than e.g. algae, phytoplankton are present in enormous quantities and so produce most of the oxygen.

Carbon sequestration

Human activity causes a continuously increasing concentration of green house gas in the atmosphere. These gases trap heat from solar radiation and cause heating of the planet, including our seas. Among the green house gases, CO₂ is the most significant (80 %). Current CO₂ concentration have increased dramatically during the last two centuries (from 280 to 381 ppm) and are suggested to be the highest for at least 400 000 years (93). This as a result of the burning of fossil fuels (carbon from ancient sinks). According to the **IPCC** predictions, CO₂ concentration may reach approximately 1000 ppm within 100 years (94).

Not all of the excess CO₂ emitted by human society stays in the atmosphere. The seas, and to some extent the land, act as carbon sinks that significantly slow the accumulation of atmospheric CO₂, and consequently, the resulting climate change. Roughly half of all CO₂ released by humans is now stored in the oceans (95) and it is obvious that without these marine CO₂ sinks, the rate of global climate change would be truly catastrophic. In fact our seas store more than 10 times as much as carbon as all land-based carbon sources put together. Rates of CO₂ sequestration

depend on both atmospheric CO₂ levels and ocean circulation and mixing - in the same way that the sugar dissolving in iced tea depends on how much you put in and how fast you stir. More CO₂ in the air leads to more in the ocean; faster circulation increases the volume of water exposed to higher CO₂ levels in the air and thus increases uptake by the ocean. The concept of CO₂ sinks has become more widely known because of the **Kyoto Protocol**, which allows the use of CO₂ sinks as a form of **carbon offsetting**. Current uptake is approximated at 30 % of current emissions (96).

Besides the buffering capacity of seawater, living organisms in the marine environment also play a significant role in climate control by acting as reserves or sinks for CO₂ in living tissue, and by facilitating the burial of carbon in sea bed sediments. The benefits of this regulatory function are global occurring in all marine environments. Naturally, it is enhanced in areas of substantial water mixing and high primary productivity.

"If you mention "climate change" to people, it often conjures up images of heat waves, melting glaciers, hurricanes, droughts, and monsoon rains - certainly not changes in the ocean, its chemistry, and tiny plankton inhabitants. But we know that future climate change will largely depend on the chemical composition of the atmosphere and the sea - and how vulnerable they are to human perturbation. Understanding how carbon cycles through the Earth system is key to unravelling vital questions about our climate."

Source: Doney & Levine 2006 (97)

Regulation of local climate

It takes a long time to heat up sea water in spring. As long as the water is cold, air temperature along the coast remains cold. Once heated during summer, large water surfaces have a warming effect in autumn and winter and contribute to the heating of coastal air, while providing energy to storms and precipitation in coastal areas. Although not particularly pronounced in Sweden, maritime climate is associated with fresh summers and mild winters with frequent precipitation. However, once sea ice is present, the warming effect of the sea is lost and the temperature will quickly be reduced. Also, daytime sea breeze, appreciated by recreational sailors and sunbathers on a hot day, is blowing from the sea due to differences in heating between land and sea and contributes to clear weather on the coast. The local coastal climate is considered beneficial for human health. It benefits inhabitants of coastal regions, while increasing potential for tourism and recreational activity in the vicinity of the sea.

Interactions with other ecosystem services

Local climate typically affects species growth, survival and reproduction. Consequently, species distributions, and consequently ecosystem function, is related to

local climate. Atmospheric regulation is directly linked to biogeochemical cycles and primary production. Thus it supports most other ecosystem services. The oxygen provided by marine primary producers supports marine as well as terrestrial oxygen-breathing organisms. Meanwhile, the reduction of atmospheric CO₂ slows down global warming, thus benefitting continuous supply of various ecosystem services. CO₂ sequestration is, however, not only a good thing. When the concentration of dissolved carbon increases, the alkalinity of the water declines (measured as pH) and so does the availability of carbonate ions (Fig. 8). Although little is understood about its consequences, increased acidity may in turn affect most other ecosystem services, as will be described below.

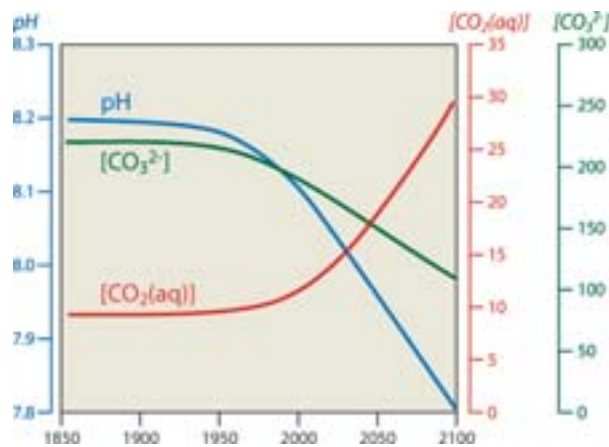


Figure 8. As CO₂ builds up in the atmosphere (red line), the fraction that is dissolved into the shifts seawater chemistry toward more acidic conditions. One consequence of this decrease in the water's pH (blue line) is a decrease of carbonate ions (CO₃²⁻) accessible for the animals that use them to build shells or calcareous skeletons. Source: Doney & Levine 2006 (97)

Status, threats and consequences

Status	Good
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Severe

The status of climate regulation is good, so far. Whether our use of this service affects this service is arguable. Although slowing down climate change, this service does not allow us to postpone radical action against CO₂ emissions. If increasing sea surface temperatures and CO₂ partial pressure is indeed threatening this service one might conclude that we are not using it sustainably. In any case, if this service is diminished the consequences will be large-scale and daunting.

No doubt, our seas will continue to regulate local climate and provide oxygen. To which extent though, will the ocean continue to take up anthropogenic CO₂?

Probably to some extent, however regarding this service much remains obscure. There are neither historical records nor analogous systems to study and due to uncertainty, our understanding of future processes is limited. It is however, a well-known fact that warmer water holds less dissolved gas than colder water. Therefore, the ability of seawater to store CO₂ is likely become diminished with increasing sea surface temperatures. Recent work showed that the CO₂ uptake by the North Atlantic halved between the mid-90s, when data was first gathered and 2002 - 2005, indicating that saturation of the ocean sink has already started (98). In addition, warmer temperatures, weaker circulation, and different stratification of the ocean will all have impacts on marine life and ecosystems, which in turn could affect the ocean's ability to store carbon in organic compartments. How these changes may occur is not clear at this point; they may indeed vary from region to region. A recent study revealed that increased CO₂ levels resulted in 39 % biomass increase among ocean plankton (33). If this result is representative, increased primary production could increase the capacity of the ocean to sequester carbon, thus counteracting any decline in the sequestering capacity of the water per se.

How does CO₂ cause seawater acidification?

When CO₂ dissolves in seawater, it forms carbonic acid, which releases hydrogen ions into solution. The amount of hydrogen ions in the water determines the acidity of the water, measured by pH. A decrease in pH corresponds to an increase in acidity. Hydrogen ions combine with carbonate ions to form bicarbonate. More hydrogen ions thus bind more carbonate ions. Carbonate ions are the basic building blocks for the shells of many marine organisms. Thus, acidification is responsible for reducing the amount of available calcium carbonate for organisms that need them. The combination of increased acidity and decreased carbonate concentration has implications for many functions of marine organisms, many of which we do not yet fully understand.

Expected consequences of the reduction of carbon sequestration

In Sweden, CO₂ emissions have remained rather constant since 1990 (approximately 55 000 000 tons) but are now decreasing. While emissions in most fields have been reduced due to technological advancement, emissions from the transportation sector are still increasing. Meanwhile, in the last 25 years, average temperature increase in Sweden has been approximately 1°C. If the ability of seawater to sequester CO₂ were to decrease, it would have consequences for global climate. With increased temperatures, the distribution and abundance of species would shift according to their thermal tolerance and ability to adapt. Accelerated global warming would have severe consequences for practically all ecosystem services as discussed in respective chapter of this review.

Marine acidification: the cost of climate regulation

Once emitted, CO₂ stays in the atmosphere for a long time. Similarly, chemical changes at the sea surface are slow and inherently difficult to reverse. Although the actual increase in dissolved carbon in surface water may seem small (estimated at 3 %), it is enough to significantly alter the chemistry of seawater and threaten whole

groups of marine life as shall be discussed below. The acidification of our seas will continue despite current action (or non-action for that matter). There are no rapid rewind buttons for running down CO₂ stocks. People living at the start of the 22nd century will live with the consequences of our emissions, just as we are living with the consequences of emissions since the industrial revolution. These time-lags are an important feature of climate change inertia. Even stringent mitigation measures will not affect average temperatures changes until the mid-2030s - nor will temperatures peak until 2050. So far a mean 30 % increase in acidity has been recorded, corresponding to a pH decline from 8.16 to 8.05 (99). By the year 2100 pH is believed to have been reduced by 0.2 - 0.4 units. Following alarming news about the lowering of sea water pH from other parts of the world, the Oceanographic Laboratory at the Swedish Meteorological and Hydrological Institute (SMHI) has analysed 14 years of monthly measurements from Swedish seas. The results are no less alarming than in other parts of the world; on the contrary, sea water pH generally shows a continuous and dramatic decline from 1993 - 2007, particularly in the Baltic Sea (100).

"The speed and size of the change show that we cannot take for granted the ocean sink for the CO₂. Perhaps this is partly a natural oscillation or perhaps it is a response to the recent rapid climate warming. In either case we now know that the sink can change quickly and we need to continue to monitor the ocean uptake."

Professor A Watson, author of a recent article on CO₂ sequestration (98)

Expected consequences of seawater acidification

Notwithstanding the paucity of results, there is consensus that seawater acidification affects a number of biological processes like fertilization, larval development and survival (76). Species living on the bottom as well as those depending on calcium carbonate for shells and skeletons are most imperilled (Fig. 9). Especially vulnerable are small marine snails and deep-water corals that live in high latitudes. The colder the water, the more carbonic acid it holds, like the canned soda. In our waters, numerous organisms may become affected, either by direct impact or via resource limitation. A recent Swedish study (101) demonstrated how, due to a complete failure of skeleton formation, no brittle star larvae could survive a 0.2 pH units decrease (the conservative forecast worldwide for the end of this century; Fig. 10). To put this result in perspective, brittle stars constitute an important food source for flatfish, while being important **bioturbators**. Accordingly, leading scientists predict increased recruitment failure among many other organisms, including commercial fishes, within decades (102). Ecosystem effects might include altered biogeochemical cycling, primary production, food web dynamics, diversity and ecosystem resilience, as well as provisioning services dependent on these processes.



Figure 9. The larvae of a marine snail. Calcifying organism will face increasing difficulties as marine acidification progresses. © *Jon Havenhand*

Effects of no action

The power of large water masses to influence local climate in regard to temperature, wind and humidity will be sustained despite current threats. This applies to the oxygen supply too. As for CO₂, there are general indications that sequestration in seawater may slow down, while primary production may speed up due to atmospheric change. In any case, it should be clear to everyone, that current levels of green house gas emissions are unsustainable and that the effects of no action will be severe. Not only for the climate and sea surface temperatures, but also for the maintenance of marine chemical composition, supporting the development of a multitude of life forms.

How to maintain climate regulation

The most sensible way to address climate change and acidification is by reducing CO₂ emissions. Sweden has committed to the environmental goal of halting global warming at 2°C. To achieve this goal, the European Council has calculated that Sweden will have to reduce emissions 17 % by 2020. To which extent this result (if achieved) might contribute (or not contribute) to mitigating current acidification remains uncertain.

"In state affairs, by foreseeing [problems] at a distance, which is only done by men of talents, the evils which might arise from them are soon cured; but when, from want of foresight, they are suffered to increase to such a height that they are perceptible to everyone, there is no longer any remedy."

Machiavelli 1532 (103)

No single threats to the marine environment occur today; rather ecosystems are subjected to a number of constant disturbances. Such chronic stress to marine organisms may be an important factor reducing their adaptability to temperature and pH alteration. Because it will be essentially impossible to halt the development within the next 100 years (or conceivable much longer), mitigation of chronic

stress to marine ecosystems might at the most provide a way to lessen the effects of climate-related deterioration of ecosystem diversity and function. Safeguarding high biodiversity to provide potential for adaptation may provide another. In other parts of the world it has been demonstrated that viable population and undisturbed ecosystems are more resilient to acute climate-related incidences, such as heat waves and storm (104). Also in our waters, protective measures may indeed help to minimise the risk of stock collapse, ecosystem disruption and biodiversity loss. Nevertheless, some researchers argue that it may become necessary to speed up and artificially strengthen the carbon sequestration process globally, by means of fertilization or by creating carbon sinks under the ocean. In the meantime, research and monitoring are essential. Recently, a number of research projects have started in order to understand ecological consequences of acidification at sea. In the light of current acidification, SMHI has been commissioned to present a proposal of a new monitoring program (105).

Examples of knowledge gaps

How much can humans depend upon the seas to continue to act as a brake on ever-accumulating CO₂ in the future? And to which extent will the build-up of CO₂ in the ocean change its chemistry, making it more acidic and threatening marine life? According to the scientists, the impacts of marine acidification are probably just as dramatic as those of increased sea surface temperatures, and the combination of the two even more so. Contrary to temperature changes, alterations in pH can be predicted with confidence. While research on the effects of seawater acidification is still in its infancy, there is a broad scientific consensus that the topic deserves serious and immediate attention. According to IPCC and all other specialist, the next 10 -20 years will be crucial. What technical breakthroughs, political will, economic incentives will be manifested?

“Considering that the expected pH drop may be unprecedented over the last several hundred million years, more research on the ecological implications of pH change is desperately needed.”

Harley et al. 2006 (92)

In order to understand this relatively new threat and make predictions which will help improve management, more knowledge is required regarding the following issues:

- Natural pH variation
- Species-specific responses to altered pH and potential ability to adapt and evolve
- Investigating synergic effects of temperature increase and acidification for individuals, populations and ecosystems

- Identification of geographic regions, where the effect of acidification may become most severe
- The effects on commercial species (fishes and shellfish)
- The combined effects of climate change, acidification and other concurrent threats
- Understanding how various ecosystem services may become affected by climate change and acidification
- Understanding longer-term resilience of ecosystems in relation to climate change and acidification

A current Swedish research project at the Sven Lovén Centre for Marine Sciences aims to assess the impacts of the predicted pH reduction on the early life-history characters of key ecosystem-structuring species of marine invertebrate. According to the researchers involved, the results may provide some insight into future capacity of ecosystems to cope with predicted pH change. Given such insight, it may become easier to draw up management strategies and promote conservation measures for the maintenance of ecosystem function and services.



Figure 10. The larvae of these brittle stars are highly sensitive to acidification because of their calcite skeleton. In water with the pH expected in 50 years (pH 7.9 rather than 8.1), they cannot grow and feed properly - and therefore their survival is in doubt. The illustrations shows the complete deformation occurring at pH 7.7 (at right), expected within 100 years, as opposed to current pH 8.1. *Source: Dupont et al. (101) © Sam Dupont.*

Regulating ecosystem services

R2: Sediment retention

Definition

Sediment retention and the related mitigation of disturbance refer to ecosystems' natural way, by means of vegetation, to stabilise and retain sediments, thus mitigating coastal erosion.

Extent of use and importance to society

Along coastlines, winds, waves, currents and sediments interact continuously. These dynamic interactions govern the appearance of beaches and sandy shallow sea floors. If more material is transported to the coast than is extracted, sand will accumulate. If the reverse is true, and sand, gravel and rocks are transported from the beach without being replaced, the beach is subject to erosion. Meanwhile the presence of structural vegetation stabilizes and collects sediments.

Globally, more people use sandy beaches than any other type of seashore (106). The beneficiaries of sediment retention and disturbance mitigation are households and industries dependent on the presence of extensive beaches and a stable substrate maintaining and allowing for coastal development. Also in the Baltic Sea and Skagerrak region, sandy beaches are prime sites for human recreation and tourism activity (chapter C1). Apart from the generation of recreational activities, beaches also harbour a range of under-appreciated biodiversity (107). In Poland (83 %), Estonia (90 %), Latvia (95 %) and Russia, Baltic shorelines are largely dominated by sandy beaches (European Commission 2004). In comparison, the proportion of sandy shorelines is lesser in Denmark, Germany and Lithuania (approximately 65 %). In Sweden and Finland (38 %) sandy beaches are not dominating the coastal environment (108).

Sediment retention and disturbance mitigation is primarily important on a local scale. The force of the sea is very noticeable, particularly during extended periods of raised sea levels. Erosion can have enormous consequences for construction, port development, maritime operators, and all human development close to shore. The severity of the impact is typically related to the shape of the beach, as well as to sediment- and wave characteristics. The Swedish Geotechnical Institute (SGI) estimates coastal erosion to be most severe in the southern part of Sweden, including Halland, Scania and Öland. Part of the problem, according to the National Board of Housing, Building and Planning, is that the risk of natural disasters such as floods and landslides are rarely considered. In addition, residents in coastal areas may see the market value of their houses decrease with increased erosion. Particu-

lar socio-economic importance may be expected in areas of major tourism development such as along the sandy beaches of the Southern Baltic and in the Gulf of Riga. Thus, along the coasts of the Baltic Sea and Skagerrak, this service is indeed of value, though not as essential as in many tropical environments subjected to higher wind, wave and tidal energy.

Interaction with other ecosystem services

All structures dampening wave and current energy favour sediment retention and coastal protection. Generally, leaf biomass reduces wave energy and root systems act to stabilize the sediment, counteract erosion and mitigates disturbance from storms and floods (109). Sediment retention is particularly important for the provision of habitat and for the existence of productive sediments. Unsustainable use of ecosystem services like recreational activity and resource extraction may limit the provision of this regulating service.

Status, threats & consequences

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Moderate

The summary includes the service of sediment retention in the whole Baltic and Skagerrak region. The region obviously include both areas where sediment retention is in good status, and others where the condition is very poor. The threats to this service are described below.

Worldwide, effects of beach erosion are becoming increasingly detrimental with significant consequences for human society. IPCC state that 70 % of sandy shorelines globally have already been subject to erosion during the last century. They further estimate that erosion and floods will increase substantially in Europe due to the combined effects of coastal erosion and climate change (94). In our region, urban development (piers, harbours, infrastructure, residential areas, dredging operations) and **marine sediment extraction** (chapter P2) alter sediment balance. Meanwhile, the loss of structurally complex marine vegetation reduces protective services. Extensive areas of sea-grass, for example, have perished due to increased sedimentation, reduced water mixing and eutrophication (63; chapter S5), potentially contributing to reduced protection from storm flood and erosion.

The EuroSION Project within the EU (108) characterized the coastlines of EU countries according to 13 indicators of sensitivity and impact. From this characterization follows that exposure to erosion is highest in Estonia, western Poland and

northwest Germany. In Estonia and Latvia, for example, urban development has increased the dependence on protection against erosion. Vulnerable developments include residential areas, sea side roads and railway. The Gulf of Riga extends 240 km and the tourism industry that the region supports is a major source of income for Latvia. 30 towns and villages are located along the coast, and the tourism capital Jurmala receives as much as 10 million visitors per year (108). The Lithuanian Baltic coast is the prime national tourism destination. While wave activity and the wind-induced surge during storm events are the principal physical erosion agents, human intervention has caused a deficit of sediments and caused beach retraction. The loss of coastal protection makes the area particularly vulnerable to severe storms. In 2004 Lithuania developed a national shoreline management strategy, which would include active measures aimed at retaining shorelines at e.g. Karkle and Butinge. In neighbouring Russia, 25 % of the Baltic Sea coastline is experiencing net erosion (110). The ultimate consequences of human-induced alteration in sediment transportation may be most noticeable for coastal residents. Loss of coastal protection may influence infrastructure, market prices on property, the development and use of recreational areas, the presence of safe waterways and the impacts of sea level rise. In summary, coastal developments are threatened in part due to their own existence.

How to secure and strengthen sediment retention and disturbance mitigation

In order to maintain the ecosystem service of sediment retention, it is essential to restore the natural function by promoting local protection of sea-grass meadows and algal beds. Where erosion has already occurred, beach nourishment may be restoring some of the original appearance and function. However, erosion will continue as long as only the symptom of the reduced service is being addressed, not its cause. Although costly and complicated, artificial sea-grass restoration by re-planting may also be possible.

Examples of knowledge gaps

Although clear relationships have been demonstrated in other parts of the world, there is a need to further establish the links between the loss of sublittoral vegetation (sea-grass, macroalgae) and coastal erosion in the Baltic Sea and Skagerrak. None the least, the identification of these links might motivate increased protection and restoration of sublittoral vegetation.

Regulating ecosystem services

R3: Mitigation of eutrophication

Definition

Mitigation of eutrophication, or the removal of excess nitrogen (N) and phosphorus (P) from the sea occurs mainly through the following processes:

1. The uptake of nutrients by marine organisms and subsequent harvesting of these organisms (particularly filter feeders which are direct consumers of phytoplankton)
2. **Denitrification** or the conversion of biologically available nitrogen to atmospheric nitrogen (N₂) by bacteria under hypoxic conditions.
3. **Anaerobic** removal of nitrogen including anaerobic **nitrification** and anaerobic ammonium oxidation.

Eutrophication in the Baltic Sea – a summary

Since the 1950s the Baltic Sea has experienced a five- to tenfold increase in nutrient load. In comparison, any reduction in recent years is negligible. Two thirds of the added nitrogen is waterborne and the rest airborne. Increase in limiting nutrients (whether nitrogen or phosphorus differs geographically) has increased primary production, which in turn leads to increased sedimentation of plant material. Decomposers of this dead material consume oxygen, and given extensive amounts to decompose, a condition of oxygen shortage on the sea floor may occur. This hypoxia or anoxia may reach up in the water column and prevent the sustenance of benthic communities as well as of spawning fish. In coastal waters, this is typically a seasonal phenomenon. However, more recently hypoxia in the Baltic Sea has become a permanent condition in an estimated area of 75 000 km² of sea floor (111). The limited flow of water in and out of the Danish Straights, as well the release of phosphorus from anoxic sediments, enlarges the effect. Thus eutrophication in the Baltic constitutes a vicious cycle, not easily reversed. In addition, the results of measures taken today will not become visible for decades.

Extent of use and importance to society

Although primary production is a prerequisite for all production in the sea, nutrient input and consequential production can be excessive, at least for societal and economic aspects of ecosystem services. The condition known as eutrophication causes increased frequency and magnitudes of algal blooms, increase of filamentous algal mats, reduced water transparency, hypoxic sea floors, habitat loss, and impaired recruitment success of commercial fish. Anoxic seafloors are devoid of life and although they have been a feature of the Baltic Sea through geological time, their occurrence and extent have dramatically increased due to human activ-

ity. Coastal areas are heavily affected by nutrient loadings, particularly sheltered water bodies with a small volume and restricted water exchange, which include fjords, bays, lagoons and archipelago areas. Anoxic bottoms are difficult to visualize. Eutrophication becomes more obviously detrimental in areas important for tourism, recreation and residential development. Nevertheless anoxic bottoms contribute to the degradation of most supporting services. Two infamous examples of eutrophication are the Archipelago Sea and Stockholm archipelago. Besides, there are particularly sensitive areas, where consequences of eutrophication are particularly harmful. These include the Straights, between Sweden and Denmark, which constitutes a gateway into the Baltic Sea. The impact of respective nutrient varies, depending on the time of the year and on which is limiting in the geographic region. In the northern Baltic Sea, phosphorus is generally limiting, while nitrogen is limiting in the Baltic proper and Skagerrak. In yet other areas, the extent and nature of nutrient limitation is predominantly seasonal. Although reductions of nutrient inputs are underway (28), the result may not become manifested within decades. Despite extensive research effort, no engineering method has emerged as a solution to the Baltic Sea eutrophication (26, 112).

Improved water quality (in terms of transparency) is believed to infer enormous benefits for the production of food and to all aspects of ecosystem diversity and function. Worldwide, the economic value of natural mitigation of eutrophication is estimated to be enormous (5). In fact, environmental conditions in the Baltic Sea would deteriorate rapidly without this service. In regions of importance for tourism and recreation, and where property prices are related to proximity and condition of the sea, mitigation of eutrophication may be particularly important.

"There are good reasons to believe that eutrophication will, in the near future become a common hazard in marine coastal areas in many parts of the world, with consequent potentially damaging effects on both inshore fisheries and recreational facilities"

Professor R. Rosenberg 1985

Nutrients may be stored in sediments. By acting as sediment traps, sea-grass and algal beds remove organic pollutants from the water column and increase water transparency. Most importantly, filter feeders play an essential role in regard to this service. A small Baltic blue mussel (ca 3 cm) filters 2 - 3L/ h while a larger mussel from Skagerrak can filter 2 - 3 times as much. This impressive filtering capacity links plankton- and bottom communities through the recycling of nutrients. Through filtration, plankton are removed from the water column and deposited as detritus, providing energy for bottom-dwelling organisms. This process contributes to increased water transparency which is beneficial to many habitat-providing marine plants as well as to valued ecosystem services such as scenery and tourism. In a semi-enclosed area, like a fjord, mussels can filter all water down to approximately 10 m and above mussel banks water transparency is typically high and de-

void of phytoplankton. In the northern Baltic proper, blue mussels are known to consume about 35 % of the annual pelagic primary production, naturally dominated by phytoplankton (113). The importance of this service is likely to vary regionally, in relation to the presence of oxygenated sea floors and the distribution of filter feeders. However, the exact extent to which natural mitigation of eutrophication reduces nutrient levels in the Baltic Sea and Skagerrak remains unknown.

Interaction with other ecosystem services

Efficient cycling of nutrients is dependent on the presence of filter feeders, which in turn are dependent on all supporting ecosystem services. The uptake and storage of limiting nutrients from the water by animals and sediments (exchange pools) is part of the biogeochemical cycle and influences primary production and thus, indirectly, various other ecosystem services.

Status, threats and consequences

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

The status of natural eutrophication mitigation is good in the Baltic Sea and Skagerrak. We benefit greatly from this service though our use does not impact the service itself. Nor are the organisms responsible for this function currently threatened. However, it should be kept in mind that natural filtration or sedimentation of nutrients cannot solve the severe problem of eutrophication that Baltic Sea countries are currently faced with.

In Skagerrak and Kattegat there are numerous filter feeders. In the Baltic Sea there is only one species with this function, the blue mussel. It occurs as far north as Kvarken, and is the most common species in the Baltic Sea. Constituting 70 % of coastal biomass, it contributes greatly to ecosystem structure and function (114). As expected, current nutrient conditions are favourable for blue mussels. In fact, they have expanded at the expense of algal beds, due to reduced water transparency. There are few threats to blue mussels. Being sturdy competitors, no invasive alien species have so far influenced them. In Skagerrak, however, the introduction of the giant oyster could potentially cause a shift from mussel beds to oyster, as has occurred in the Wadden Sea. Typically, bivalves are also relatively tolerant to hazardous substances (chapter R5). Potentially more threatening, and currently under investigation, is ongoing marine acidification. As demonstrated for other marine

invertebrates, lowered pH may disrupt fertilisation and larval development (chapter R1).

Although there are no obvious threats to the filtering of nutrients by e.g. mussels, the situation is more uncertain for other important exchange pools. For example, anoxic conditions impairs storage of phosphorus in benthic sediments and loss of sea-grass, reduces sediment retention (chapter R2) and consequently the potential for nutrient storage.

Mussels and ecosystem services

Blue mussels hold a key regulating role in many marine ecosystems. Their value to society is foremost manifested by the following ecosystem services:

- Storage and recycling of nutrients (chapter S1)
- Maintenance of habitat (chapter S5)
- Food for harvest (chapter P1)
- Fodder and fertilizer (chapter P2)
- Mitigation of eutrophication (this chapter)
- Pharmaceutical and biochemical products (chapter P4)
- Biological control (chapter R4)

How to strengthen natural alleviation of eutrophication

The Baltic Sea countries have committed to substantially reduce nutrient levels to the Baltic Sea no later than 2016 (28). Although reducing high inputs of nutrients is the foremost measure to combat eutrophication, preventive measures could be complemented by increasing densities of filter feeders. To date, the overall potential to strengthen this service by harvesting nutrient-storing organisms (e.g. algae and bivalves) remains under-used, possibly as a result of poor economic incentives and technical restrictions. In Skagerrak as well as in many areas of the Baltic Sea, conditions for mussel farming are considered favourable. According to a number of researchers, mussel farming is a *“simple, flexible and cost-effective measure to counter marine eutrophication”* and *“compared to other measures, the added benefits of mussel farming for society are striking at the same time as the negative effects for the environment are minor and acceptable”* (115). The harvest of 1 ton mussels contains approximately 8.5 kg N and 0.6 kg P. In an area large as a football field, 150 tons of mussels can be harvested each year resulting in withdrawal of 1275 kg N and 90 kg P. Two thirds of this harvest can be used for human consumption and the rest can be used as fertilizer or fodder for e.g. poultry (115). Additional benefits of mussel production include increased denitrification under mussel farms, causing increased removal of nitrogen. Using Limfjorden, a shallow Danish estuary as an example, it can be shown that even though realistic numbers of mussel production and related nutrient removal are low compared to nutrient

run-off, they are significant in relation to management goals for nutrient reduction. Being a key habitat provider, mussel farms, can in themselves create a rich and diverse environment, meanwhile providing food resources for sea birds, fish and crustaceans. Resuspension of sediments, increased oxygen consumption due to faecal deposits and the release of ammonia, hydrogen sulphide and phosphate are less appreciated consequences of mussel farming. Interesting trials with integrated marine aquaculture is currently carried out in Norway, where European lobsters are bred, raised and introduced to mussel farms in an attempt to clean the bottom below the mussels of discarded organic material, while producing lobster for human consumption (116). Integrated multispecies marine aquaculture, as it is called, may provide an alternative for sustainable aquaculture in the future (117). Less efficient but potentially more commercially viable (chapter P1) is the cultivation of oysters (*Ostra edulis*); their filter capacity is estimated at approximately half of that of blue mussels. According to the industry, the problem of wastes and habitat alteration is not applicable to present cultivation methods in the Skagerrak (118).

Swedish Environmental Objective No 7 – Zero Eutrophication

“Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water.”

An additional way to mitigate eutrophication is the recovery or farming of algae. Whether used for food, fertilizer, cellulose or landfill (chapter P2), the removal of organisms rich in nutrients can help reduce current eutrophication (119).

Economic incentives for activities strengthening natural mitigation of eutrophication are typically low or inexistent. Water quality trading or the trading of nutrient quotas, essentially analogous to CO₂ trading, although more locally or regionally applied, might however increase their viability. The idea simple but yet in its infancy: Those responsible of nutrient release pay and those engaging in nutrient removal are compensated. The first example in Sweden of this system is found in the municipality of Lysekil, on the Skagerrak coast (120). There, the local sewage treatment plant yearly releases 39 tons of nitrogen. The municipality of Lysekil recently signed an agreement with a mussel farming company which are to harvest 3 900 tons of blue mussels yearly. The arrangement has been a success and in effect, the mussels clean the water more efficiently than the sewage plant would have (and is required to). At the same time, the municipality spends approximately 106 000 € less on the mussel farm, than had traditional nitrogen reduction treatment been applied. Any detrimental effects of the large-scale farming are monitored by the Sven Lovén Research Centre in cooperation with the County Administrative Board of Västra Götaland. Should this system become more commonly adopted, the current expansion of oyster farming in Sweden might receive economic support as well. Being less traceable, non-point sources of nutrient releases

are less practicable for trading. A current assignment to SEPA is investigating various potential ways in which fees or tradable quotas can be applied to nutrients. Finally, it is important to stress that the aforementioned ways to strengthen this service may act as local remedy, but it will not singularly restore the present condition of eutrophication.

Examples of knowledge gaps

At certain times of the year mussels are not safe for human consumption due to the presence of algal toxins. If mussel farming is to expand, a reliable and cost-efficient method for the detoxification of mussels is needed in order for harvest to become less seasonally dependent. Furthermore, finding ways in which plankton, algae or filter feeders could be of commercial use would generate the incentives for harvest, thus strengthening natural mitigation of eutrophication. If economically viable, large-scale farming and harvest of these organisms could contribute to the mitigation of eutrophication (121).

Regulating ecosystem services

R4: Biological regulation

Definition

The wide definition of biological regulation refers to the situation where one organism regulates the abundance of another organism, typically by trophic interaction (one species feeding on another). In an ecosystem service perspective, the regulation of pests, pathogens and detrimental processes is directly or indirectly beneficial to society.

Extent of use and importance to society

Filter feeders can reduce the amount of phytoplankton and cyanobacteria in the water column. Several toxic substances can be found in algae and exposure to these **algal toxins** can cause illness among humans and animals. By filtering phytoplankton, including toxic algae, filter feeders like blue mussels help maintain water fit for swimming. This is a typical example of biological control, which in a societal perspective act as to mitigate algal blooms detrimental to recreational activities and scenic values. Biological regulation is also exercised by organisms grazing on **epiphytes** in algal beds, which appears to be important for the distribution and condition of algal beds (chapter S5). However, excessive grazing may become detrimental to algal communities (122) and is in turn controlled by predators, such as perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*). Grazers can also control the growth of filamentous algae on hard surfaces, thus enabling the colonization of habitat-forming macroalgae (123), with possible consequences for the recruitment of e.g. herring (124).

Interactions with other ecosystem services

Biological control is essential for many other ecosystem services including habitat maintenance, recreation, food provisioning and scenery. The biological control carried out by filter feeders is closely interlinked with mitigation of eutrophication as well as with the control of hazardous substances. Biological regulation is, like most other service, in turn, related to the previously described supporting services.

Status, threats and consequences

Presently biodiversity is subjected to a number of human-induced threats. Consequences of biodiversity loss include alterations in trophic structure (Chapters S3-S4, Maintenance of food web dynamics and diversity) with potential implications for biological regulation.

Status	Good
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

How to strengthen biological regulation

In order to maintain biological control it is essential to preserve biodiversity and maintain all functional roles in an ecosystem. Considered all supporting services when managing and conserving marine environments and their resources, will allow for continuous biological regulation of unwanted pests and processes. Increasing this service can be done through the harvest of organisms which have accumulated the unwanted substances. Thus, the expansion of mussel and oyster farming (chapter R3) could increase this service's potential to benefit human society.

Examples of knowledge gaps

There is a general demand for research into the functional roles of marine organisms and how trophic interactions are affected by human impacts. Research into trophic interactions become particularly pressing with current threats from over-extraction, invasive non-indigenous species, global warming and marine acidification. Already food webs are severely disturbed and the risk of sudden ecological surprises related to decreased biological control is imminent.

Regulating ecosystem services

R5: Regulation of hazardous substances

Definition

The marine environment holds the following critical functions with respect to toxic substances and societal waste:

- breaking down (bacteria)
- storing (most organisms)
- burying (sediments)

Extent of use and importance to society

Recreational users and tourism operators are dependent on clean waters which at minimum do not cause illness. Commercial fishermen are dependent on catches that are fit for human consumption. It should be stressed that natural control of hazardous substances is not a service which in its own can take care of current waste loads or decontaminate all the toxic material we release. Regulation of hazardous substances is primarily carried out by preventive measures. However, without this natural service the consequences of our emissions would be even worse.

Some hazardous substances can be broken down in seawater. Hydrocarbons (PAH) from oil spills, for example, are degraded and transformed into water and CO₂ by naturally occurring bacteria in the water and on the sea floor. In 2001 the Baltic Carrier oil spill resulted in 2 400 tons of crude oil to spread in Grønsund, Denmark. Due to physical and chemical processes including biodegradation, hydrocarbon content of the seawater had decreased to baseline levels after 2 ½ months.

Artificially derived organic pollutants, such as DDT, PCB and dioxins, as well as heavy metals, such as mercury, lead, copper and arsenic are not readily degraded. Nevertheless, our marine ecosystems provide the service of binding them with sediments in a way that render them to some extent harmless. Given the importance of sediments for storage, sediment traps like algae and sea-grass also become valuable in the regulation of hazardous substances (chapter S5). However, it should be stressed that despite the capacity of sediments to isolate much of the waste through burial, no complete sequestration can be expected.

In contrast, consumed or bioturbated, hazardous substances constitute a risk to ecosystem health and function, while decreasing the value of ecosystem services like food fit for consumption (chapter P1) and enjoyment of recreation (chapter

C1). Owing to bioaccumulation, organisms transfer pollutants up the food chain. However, when contaminated organisms are harvested, these substances are removed from the marine environment (and must be taken care of in the terrestrial environment). Mussels, for example, can store relatively large amounts of toxins without themselves being affected. Being long-lived, this storage helps preventing the toxic substance from ending up in far more sensitive organisms.

Interaction with other ecosystem services

The release of hazardous substances is exclusively related to human activity. Whether it can be subjected to natural regulation is related to diversity (animals which can break down or store hazardous substances over considerable time), suitable habitat (e.g. sea-grass acting as sediment trap) and food web dynamics among others. In turn, the regulation of hazardous substances foremost influences the availability of food fit for consumption and recreational activities. Documented population effects related to hazardous substances in the marine environment are rare, let alone long-term effects of sub-lethal doses (57). The regulation of hazardous substances is counteracted by the regulation of eutrophication in the sense that anoxic bottoms, an effect of reduced regulation of eutrophication, indeed constitutes the best sink for hazardous substances.

Status, threats and consequences

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Moderate

The moderate status of natural regulation of hazardous substances does not imply that the ecosystem cannot take care of all our waste. Rather, that our waste and other anthropogenic disturbances may be affecting important regulating processes, so that their capacity to break down, store and bury hazardous substances is reduced. Being a non-extractive regulating service, natural regulation of hazardous substances cannot be used unsustainably.

Export of chemicals is currently the third largest export industry in Sweden. The country further harbours a large number of chemical-intense industries (54). Although the new European chemical law (**REACH**) requires detailed information on particularly hazardous substances contained within new import goods, the reality is another story; millions and millions of tons of goods reach our society yearly, the contents of which we are largely unaware of.

Today, eutrophication is believed to have caused widespread anoxia, particularly in the Baltic Sea. As seen above, many hazardous substances remain in storage under anoxic conditions. Promoting storage, the abundance of blue mussels in the Baltic has positive effects on the natural regulation of hazardous substances. In contrast, the loss of sediment-trapping algae and sea-grass may infer negative consequences for the burial of hazardous substances.

How to strengthen the regulation of hazardous substances

Removal of contaminants from the marine environment can only occur through the harvest of contaminated organisms. Although species in the top of the food chain have typically accumulated the largest amount of hazardous substances, their current low numbers and ecological importance make them less suitable to these kinds of measures. Instead, the cultivation and subsequent removal of filter feeders may be a valuable tool in the mitigation of marine pollution. Nevertheless, for toxins that are not easily degraded, this service essentially transfers the problem of hazardous substances to the terrestrial environment, rather than solves it, and thus should not be assigned too much value until we know how to manage this problem.

Swedish Environmental Objective No 4: A Non-Toxic Environment

“The environment must be free from man-made or extracted compounds and metals that represent a threat to human health or biological diversity.
The overall goal is that, one generation from now, the major environmental problems currently facing us will have been solved.”

Examples of knowledge gaps

Some of the knowledge gaps related to this field have been covered in the chapters on food web dynamics, mitigation of regulation and biological regulation.

Provisioning ecosystem services

P1: Provision of food fit for consumption

Definition

Non-toxic fish, shellfish and potentially also algae can be used for human consumption. Provision may be the result of harvest (commercial or subsistence) or farming. Not only does the provision of food benefit human nutrition, it also as creates employment and economic benefits.

Extent of use and importance to society

Marine fish and shellfish provide humans with food, meanwhile providing employment opportunities. Despite increased effort, the extent and economic benefits of fishing in Sweden are today relatively minor and limited to a few species (125). In total, the Swedish fishery sector employs a good 4000 people while contributing to less than 0.1 % of the Swedish GDP (126). In 2006 there were 1 880 licensed commercial fishermen in Sweden among which approximately 1000 were full time fishermen. At the same time 1 552 ships had permission to carry out commercial fishery. The number of people in the fishery sector continues to decrease, particularly in the small-scale fishery, while the average age of a commercial fisherman is continuously increasing. Although landed in 300 Swedish ports, the most important fishing regions border Skagerrak and Kattegat. However, since marine food products are widely distributed to consumers within the entire country and outside, this service is typically of national, as well as international concern. In 2005 252 000 tons of fish were landed, the added value of which was 40 million EUR (127). The most important landings in 2006 are presented in Table 2. Total landings for human consumption reached 147 601 tons, among which 11 497 tons were cod and 67 023 tons were herring and sprat (128). The herring fishery is the largest fishery of the Baltic and yet the Swedish fleet only lands 5 % of it, with Finnish fishermen landing the other 95 %.

Region	Cod	Herring	Sprat	All other species
Baltic Sea (excl. Kattegat)	12250	53165	97583	50208
Skagerrak-Kattegat	688	36702	5165	165934

Table 2. Catches in the marine fishery 2006 (weight in tons) (129)

In comparison, Danish landings from the Baltic Sea and Skagerrak were in 2006 estimated at 191 310 tons, with a landing value of approximately 158 million EUR (130). In the previous year, the following catches were reported in the Baltic Sea

and Skagerrak: Estonia 98 772 tons, Finland 131 741 tons, Germany 285 668 tons, Latvia 150 618 tons, Lithuania 139 785 tons and Poland 156 247 tons (131).

The most important commercial shellfishes in Kattegat and Skagerrak include pink shrimp (*Pandalus borealis*), Norway lobster (*Nephrops norvegicus*), edible crayfish (*Cancer pagurus*) and European lobster (*Hommarus gammarus*; Tables 3 – 4). Following reduction in cod catches, the Norwegian lobster fishery have become increasingly important along the Skagerrak coast. In terms of bivalves, Sweden landed 107 tons of mussels in 2006 while the oyster and cockle (*Cardium edule*) fisheries were insignificant.

Region	Pink shrimp	Norway lobster	Edible crab	European lobster
Skagerrak	2116	766	67	18
Kattegat	100	358	67	3,8
Baltic	0	0,2	0,2	0

Table 3. Swedish Commercial catch of crustaceans (in tons), landed along the Swedish coast 2006 (129)

Region	Pink shrimp	Norway lobster	Other crustaceans
Skagerrak	2 780	1 516	110
Kattegat	57	916	123
Baltic	0	42	47

Table 4. Danish commercial catches of crustaceans (in tons) in 2006 (132).

Processing

Swedish fish processing employed 1767 people accounted for an added value of 103 million EUR in 2004 (133). Geographically, processing is dominated by the county of Västra Götaland. Despite its relatively small scale, the processing industry creates jobs in sparsely populated areas while maintaining cultural heritages in coastal communities and is therefore of local importance.

Aquaculture

As the demand for marine food increases, society responds by modifying ecosystem to increase their provisioning capacity. This anthropogenic transformation of ecosystem typically enhances provision of the sought after resource, though commonly at the expense of other services. Aquaculture is modified system which offers an alternative to capture fisheries. In Sweden marine aquaculture (mariculture) is an industry located to sparsely populated areas and dominated by rainbow trout. In 2006, 1 769 tons, or 29 % of all trout farming took place in marine environments (134). Almost two thirds of these farms are located in the northern Baltic Sea. Currently, the possible establishment of two large rainbow trout farms in Ullerångerfjärden, along the northern Baltic coast of Sweden, is subject to much debate.

Salmon and sea trout production and release into rivers and coastal areas is primarily carried out to compensate for loss of natural reproduction sites due to the development of hydro-electric power and therefore, do not bring additional value. The compensational release can be considered to replace a natural ecosystem service. Its original value is represented to the cost of releasing 1 701 tons of salmon and 744 tons of sea trout into the Baltic and 173 tons of salmon and 5 tons of sea trout into Skagerrak.

In 2003, 1 742 tons of blue mussel were produced in Sweden and still, according to mussel farmers, Skagerrak holds great potential for mussel farming. Swedish consumption of mussels is however limited to 2000 tons, among which 600 tons are consumed fresh, and a large part are imported from e.g. Denmark, a large producer of processed mussels. Although the majority of Danish mussels are farmed in Limfjorden, on the Danish west coast, 20 - 30 000 ton are landed in the Belt and Kattegat. Germany produces 11 000 tons of mussels of which a minor part originates in Schleswig Holstein and Nieder Sachsen. Compared to the farming of carnivorous fish, the farming of shellfish is for many reasons considered an environmentally friendly form of marine aquaculture. Its benefits are discussed in several chapters dealing with regulating ecosystem services (chapters R3–R5). With the energy pyramid in mind (chapter S3), the harvesting of bivalves is energy efficient. In fact, the production of 1 kg mussels requires 5 -10 kg phytoplankton. This should be compared to the production of 1 kg cod, which requires approximately 1000 kg phytoplankton.

In the near future, farming of the European flat oyster may become commercially viable in Skagerrak (Fig. 11). According to a representative of the industry Swedish oyster farming could yield at least 300 tons per year, with an estimated value of 3 million EUR (118). An oyster farm is under development in close co-operation with scientists at nearby Sven Lovén Research Institute (previously Tjärnö Marine Biological Laboratory), and the first larvae are to be reared during 2008. Given the last decades' collapse of flat oyster farming in southern and western Europe, Swedish farmers foresee a market opportunity in these countries, where only the less valued Japanese oyster is farmed nowadays. Due to recent mild winters, the Japanese oyster now resides in our waters as well, and could potentially be farmed here too. Japanese oysters have broader salinity requirements and could thrive as far down as Falkenberg, given relatively ice-free conditions.



Figure 11. Farming of the European flat oyster is expanding in Skagerrak. Oyster farmers are optimistic about the future and see potential customers in southwest Europe where the flat oyster is very sought-after. © Ostrea Sverige AB

Recently, the Ministry of Agriculture in Sweden initiated an investigation with the aim to promote aquacultural sectors with potential for economic and social benefits (135). Whether the farming of filter feeders will receive attention in this investigation, is almost certainly related to whether or not an ecosystem approach will be applied.

Global production of algae is considerable and chiefly located in the far east. For example the Chinese production of *Laminaria japonica* is 3.8 million tons/ year. Only in Japan, farming of the most economically valuable algae, *nori* (*Porphyra sp.*) generates 1 billion USD. The use of seaweeds as food in Europe is currently limited to a few countries, including Ireland and Scotland. Algae have relatively low nutrient content, but high protein, mineral and vitamin contents (vitamin C content in *Porphyra sp* is 50 % higher than in oranges). A market for the algae as health food is currently expanding. Although the farming of filter feeders or even algae for consumption may be more environmentally friendly, it will nevertheless result in a lower intake of health-promoting fatty acids.

Interactions with other ecosystem services

The provision of food for human consumption basically depends on our marine ecosystems' capacity to provide nutrients in an accessible and digestible form. Although primary producers rarely are consumed in our part of the world, we are dependent on them to provide our food with food. By means of photosynthesis, primary producers convert solar energy and nutrients to biomass and starts off a flow of nutrients, which at higher levels in the food web, will be consumed by humans. Hence, food availability in the marine environment relies on

biogeochemical cycling, primary production and food web dynamics. Indeed, the existence of viable populations of fish and shellfish are inasmuch dependent on all supporting ecosystem including habitat availability, biological and genetic diversity as well as resilience, the capacity to cope with disturbance. In turn, the provision of food fit for consumption contributes to several cultural services, creating opportunities for recreational fishing (many fishermen wish to consume their fish) and maintaining cultural heritage by creating opportunity for traditional activities like small-scale fishing. As for the quality of the food, it is related to ecosystem services such as the regulation of hazardous substances. Although natural ecosystem services are vital for the reduction of accessible contaminants, the provision of fish fit for consumption is ultimately related to the extent to which human society allows the release of hazardous substances. .

Status, threats and consequences

Status	Poor
Sustainability of use	Unsustainable
Level of threat	High
Expected consequences	Severe

The summary speaks for itself. The situation is critical for the provision of food. Being an extractive ecosystem service, our excessive use can and does indeed impact it. The unsustainable use of this service is alarming, not only for human consumers; it also has major negative consequences for supporting and regulating services less appreciated by humans, yet vital to ecosystem function.

Modern fishery – service or theft?

The provision of marine food resources is an ecosystem service with an amazing capacity to renew itself. Well governed, its potential value is tremendous. Highly exploited and badly governed, its potential decreases rapidly. 19th century marine biologist Thomas Huxely's view of the ocean as inexhaustible (136) remained well into the 20th century and only recently, the actual impact of human extractive activity in the marine environment is becoming perceptible (91). It seems likely that the *invisibility* of all exploitive or otherwise degrading activity taking place under the sea surface, have contributed to the problem. For comparison, it seems unlikely that analogous activities (c.f. bottom trawling, discard of unwanted catch, 21 km drift nets, dumping of garbage) would have been permitted on land, within human sight.

There is a global crisis in the fishing industry. Worldwide, fish stocks have been significantly degraded or subject to collapse (87), the consequences of which may become increasingly critical in the decades to come (11, 137). The Millennium Ecosystem Assessment acknowledged over-fishing as one of the most pressing

environmental issues in the world today (13). Globally, 80 % of the fish biomass has been reduced in as little as 15 years. Today, more than 25 % of fish stocks are over-exploited and as much of 90 % of predatory fish are gone. Meanwhile 25 % of catches are thrown dead back into the sea (138). Over-exploitation within the European Community has been estimated to as much as 81 % (139) and over-capacity in the fishing sector is estimated at 40 - 60 % (140). The situation in our region constitutes no exception. In the last two decades cod catches in the Baltic Sea and Skagerrak have dwindled, despite increasing effort, primarily due to unsustainable harvest, but possibly also as a result of reduced water quality, degraded habitats (141) and distorted food webs (37). Fishing capacity exceeds stock availability with limited profitability as a consequence. Despite warnings from a united scientific community, unsustainable exploitation continues. From an ecologist's point of view it is highly questionable if, for example, current landings of cod from the Baltic Sea and Skagerrak represent a beneficial ecosystem *service*; rather, they might constitute an example of ecosystem *theft*. A general rule is that in order to maintain natural capital, exploitation should be limited to the resources' interest, or else ecosystem functions may be imperilled. Threatened fish stocks do not provide interest; in the Baltic Sea and Skagerrak, fishing is without doubt aiming at the natural capital itself, thereby reducing the value of ecosystem services provided to society.

"I still believe the cod fishery. . . . and probably all the great sea-fisheries are inexhaustible; that is to say that nothing we can do seriously affects the number of fish."

British marine biologist, Thomas Huxley, 1883

The tragedy of the common

Over-extraction in the fishery sector is related to two of the factors which distinguish this sector from land-based resource extraction. First, there is no way to control or promote production, which is commonly done on land via nutrient input and the amount of e.g. seedcorn, seedlings or breeding stock. Second, and perhaps worse, is that fishery resources lack individual ownership. Over-fishing is a typical example of the 'tragedy of the common', a situation typically related to irresponsible and unsustainable use. The concept goes as far back as Aristotle, who stated "*that which is common to the greatest number has the least care bestowed upon it*" (142). Accordingly, short term profits for resource extractors are jeopardizing the availability of healthy and environmentally sustainable food sources for millions of people, as well as their own future profits.

Over- fishing in Swedish waters

Today, fisheries are controlled with set quotas referred to as total allowable catch (TAC). TAC decisions for each region are taken by the Council of the European Union, and have repeatedly exceeded recommendations from ICES Advisory committee (Fig. 12). In fact, the European commission has calculated that member-

state quotas for 2003 - 2007 were on average 50 % higher than recommended by fishery scientists (143). According to SBF, current EU fishery policy is in part responsible for the critical situation of e.g. cod stocks (144).

In Sweden, half of the 12 most important fish stocks are below the biological reference points, much due to a fishing fleet with a disproportionally high capacity. Overall, there has been a 70 % reduction of cod stocks in the last 15 years in Swedish waters. According to ICES, the decline is in part attributed to deteriorated spawning grounds (due to anoxia), but primarily it is a result of inflated quotas. On the west coast of Sweden the situation is particularly severe with the complete loss of certain stocks and a complete lack of fishes older than two years. According to ICES advice for Baltic cod, the status was described as *historically low*. Despite

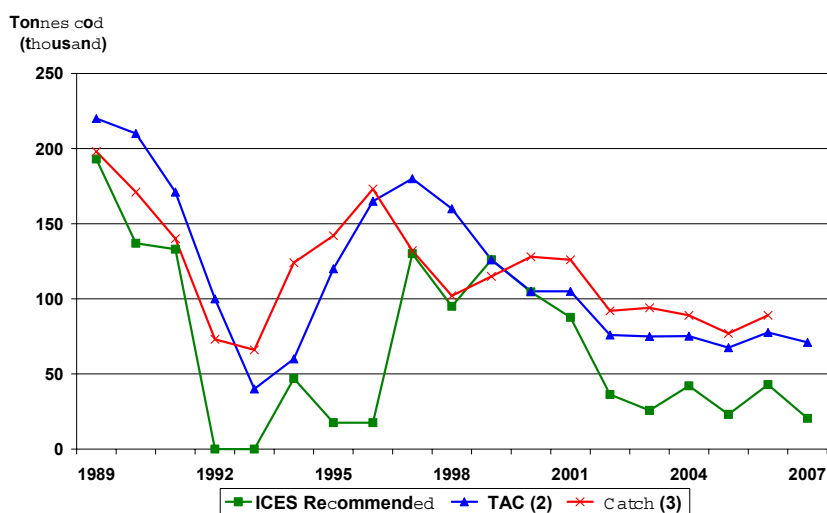


Figure 12. ICES recommendations (green) in regard to cod in the Baltic Sea and Skagerrak in relation to TACs decided upon by the Council of Ministers (blue) and reported catches (red). Note that catches 1992-1995 are underestimated due to incomplete reports. In 2005, 2007 and 2008 ICES recommended a total ban on cod fishing in the Baltic proper (ICES subdivisions 25 – 32). Sources: Brady & Waltho 2008 (145) using data from ICES (146).

alarming reports and subsequent recommendations of the ICES advisory committee, fishing quotas for 2008 were issued. In the Baltic proper cod have suffered reproductive failure due to widespread anoxia and in the eastern Baltic, where several of the Baltic Sea countries are fishing, the cod stock constitute approximately 35 % of what is considered biologically safe (147; Fig. 13). In Skagerrak, current status appears somewhat brighter; an increase in cod stocks has been noticed in the last couple of years. Besides cod, the threats to e.g. pollack (*Pollachius pollachius*), ling (*Molva molva*), haddock (*Melanogrammus aeglefinus*), turbot (*Scophthalmus maximus*) and eel (*Anguilla anguilla*) in our waters are so imminent that they were recently included on the IUCN red list (148). As for the common eel, it is to be comprised by CITES (B-list). Although sprat stocks have generally increased in the Baltic Sea, preliminary investigations in the Bothnian Bay in

October 2007 recorded a remarkable low proportion of large sprat. According to SBF scientists, reduced growth may be the result of the shortage in zooplankton (149).

Discard and unreported harvests

Large quantities of fish are discarded when unwanted, when quotas have been

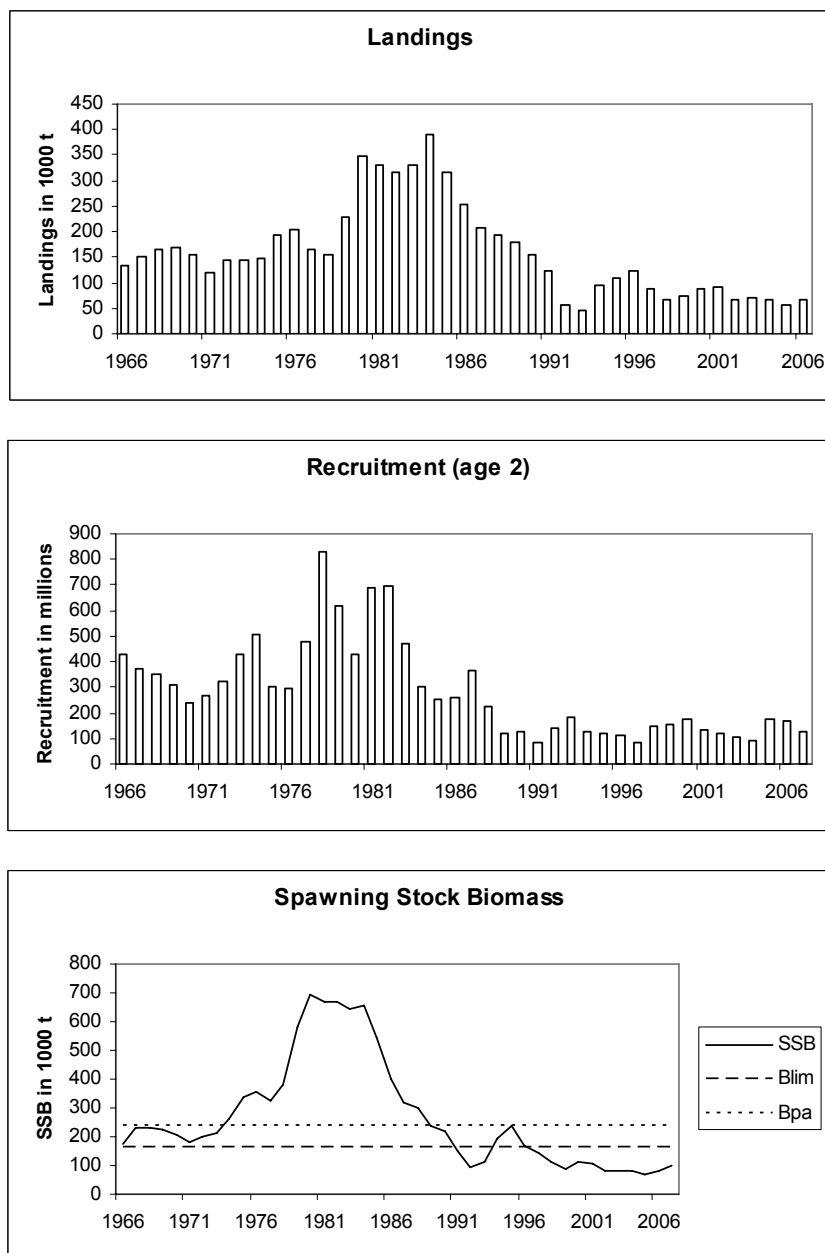


Figure 13. Cod in the Baltic Sea. Landings, recruitment of two-year old fish and spawning stock biomass (SSB). *Bpa* is precautionary level and *Blim* is the danger level. Source: ICES 2007 (146)

filled or when considered of less value due to small size (so called **high-grading**). According to SBF, discard in the Swedish trawling fishery reached 26 % in 2006 (81). Besides reported catches, there is reason to believe that some catches are not

reported when landed. Recently, the European Commission inspected fishing vessels throughout the Baltic and found that vessels consistently reported proportional differences between landing weights, when inspected and when not inspected (150). In the case of Poland the inspected landings were on average 48.7 % higher than the uninspected. According to the investigation, surveys of Swedish vessels indicated the second highest proportion of unreported fishery among the surveyed states (21.4 %). A subsequent investigation by the SBF suggested that this figure was overestimated and the figure was accordingly corrected to 8 %. In Lithuania the difference was 15.6 %, in Germany 13.6 %, in Denmark 12.7 % and in Latvia 8 %. The proportion of assumed illegal fishing were then subtracted from the respective country's TAC in 2007.



Figure 14. European plaice. © Kajsa Garpe

The combined threats of over-fishing and eutrophication

It should be noted that excessive uptake of one species not only jeopardizes the population of this particular species, but may further cause altered interspecific processes with implications for food web dynamics and ecosystem function and, as a consequence, loss of other ecosystem services. If, for example, the number of predators is reduced, plankton-eating fish may increase. In the Baltic, the decline in cod populations has favoured their prey, sprat. This may, in turn, decrease the number of zooplankton, which feed on phytoplankton. Consequently, the loss of top predators may result in eutrophication and reduced water transparency – a typical case of **top-down control**. Sprat dominance is believed to be further stabilized by increased predation on cod eggs and larvae by sprat (37) as well as by the competition between sprat and cod juveniles for zooplankton food (151). As an example of **bottom-up control**, the deterioration of water quality, due to eutrophication has consequences also for top predators, such as cod, thus creating a feedback loop.

Juvenile cod are often associated with macroalgal beds or sea-grass, habitats which are sensitive to light conditions and may become limited in extent with decreased water transparency. In summary, over-extraction may exacerbate loss of habitat with consequences for recruitment to the adult population.

Flatfish, like the European plaice (*Pleuronectes platessa*; Fig. 14) are also significantly affected by eutrophication. Their recruitment is negatively affected by abundant filamentous algae covering shallow soft bottoms. The recruitment loss resulting from current dominance of algal mats has been estimated to result in a 30 – 40 % reduction in commercial catches (152). Commercial catches of perch, pike (*Esox lucius*) and zander have also declined significantly in the Baltic proper (Fig. 15). Regarding perch and pike this is believed to be the result of major recruitment problems (153).

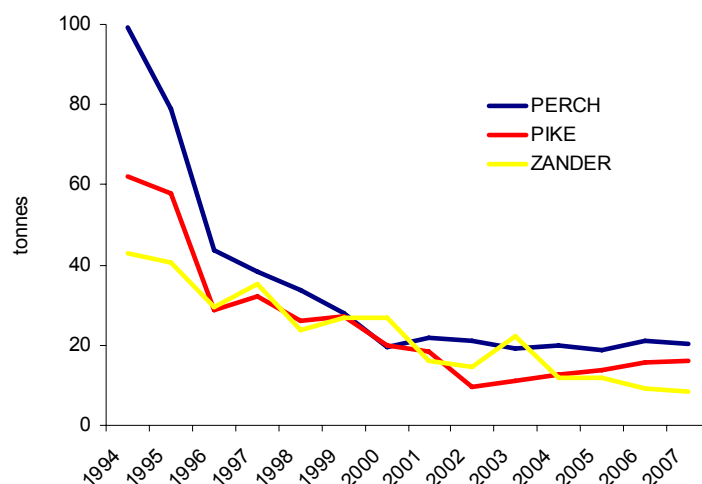


Figure 15. Swedish commercial landings of perch, pike and zander in the northern Baltic proper (Kalmarssund – Stockholm). Source: Fiskeriverket 2008 (81).

Pollution

On the one hand we are recommended to eat fatty fish due to its health-promoting content of **omega-3 fatty acids**. On the other hand, there are constraint to the recommended intake due to high levels of environmental pollutants, such as dioxins and PCBs. Moreover fatty fish from the Bothnian Bay cannot be exported to other EU countries due to its toxicity. Although concentrations of PCBs have been significantly reduced, they remain high in the Baltic proper (154). Similarly, unsatisfactory levels of dioxins are maintained and have not decreased further since their initial reduction in the 1980s. Today, some of the hazardous substances threatening the provision of food fit for consumption include heavy metals, PFCs (perfluorinated substances), BFRs (brominated flame retardants) and TBT (tri-organic tin compounds), the latter released from anti-fouling paint and known to cause sterility and other hormonal disorders in marine invertebrates (155). In addition, cadmium levels in Baltic mussels are high (three times those in Skagerrak) but have at least ceased to increase. Although sub-lethal effects of

various contaminants have been demonstrated, to date there are no indications of population effects on fish (156).

Alien species

Alien species, which commonly arrive with ballast water, could if invasive threaten native populations of commercially important fish as well as create problems for the fishing industry. One example of an unwelcome guest is the spiny water flea. The flea originates from the Black Sea from where it was transported via ballast water. The first official sightings of large populations of spiny water flea were made in the summer of 1992 in Pärnu Bay in the Gulf of Riga from where it is believed that it has spread to other parts of the Baltic Sea. When spiny water fleas reach high densities, they aggregate to form a jelly-like mass that resemble wallpaper glue. Fishermen in the Gulf of Finland have reported that flea aggregations make gill nets useless. In a recent memorandum, SBF presents ways in which marine alien and invasive species may threaten fisheries (157).

The Swedish National Food Administration has, among others, issued the following advice concerning the consumption of food fish:

- Fish is healthy food rich in vitamins and minerals
- Fatty fish like herring, sprat, salmon (*Salmo salar*) and mackerel (*Scomber scombrus*) contain polyunsaturated fatty acid which can reduce the risk of cardio-vascular disorders. From a health perspective people should eat more fish.
- Certain freshwater fishes and fatty Baltic fishes contain exceeded concentrations of environmental contaminants. Therefore pregnant and nursing should be careful. Most consumers do however not need to limit their fish consumption.

Limited sustainability of aquaculture

The farming of fish-eating fish has many critics. Today farmed fish are typically reared on fish meal and fish oil, originating from wild-caught fish. This production of food for fish from fish is a questionable use of resources (chapter P2). An investigation from the Swedish Institute for Food and Biotechnology (SIK) estimated that if half of the salmon fodder is of marine origin, it typically takes 3 kg of wild-caught herring, sprat or tobis to produce the 1.3 kg of fodder which is necessary to farm 1 kg of salmon, which in turn provides a filet weighing 600 g. In other words, 5 kg of wild caught fish supplies one 1 kg of salmon filet. (158). Another common objection against fish farming is the narrow genetic make-up of farmed animals, as well as the many diseases and parasites that farmed fish may spread, jeopardizes the sustainability of the whole industry. Fish farms further contribute to nutrient release from discarded food and fish excrements. This nutrient input may affect food web dynamics and primary production. Critics argue that while nutrient leakage is battled in other industries, it appears counter-productive to allow for the establishment of major fish-farms, known to release substantial amounts of nutrients to surrounding waters. However, it may be argued that in the Baltic Sea, not all regions are eutrophied and in contrast to nutrient

leakage from land use, part of the nutrients from fish farms (discarded food) may become ingested by wild fish, thus rapidly reaching higher trophic levels. SEPA is currently financing an investigation of the effects of local nutrient release from fish farms on bottom substrate composition. Although relatively minor and more localized, the farming of mussels also results in increased sedimentation of organic material below farms.

Climate change

There is concern that fishing and climate change act in concert to reduce exploited population below a population size from which they cannot easily recover (159). For example, effects of diseases and pathogens may become more severe given warmer waters (160). Also, different responses to climate change could affect relationships in the food web (chapter S3), with potential consequences for fishery production.

Potential impacts from fish farms

Sea lice - migrating fish risk acquiring the infective larval sea lice parasite as they pass through the areas around the cages.

Contamination - transfer of infectious disease from farm fish.

Genetic dilution - the impact on natural genetic diversity resulting from escaped farm fish breeding with wild naturals.

Pheromone barrier - it is theorized that a chemical messenger can be released by caged fish which creates a "fear" marker that will frighten migrating fish from returning to their breeding streams or rivers.

Chemical and medicine controls - agents used to control or reduce disease or infestation can have a harmful effect on a significant range of living organisms. There is a European Directive that the fish farm must obey and the Swedish environment agency must enforce. This directive, "The Dangerous Substances Directive" stipulates the limits of concentration of chemicals (specifically medicines) that are used by fish farms. This directive was not made without good reason.

Release of nutrients - a fish farm exports nutrients from discarded food and fish excrements. This nutrient input may affect food web dynamics and primary production.

Impact to sea floor - the sea floor can be changed in numerous ways by the presence of fish farms.

Marine acidification

The most recently acknowledged threat, ocean acidification, is potentially threatening a number of resources, including most organisms with calcareous skeletons. This includes shellfish, corals and plankton and may lead to additional distortion of food webs. Moreover, reproductive failure among invertebrates and a possible failure to produce functional ear bones among juvenile fish may cause

impaired hearing and navigation capacity in juvenile fish, thus dramatically altering the scene for all commercial fishery activities (76, 161)

How to strengthen the ability of our seas to provide us with food

Attaining environmental objectives

In order to maintain fish stocks that can both supply humans with food fit for consumption and support other ecosystem services, fishery capacity has to be adapted to the extent of the resource. This may sound simple, but has so far not been achieved. In the revision of the Swedish environmental objective, the proposed deadline for ecological sustainability in Swedish fisheries is postponed to 2015 (82). The Swedish Government's strategic plan for the fishery sector provides a review of current status and threats (including SWOT-analyses of the sector), but also a scheme for coming years (126). According to the plan, Swedish national priorities include that management decisions shall be based on recommendations from ICES and that the fishing fleet shall be adapted to the extent of the resource (thus addressing the issue of current over-capacity).

Swedish Environmental Objective No 10: A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos - Interim target 5, 2008

"By 2008 catches of fish, including bycatches of juveniles will not exceed levels commensurate with maintaining fish stocks of a size and composition sufficient to ensure that the ecosystem's basic structure and functions are preserved. Populations will have been restored to levels well above biologically safe limits"

Overcapacity is commonly addressed by restricting effort. However, effort reductions are frequently questioned, as they do not address the reasons for excessive resource extraction, i.e. the lack of ownership (162). In practice, fishermen generally circumvent restriction by increasing effort in other ways. If fishing time is restricted, gear is maximised. If the amount of landed fish is restricted, throwing overboard of small and thus less valuable fish will increase. Typically, the fishery adapts to the new conditions and the problems remain. In an attempt to reduce fishing effort, grants have been paid to fishermen who wish to dismantle their vessels. However, any effects of this action have been obscured by contemporary subsidies and the modernization of others vessels. Conclusively, fishery-related measures are not enough to strengthen the provision of food fit for consumption. More likely, a combination of measures are called for, including fishery measures, habitat restoration measures, and measures towards increased water quality (i.e. preventive and direct measures addressing eutrophication and pollution). A number of suggested measures will be discussed below, the socio-

economic consequences of which have been investigated by SBF (144) as well as by Brady and Waldo (145). While certain measures to protect fishery resources can surely be taken in each respective country, a continued dialogue within the EU is required to influence the EU fishery policy. To add to the complexity of this issue, the Swedish National Heritage Board stresses the importance of commercial fishery to sustain coastal cultural environments (163). Finally, the question should be raised as to which sector is responsible of effectively protecting marine resources, the sector using the resources (represented in Sweden by the Ministry of Agriculture and the Board of Fisheries) or the one protecting the environment (Ministry of Environment and Environmental Protection Agency).

Alternative fishery management

The recent adoption of the ecosystem approach, also in the fishery management sector, is promising and will hopefully result in more hands-on measures. A valuable tool for marine resource managers may be what is commonly referred to as **adaptive management**, a process whereby decisions are made on the information available and in which the outcome of these decisions is continuously monitored. Where the outcome falls short of what was intended, management decisions should be readily altered. If there is a reasonable doubt of the sustainability of an extractive activity, the Precautionary Principle should be applied and measures taken to exert effective control over that activity. The use of region-specific quotas of uptake stimulates an indiscriminant race which has led to the impoverishment of our fish resources. Alternative management may be an opening for a more responsible and sustainable resource use.

Basic Principles of Ecosystem Management

'The overarching principles of ecosystem-based management of fisheries, aim to ensure that, despite variability, uncertainty and likely natural changes in the ecosystem, the capacity of the aquatic ecosystems to produce food, revenues, employment and, more generally, other essential services and livelihood, is maintained indefinitely for the benefit of the present and future generations, to cater both for human as well as ecosystem well-being. This implies conservation of ecosystem structures, processes and interactions through sustainable use.'

Source: UN Atlas of the Ocean (52)

Alternative ways to manage fisheries include rights-based management, which has been successfully introduced in other parts of the world (e.g. New Zealand, Iceland, and Norway). There are four major forms of rights-based management. Their respective benefits and the consequences they might have are discussed in detail elsewhere (145).

- Individual transferable quotas (ITQs)
- Territorial use right in fisheries (TURFs)

- Time- and gear rights (including days at sea)
- Co-management

For rights-based management to promote sustainable use of resources, the rights need to be efficiently protected and issued for an extensive period of time. In a rights-based management, resources may become allocated to the most cost-efficient actors. Critics argue that increased concentration of commercial fishery to a few actors might affect the maintenance of cultural heritage, due to regional impoverishment. It may however be argued that managed marine ecosystems (in which fish is a vital part) may create openings in other industries, such as recreational fishery, diving and marine mammal safaris.

Unreported catches

Recovery of commercial stocks requires an end to illegal fishing. A recent EU initiative aims to strengthen fishery control by contributing towards control vessels for the Coast Guards in respective countries. Other potential measures include satellite monitoring (VMS) and on site monitoring equipment. A report, recently adopted in the European Parliament, proposes that cod fisheries should be selected as pilot projects for the complete elimination of discards. In the next phase, the scheme would be extended across the entire EU fishing sector (164). How the discard could be used and what economic consequences this might have for fishermen remains to be investigated. SEPA recently initiated a pilot project, carried out by SBF, investigating the operation of surveillance systems, like cameras, on fishing vessels. At present, surveillance has been aimed at monitoring bycatch of sea mammals and birds, but should be extended to include the monitoring of fish bycatch.

Zonation and marine protected areas

Commercial fish stocks are subjected to various threats, among which over-extraction is the most apparent. Habitat loss is another, albeit less direct threat. Responsible fishery management and environmental habitat protection must be carried out hand in hand, with the point of departure that fish do not constitute remote entities in the open sea. Instead, they are essential parts of a complex ecosystem, spending considerable time in coastal environments, or on shallow offshore banks, requiring healthy bottom habitats in which complexity often plays essential part. Thus, concurrent fish- and habitat investigations are essential in order to make appropriate decisions about relevant management and protection measures. Different locations sustain different types of resource use; in places no resource extraction may be supported. Therefore, Swedish waters should be zoned according to suitable activities. Temporal zonation may allow for recovery in areas with important spawning and nursery functions. Permanently protected areas may promote the recovery of both stocks and habitats, while potentially producing long-term spill-over of commercially important species and their prey. Current examples of temporary closures include spawning areas for the eastern Baltic cod stock, which are

closed between May and October. However, recent data shows that in the case of the Bornholm Deep, spawning actually occurs outside the protected area (165). Before 2010, SBF is assigned by the Swedish Government to introduce six no-take areas, three in the Baltic Sea and three in on the west coast of Sweden (81). A recent sub-report identified six stocks which motivate no-take areas. These included cod spawning grounds in Kattegat, a remnant of the coastal cod stock in Skagerrak, valuable lobster reefs at Vinga (off Gothenburg), eastern Baltic cod stocks and offshore herring stocks in the Bothnian Bay. Finally, a network of no-take areas in the Stockholm archipelago was suggested with the purpose to protect coastal perch and pike stocks.

Altering consumption patterns

Consumers demand predatory fish like cod and salmon. Yet, before commercial stocks of marine top predators have recovered, the provisioning of marine food resources (as well as many other ecosystem services) may only be sustained by directing consumption towards sustainable sources, including non-threatened fish and shellfish. For example, while the sustainability of fish farms is questioned, there is great potential for mussel and oyster farming in Sweden, particularly on the west coast (115, 118).

Examples of knowledge gaps

Programmes of data collection remain vital to sound management. Today, coastal fish monitoring is nonetheless absent in eight out of fourteen coastal water types (166). One of the main worries is the limited knowledge of what constitutes a *normal* or *healthy* population, given that there was no proper monitoring of fish populations prior to the onset of industrial fishing (167). Sustainable management of commercial fish also requires extensive knowledge about the ecosystem function that the species in question perform. Only then can the effects of different management schemes be fully understood. There is also need for more knowledge in the fields of connectivity (recruitment and migration patterns), interspecific interactions including food web dynamics and habitat requirements. Particularly, the distribution of juveniles among habitats needs to be investigated further (168). Appropriate mapping of recruitment distributions may provide the information necessary to appreciate the importance of recruitment habitat in regulating adult populations. How can degraded habitats be restored? One alternative is to use artificial habitats, and the potential of such solution may be explored. Further priorities related to the provision of food include **life cycle analyses** (LCA), which should be conducted for all marine resources in order to identify and avoid detrimental aspects of resource use. To increase sustainability in the fishery, the development of increasingly selective gear with the purpose of reducing by-catch is crucial.

Within the EU several research programmes exist within which marine protected areas are evaluated in respect to biodiversity protection, but also as a tool for management of commercial stocks. SBF is active within PROTECT (169), which is such a program. Finally, more detailed information on the population structure of fished populations would provide managers with a more comprehensive understanding of the state of stocks under their stewardship, and allow them to fine-tune their management tools. Recent research on population genetics and behaviour of cod implies that in Kattegat, for example, there is not only one single stock, but numerous sub-populations that aggregate and reproduce separately (170). As it is, such small populations may in fact be lost, due to erroneous assumptions that they are part of the larger managed population. More genetic research could also shed light on the interactions between wild and farmed fish stocks, an issue of increasing concern. Fish that have accidentally escaped from farms or fish that are intentionally released into the, wild mix with native non-bred populations with often unwanted consequences.

Other measures, which yet have not received righteous attention, are traceability and certification of fished resources. Traceability and environmental certifications, like Marine Stewardship Council (171) and KRAV (172), increase consumer power. Provided with alternatives of guaranteed sustainably caught or farmed marine products, or at least products of known origin, consumers may put pressure on the industry and resource managers to increase the supply of sustainably harvested products.

Provisioning ecosystem services

P2: Provision of inedible goods

Definition

The ecosystem service in question refers to the provision of a number of marine products. A significant proportion of fish catches are converted to fish meal and used for fodder. Due to high nutrient content, marine resources such as algae and shellfish may potentially be used as agricultural fertilizer (given that levels of contaminants are not excessive). The provision of breeding stocks and larvae supports the production farmed fish and shellfish. The extraction of sand, gravel and rocks for landfill, construction, beach nourishment and glass production is yet another example of inedible goods originating from the marine environment. Finally, the extraction of oil products from the sea floor is considered.

Extent of use and importance to society

Fodder

Fish meal and fish oil are used as a base for fodder for poultry, pigs and farmed fish. Of the global fishmeal production in 2000, 35 % was used for fish fodder. SBF reports that in 2006, 76 % of the Swedish sprat catch of 102 748 tons, and 34 % of the herring catch of 103 323 (among which some originated from the Atlantic and North Seas) were used as fodder (129). Together with sand lance (*Ammodytes* sp.), fished in the North Sea, these fishes constitute the basis for fishmeal production. Altogether, 47 % of the weight of all landed fish in Sweden was used in fish meal production (129; Fig. 16). The benefits of these services could be quantified in terms of productivity in aquaculture and farming (chapter P1).

Trial with mussel-based fodder has so far primarily been made in the poultry industry. The results have been satisfactory and accordingly, mussels could become an important source of organic fodder (in which fish meal cannot be included) for the production of organic egg and chicken (173). Similarly, in the aquaculture industry, fodder based on mussels might in the future replace unsustainable use of fodder based on wild caught fish. To some extent, fishmeal might also be replaced by marine worms, bacteria or even non-animal food sources such as algae.

Fertilizer

During the days of Linnaeus the use of macroalgae for fertilizer was widespread. Since then, it has become an under-used source of nutrients in agricultural production. Yet, for more than a decade organic farmers on the island of Orust have used mussel scraps as fertilizer, with promising results. One draw-back appears to be the

unpleasant smell. However, composting may be able to solve this problem. Toxic content of mussels and other marine resources may confer additional problems. Mussels accumulate and sustain high levels of various toxins. When used as fodder and fertilizer, toxic contents may be transferred to crops and consumers.

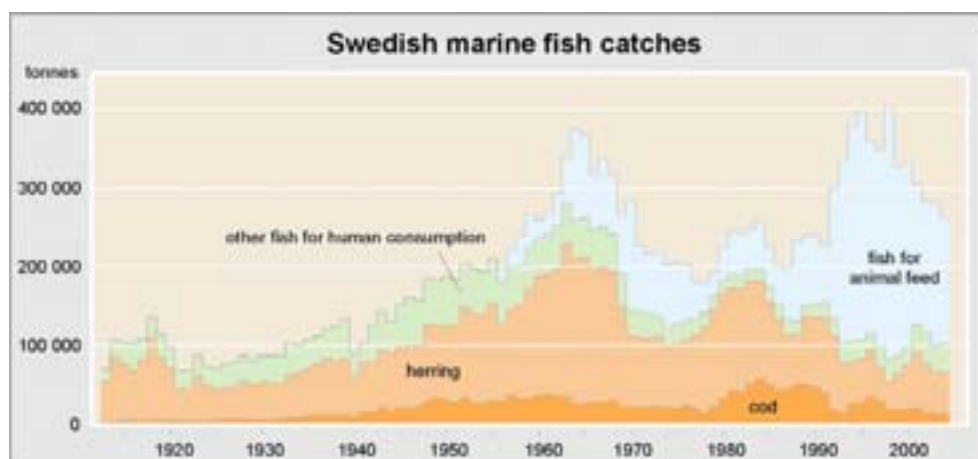


Figure 16. Source: Bernes 2005 (14).

Extraction of material for construction and filling

For decades, marine aggregates have been extracted and used for land filling and construction in ports and other coastal areas. There are several examples of how port- and recreational areas have benefited from this activity (174). Sediment extraction is of increasing economical importance in many regions of the Baltic Sea area. In Germany, 1.25 million m³ of sand for beach nourishment and 147 000 m³ for construction were extracted during 2006. In the same year, 2.2 million m³ was extracted from the Gulf of Finland and used for the construction of the new port of Helsinki. In Finland, there are also plans to carry out major extractions in Loviisa area, in the Gulf of Finland as well as in the Pori Area, in the Bothnian Sea. In 2003 – 2004 Denmark extracted a total of 1 million m³ from three areas in the Baltic to use at a new artificial beach resort near the island of Amager, Copenhagen. In 2006 Denmark extracted another 1.57 million m³ from Baltic waters.

In Sweden limited extraction of marine aggregate was carried out in the areas of S. Middelgrund in the early 1990s, Västra Haken and Sandflyttan. According to SGU, the latter two are characterized by sand reserves of high quality and should be preserved for future use in glass production (175). Since 1998, however, there has been no permitted marine extraction. An application in 2003 to dredge 500 000 m³ sand for beach nourishment purposes at the bank of Sandhammaren off the coast of Scania, southwest Baltic, was turned down, following the recommendations of the Geological Survey of Sweden (SGU) and SEPA. The recommendations referred to natural ongoing beach erosion and to the site being situated within a Natura 2000 area. The last permission concerned the non-aggregate dredging of a new stretches for part of the Flint shipping channel between the island of Saltholm and the coast of Scania in connection with the building of the Öresund Link between Sweden

and Denmark. All the material dredged was used for construction of an artificial islands south of the Saltholm Island at the Danish side of the Sound.

Oil extraction

The use of fossil carbon sinks under the seafloor may be lucrative and Swedish oil prospecting is underway (176). Oljeprospektering AB (OPAB) is planning for oil prospecting in the Dalders area, southeast of Gotland in the southern Baltic Sea, where the borders of Sweden, Poland and the Baltic states meet. OPAB estimates the chances of finding high quality oil at about 30 %. According to OPAB, the source in the Dalders area could be considerable, generating 2 – 4 billion EUR to the Swedish government in taxes. OPAB are expected to present an EIA shortly, which will have to be approved by the government before prospecting can begin. Already, oil prospecting and production is carried out in the Polish and Russian economic zones.

Interaction with other ecosystem services

The provision fodder and fertilizer is linked to the presence of fish stocks, shellfish and algae, which in turn is intimately linked to services such as biogeochemical cycling, maintenance of habitat, maintenance of biological and genetic diversity, primary production, and food web dynamics as well as to the maintenance of ecosystem resilience. In turn, the extraction of marine living resources may affect supporting and regulating services, with ultimate consequences for other provisioning services like the availability of food and genetic resources. The provision of raw material such as sand and gravel for construction and landfill is affected primarily by physical factors such as waves, currents, runoff, and topography and as a consequence, the distribution of different bottom types. The use of this service may in turn affect regulating services such as sediment retention and protection against coastal erosion.

Status, threats and consequences

Status	Good?
Sustainability of use	Unsustainable?
Level of threat	Moderate
Expected consequences	Moderate

This service includes a variety of goods many of which have little in common. Most stocks fished for fodder are still considered within safe biological limits. However, applying an ecosystem approach, one may ask how this extensive fishing affects food web dynamics. Like marine food for consumption, the species fished are currently faced with a number of ecosystem threats including over-fishing, eutrophication, distorted food webs and habitat loss. As for non-living resource,

like marine aggregates and oil, their use cannot be considered sustainable. In contrary, they are not particularly threatened.

Fodder

Current demand for fish meal may add to the fishery crisis and limited sustainability of this service might reduce its value to the industries concerned. Today farmed fish are typically reared on fish meal and fish oil, originating from wild-caught fish (chapter P1). Recalling the 5 kg of wild caught fish supplies one 1 kg of salmon filet. (158), it becomes apparent that large supplies of fodder fish are the currently prime requisite for continuous fish farming. Meanwhile the small-pelagic fish typically used for fodder typically provides an important function in the ecosystem, constituting food source for many predatory fishes and seabirds. Fodder fishing is a typical example of what's referred to as "*fishing down the food chain*" (177). In response to declines of commercially valuable stocks of larger, slower growing species (e.g. cod), commercial fishing fleets have turned to targeting increasingly large quantities of smaller species of fish with less commercial value. Within the fodder fishery, sprat may be the most sustainable target species, as its stock is currently dominating the Baltic. In fact, experiments to significantly reduce sprat stocks in order to restore food webs are currently carried out by SBF (25).

Marine aggregates

The extraction of marine aggregates cannot be considered sustainable. It causes considerable damage and the renewal of this resource is extremely slow. Marine aggregate extraction increases the risk of erosion on shores where sand has been taken. Long-term environmental impact of removing sea sand results in changes to currents and sedimentation and possibly also locally to oxygen depletion. These changes are likely to affect fauna, fish stocks, and seabed vegetation and erosion patterns. An environmental impact assessment (EIA) examining proposed extraction of rock material for harbour filling in the Gulf of Finland concluded that the activity could significantly increase turbidity and destroy local bottom communities (178). As an example, though not from our region, marine aggregate extraction off Dieppe in France caused 80 % reduction in the species richness and 90 % reduction in abundance of local macrofauna. Subsequent recovery was slow and incomplete (179).

Oil

Oil prospecting and extraction have severe environmental consequences, not to mention the burning of the fuels generated from the crude oil. While Sweden is currently developing techniques for renewable energy, in order to reduce CO₂ emissions, introducing oil extraction in Swedish waters clearly appears counter-productive. The extraction of oil from the sea bed may infer mechanical disturbance with detrimental consequences for the maintenance of habitat and biodiversity. Finally, subsequent transport of the oil, being a hazardous substance, always poses increased risk to various aspects of the marine environment and the services which

it provides, including enjoyment of recreation, maintenance of habitat and provisioning of food fit for consumption.

How to strengthen the provision of inedible resources from our seas

Restraining harvest to fish populations within biologically secure limits is a first step towards sustainable fish meal provision might be reached. However, despite remaining within biologically safe limits, uptakes may nevertheless affect the predator or prey of the targeted species. Once again, the ecosystem approach should be applied, using all information on food web dynamics at hand. In terms of fodder, the contribution of shellfish to fodder production may further increase sustainability. As phytoplankton feeders, mussels play a key role in the ecosystem, particularly in the light of ongoing eutrophication (chapter R3). In a typical mussel farm, two thirds of the production can be used for human consumption and the rest can be used for fodder and fertilizer. Toxicity in mussels caused by certain algal blooms may be avoided in part by harvesting at certain time. For the purpose of fodder for poultry it could be added that blue mussels are rich in the **essential amino acid methionine** as well as in omega-3 fatty acids.

The **EU LIFE** Algae project (119) aimed at finding areas of use for harvested filamentous algae. Traditionally, algae has been used as fertilizer for example on Åland, but experiments within the EU Life Algae project showed insufficient nutrient content for current agricultural practises, unless mixed with other fertilizing compounds. In contrast, the use of filamentous algae in the production of paper worked relatively well. Furthermore, the potential use of algae in the biogas industry was investigated but results were far from exhaustive. Finally, in the pharmaceutical industry, algae were found to have potential for the production of crystalline cellulose.

Regarding marine aggregates, HELCOM expresses concern and states that “*decisions of national authorities on permits for marine sediment prospecting and extraction shall be based on an adequate investigation and evaluation of the natural conditions, the ecological consequences and possible interferences with other legitimate uses of the sea*” (180).

Exampel of knowledge gaps

In regard to this ecosystem service, knowledge gaps are apparent in the following fields:

- Development of sustainable fodder for farmed fish, using not only finfish
- Use of current underused resources like plankton, algae and shellfish
- Cleaning algae and shellfish from contaminants before using them for fodder and fertilizer

Provisioning ecosystem services

P3: Provision of genetic resources

Definition

Genetic resources are defined as the “genetic material of actual or potential value” (181). Genetic material, in turn, is defined as “any material of plant, animal, microbial, or other origin containing functional units of heredity”.

Extent of use and importance to society

Typically, genetic plant and animal resources are used to increase agricultural crops and livestock health or production. Already, genetic manipulation has improved production, resistance, taste and adaptation in a variety of commercially important terrestrial plants and animals. In contrary, the use of marine genetic resources is so far limited. Nonetheless, its potential may be considerable and for example, genetic resources may be needed to help meet the world's growing demand for fish. By 2030, an additional 40 million tonnes of fish per year will be needed to meet global needs. If unlocking the secrets of fish **genomes** can lead to the breeding of fish that grow more efficiently or require less animal protein, aquaculture might become part of the solution and fish farmers could increase their production levels without emptying the seas of fish for fodder. In addition, the use of genetic resources could possibly have widespread importance for the restoration of degraded habitats (e.g. eel grass or cold-water reefs) or critically endangered populations. Altered environmental conditions due to human impact may require increased abilities to withstand e.g. increased temperature, low pH, low salinity, high turbidity. The answer might be to use other organisms or populations with the required qualities, and artificially transfer them to those who need it by means of genetic **manipulation** or **selective breeding**. Development in the biotechnological sector has opened up new markets where the genetic resources are sought after and traded.

Interactions with other ecosystem services

Genetic diversity is the foundation for all genetic resources. Genetic diversity is promoted by evolution, intimately coupled to resilience and may be lost when faced with excessive resource extraction, habitat loss and other detrimental activities (typically of human origin).

Status, threats and consequences

Status	Unknown
Sustainability of use	Sustainable
Level of threat	High
Expected consequences	Unknown

Genetic diversity, and consequently the supply of genetic resources, is threatened by all activities detrimental to the marine environment. Its status remains largely unknown and meanwhile we do not know what we are losing. However, increased awareness of its importance has resulted in for example a Strategy for Genetic Resources in the Fisheries, Agriculture, Forestry, and Food Sectors in the Nordic Region, set up by the Nordic Council of Ministers (182). One of the main goals in this program is to *“reinforce and refine work on the conservation and sustainable use of the diverse genetic resource that are of importance to the agriculture, forestry, fisheries and food sectors”*.

“Living marine resources are one of the Nordic Region’s big sources of riches and a major area of joint responsibility. Developments in sea fishing necessitate studies of their possible effects on marine biodiversity. The use of selective tools and the heavy fishing of certain species may have a long-term effect on the genetic composition of fish stocks”

Source: Nordic Council 2005 (182)

Examples of knowledge gaps

Knowledge is limited about the genetic material present (chapter S4); let alone its potential fields of use and value. Meanwhile human activity is altering conditions for all marine life. The significance of environmental impact on genetic resources is likely to be manifold. Yet, our understanding of these effects is only partial. For example, better understanding of genetic makeup of exploited resources is required in order for sustainable management (see previous chapter). Furthermore, adaptive capacity related to genetic make-up needs to be investigated, particular among species threatened by environmental disturbances, such as alterations in water temperature, salinity and pH.

Provisioning ecosystem services

P4: Provision of marine resources for the pharmaceutical, chemical and biotechnological industry

Definition

This ecosystem service includes all pharmaceutical, chemical and biotechnical use of marine resources that we have, or may have, today and in the future.

Extent of use and importance to society

Nobody can accurately quantify all species on this planet. Nor can anyone foresee their benefits to humans, industries, economy and society. Nature is a source of inspiration, particularly in pharmacology and biotechnology. More than 35 000 species in the world produce substances which are – or have been – used for pharmaceutical purposes. Some discoveries have been more spectacular than others. Had humans not learned about quinine, for example, extracted from the bark of the South American cinchona tree, the victims from malaria would have been significantly higher in historical times.

Bioprospecting in marine animals

After the advent of scuba technology (first tested in 1943) the oceans became a veritable source of pharmaceutical compounds and models for the western medicine (183). Yet, there is nothing new in using marine products for medicinal purposes. Seahorses, for example, were used for centuries in traditional treatments for sexual disorders, respiratory and circulatory problems, kidney and liver diseases in Southeast Asia. In Roman times, the mother of Nero the emperor, is said to have used a poison derived from sea hare (a shell-less mollusc) to make way for her son's reign. The compounds in question, **dolastatins**, are today tested as remedies against breast cancer, other tumours and leukaemia.

Many marine organisms have evolved complex chemical compounds and processes for defence and predation. This is particularly true for soft-bodied benthic organisms which can neither flee from aggressors nor protect themselves with hard structures. These compounds, and the underlying genetic diversity, have tremendous potential that may be foreclosed by the loss of marine biodiversity. The commercial beneficiaries of this service include bioprospecting and pharmaceutical companies, the food, cosmetic and biotechnological industries among others. For people suffering from illness as well as for potential consumers, ongoing investigation in marine biological and chemical diversity can be vital for health and well-being.

Over the past 30 years, marine chemists have extracted at least 20 000 new biochemical substances from marine life globally and today, marine bioprospecting is a rapidly expanding sector. So far, there are four drugs based on marine substances on the market and about 40 in clinical/preclinical development (184). Examples of progress within this industry include a cancer therapy made from algae, asthma treatment, anti-viral and anti-cancerous agents derived from reef sponges and pain relief from venomous cone shells. A good example of the importance of this business are the arabinosides, anti-viral medications derived from the sponge *Tethya crypta*, used in treating herpes. Testing is in place to see if these drugs can also be used in treating AIDS and HIV. The development and production of arabinoside drugs are estimated to have resulted in a profit of about \$ 50 million in annual sales.

The search for new interesting organisms in the bioprospecting process is naturally related to biodiversity, and accordingly many of the aforementioned discoveries have so far been made in the species-rich tropics. Many of the examples in this chapter are from outside the Baltic Sea and Skagerrak. Nonetheless, bioprospecting occurs in our waters too; indeed, species new to science are in fact still being discovered in Skagerrak (chapter S4). Moreover, the organisms in question are in some cases present in our waters too, though not yet exploited. Exploring the diversity of bioactive compounds in the Baltic Sea and Skagerrak is among others carried out by researchers at the Division of Pharmacognosy at Uppsala University. Examples of successful bioprospecting in temperate and arctic waters include the identification of important anti-infectious substances in the north Atlantic spider crab (*Hyas araneus*) and northern sea urchin (*Strongylocentrotus droebachiensis*) both present in Skagerrak and Kattegat. Moreover, marine microorganisms present in the Baltic are believed to be an unexpectedly rich source of antitumor agents. Also, compounds in Baltic cyanobacteria could stop the death of liver cells and thus may become useful in preventing liver disease (184). Finally, research is carried out on for example synthetic analogues of substances found in *Agelas* sponges, and on bioactive compounds in barnacles (*Balanus improvisus*).

Pharmacognosy and marine algae

Marine algae also contain biologically active substances of pharmaceutical interest. Examples include hypotensive agents found in kelp (*Laminaria* sp) and potential properties for preventing the transmission of infectious sexually transmitted diseases (STDs) such as HIV/AIDS in Irish moss (*Chondrus crispus*). Yet other seaweeds present at our latitudes have demonstrated anti-bacterial properties. Filamentous green algae appear most potent, but also red and brown algae like sea beech (*Delesseria sanguinea*), sea oak (*Halidrys siliquosa*), finger tare (*Laminaria digitata*), channelled wrack (*Pelvetia canaliculata*), wrack (*Fucus* sp.), witch's hair (*Desmarestia viridis*) and the red algae *Rhodomela confervoides*, have demonstrated antibacterial activity. Another area where marine algae have received attention is in preventing post-surgical infections following e.g. hip and knee implants and the introduction of other biomedical devices such as catheters. Recent Austra-

lian research has revealed that nanometre-thin antibacterial coatings derived from macroalgae can prevent this bacterial colonisation (185).

Templates for pharmaceuticals

Although the actual compounds under scrutiny are usually extracted from the marine organisms, there are also examples of drugs where active substances have been inspired by marine chemistry.

Health food and dietary supplements

Red marine algae are believed to possess highly nutritious qualities and are promoted as dietary supplements. Currently, the demand for Irish moss (occurring in Skagerrak-Kattegat) is increasing, to supply various uses including biotechnology, health food and carrageen production. Similarly, the demand is increasing for omega-3 supplements derived from fatty fish, promoted for their cardio-vascular benefits.

Thickening agents

Marine algae are commonly used in the food- and cosmetics industry as thickening agents. **Alginates** (E400-E405) are produced from wrack and kelp, while **agar** (E406) and **carrageen** (E407) originate from red algae (represented in our waters by e.g. *Furcellaria* sp, *Chondrus* sp and the invader *Gracilaria vermiculophylla*). Although there are artificial alternatives, the actual algae-derived products remain preferred. These products are found in a variety of commodities such as ice cream, shampoo, paint, tooth paste, pet food and yoghurt. Although Baltic supplies were largely depleted in the 1980s, some 10 000 tonnes of algae is harvested yearly in Denmark and Estonia (60). A current project at the National Environmental Research Institute is investigating the potential for commercial farming of *Chondrus crispus* in Denmark.

Cosmetics

Apart from emulsifiers commonly derived from marine algae, the cosmetic industry has successfully introduced a number of other marine substances. Within the continuously expanding cosmetic industry, the highest growth rate is found in the anti-aging market. To illustrate the potential in this market, an international example is used. Substances called pseudopterosins from soft corals have anti-inflammatory properties and are used in Estée Lauder's anti-wrinkle cream. The development of this substance constitutes one of University of California's top ten most valuable royalty generating inventions and the resulting product today has an annual market value of \$ 3 - 4 millions (52). Another successful example is a new skin depigmentation substance, developed by a French company in the field of engineering natural active ingredients for the cosmetic industry, and claimed to reduce skin-aging spots created by aging and excessive UV exposure. The ingredient is developed from the red algae dulse (*Palmaria palmata*) used already in the 10th century for human- and animal consumption. Although this alga, like the Irish moss, is native to Skagerrak, Kattegat and the Baltic as far as Scania, no attempts

to commercialize it in our waters have been made. Another example of successful products is a cleansing lotion containing polysaccharides from *Zostera marina* sea-grass (REN Zostera Marina Comfort Restoring Milk Wash).

Gene probes

Sequencing of the total genomes of marine organisms is a rapidly advancing yet new area of bioprospecting research. **Genetic screening** will become increasingly important in the near future and will lead to the development of **gene probes** for antibiotics and other molecular targets.

Test models

The use of marine animals as alternatives to living terrestrial mammal models has in some cases been very successful. Research has revealed receptor similarities between marine invertebrates and humans, opening up for the use of new pharmacological tools, of marine origin. International examples include the rainbow trout (*Onchorynchus mykiss*) model of cancer, the Californian black sea hare (*Aplysia californica*) model for memory and the elegant round worm (*Caenorhabditis elegans*) for genomics. In fact, the development of marine test model resulted in the award of the year 2000 Nobel Prize in physiology and medicine to Dr. Eric Kandel.

Glue

Molluscs excrete long fine filaments by which they attach themselves to the sea bed. These so called **byssus threads** are investigated for their gluing properties; in comparison they are stronger than all currently existing glues. Sweden has great potential for mussel farming and a Swedish research company is currently developing a commercial product from our commonly distributed blue mussel. This glue would be non-dissolvent and water resistant, making it immensely useful for a variety of applications such as bone grafting, dentistry, orthopaedics, and electronics as well as in the construction sector. Approximately 10 kg of mussels are needed to produce a few milligrams of glue (186).

Antifouling

The reef building sponge, *Geodia baretii*, contains substances which could prevent undesired growth on hulls and jetties of e.g. mussels and barnacles, so called bio-fouling. Biofouling on ship increases the fuel consumption and speeds up corrosion. Meanwhile, anti-fouling paints typically have contained substances toxic to marine organisms. Hence, the search for an environmentally friendly anti-fouling agent has been an urgent task. The breakthrough with *Geodia baretii* is a much welcomed result, opening up new possibilities (187).

Renewable energy

Given their relatively minor agricultural potential, Sweden and other Baltic Sea countries are dependent on import of biofuel. That is, unless another source of abundant biomass can be found. Danish state-owned Energinet.dk, one of whose tasks is to support the development of eco-friendly energy production, recently

granted 1.14 million EUR of funding to a project designed to assess the potential of the green alga, sea lettuce (*Ulva lactuca*) for producing bio-ethanol (188). In warm waters, and provided with plenty of nutrients – including nitrogen and phosphorus from agricultural land (the service of eutrophication mitigation is discussed in chapter R3) - sea lettuce traps large amounts of CO₂ (the benefits of which is discussed in chapter R1) and grows remarkably quickly. The sea lettuce can double its weight in just two or three days. When dried, up to 60 % of that weight consists of polysaccharides that can be enzymatically converted into ethanol. The sea lettuce could be harvested close to shore and contribute to various ecosystem services. Along the same line, the company Biofuel Systems is developing a system for producing energy from the hydrogen released by photosynthesizing marine phytoplankton. Thus the next generation renewable energy would be produced while sequestering CO₂ and without pollution. With respect to the surface areas needed to produce biofuels, phytoplankton is incredibly space-efficient. While soya produces 50 m³/km², rape seed 100-140 m³ and palm oil 610 m³, plankton could potentially produce 10 000 – 20 000 m³/ km² yearly (189).

Other uses

Agar from red algae has many uses including as a laxative, as an alternative to gelatine and for the production of plates for bacterial cultivation. Hospital laboratories use the so called **petri dishes** lined with agar to grow and identify infectious bacteria. **Agarose**, which is also developed from seaweed, is a gel used in **chromatography**, a laboratory process in which proteins are purified. Cellulose from filamentous green algae seems to have potential in the production of paper pulp as well as in manufacturing of tablets in the pharmaceutical industry. Sweden currently uses 200 - 300 tons of cellulose powder, corresponding to 1 - 2 % of the world market (190). Furthermore, fatty acids, similar to those present in human breast milk are produced by a marine microalgae (*Cryptocodinium cohnii*) and used in infant formula. In recent year the old household remedy of using cockle shells (*Patella vulgate*) for ulcerated nipples, resulting from breast feeding, has returned. Child health centres, at least in Sweden and Denmark, commonly recommend their use and cockle shells are sold at pharmacies (191). Yet another example of how marine organisms can be use in biotechnology is provided by the study of microbes in marine sediments to develop inexpensive electricity in remote places (192). In the field of photonic engineering, the use of sea mouse (*Aphrodite* sp, a marine worm present in Kattegat-Skagerrak) spines may bring about increased potential for communication technologies as well as medical applications (193). Finally, a contemporary field of research is the development of tougher, wear resistant ceramics for biomedical and structural engineering applications inspired by the bi-valve shell (194).

Interactions with other ecosystem services

The prerequisite for cost-beneficial bioprospecting is biodiversity. In that, the ability of the marine environment to provide consumers and industries with valuable substances and models – now and in the future – is dependent on all supporting ecosystem services. If sustainably used, this service does not impact other services. In contrast, where large monocultures are farmed (in the case of macroalgae) or too many individual harvested, impacts could become detrimental.

Status, threats and consequences

Status	Unknown
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Unknown

Provision of pharmaceutical, chemical and biotechnological resources is subject to the same threats as biodiversity (chapter S4). Environmental sustainability of bioprospecting activities can only be determined from case to case. Naturally, it is dependent on the abundance, distribution and vulnerability of the species in question, as well as the habitat in which it is harvested or farmed. When it comes to blue mussels (used in glue development), for example, they are widely distributed, readily farmed and their collection leads to the mitigation of eutrophication. Hence no conflicts arise.

Despite often used in small quantities, or even synthesized in the final product, bioprospecting and manufacturing could in fact involve large-scale collection. An example from the UN Atlas of the oceans describes how 1 600 kg of sea hare was gathered only to isolate just 10 mg of the desired compound (52).

Most macroalgae are important habitat providers and over-extraction can become detrimental. Danish agar was previously produced from a detached form of *Furcellaria fastigata*, collected in Denmark. Now stocks are exhausted and all carrageen produced in Denmark comes from foreign sources. In order to respond to current demand for Irish moss, exploitation requires a more sustainable resource use. In Kattegat-Skagerrak Irish moss and dulse are considered sensitive to disturbance and are typically only found in relatively healthy habitats (195).

As for the recent demand for cockleshells by nursing mothers, it cannot be met by Sweden given that the distribution and abundance of cockles became significantly limited already in the 80s and 90s, possibly due to an alteration in phytoplankton composition related to coastal eutrophication. Indeed an example of how loss of

biodiversity, though only subject to local or ecological extinction, may compromise the provision of an ecosystem service.

Worldwide, the pace of current extinction is dramatic. There is only limited knowledge about the potential of marine organisms to provide us with ingredients for e.g. life-supporting medicines or green technology. With each extinction chemical and genetic diversity is lost, the use of which will never be investigated. In Sweden, 216 species are threatened by extinction (chapter S4). To protect these species is a major challenge.

How to ensure future availability of marine resources for chemical purposes

The technological advances in the pharmaceutical- and food production rely heavily on the conservation of natural genetic diversity of plants, animals, and micro-organisms. The best we can do to safeguard future development potential within affected industries is to consider ecosystem processes and functions in all aspects of human activity (measures to strengthen diversity are further discussed in chapter S4). Commercially interesting species could be used as umbrella species to motivate the protection of entire habitats or ecosystems. In the work with the marine sponge *Geodia baretii*, for example, commercial interest and conservational concern go hand in hand. So far, exploitation of our seas has resulted in noticeable impacts on this organism's distribution and on the distributions of others alike. Concurrent with the research in its anti-fouling properties, research is also carried out in respect to its general ecology. This way its habitat and its other inhabitants may gain increased protection and the door will remain open for discoveries to come.

Examples of knowledge gaps

In the field of pharmaceutical, chemical and biotechnological use of marine organisms there is little we know compared to what we do not know. For instance, the identification of hotspots of diversity, and thus of potential interest to bioprospecting, may be a valuable tool in marine planning and resource management.

Provisioning ecosystem services

P5: Provision of ornamental resources

Definition

The provision of ornamental resources refers to the provision of marine products for the purpose of decoration or handicraft. Examples of products include shells, amber, driftwood and aquarium fish.

Extent of use and importance to society

The trade in marine biota, such as molluscs, urchins and star fish for living or non-living decoration is limited in our part of the world. Nevertheless the use of this service may be of local importance, particularly in areas where tourism is well developed. Non-biological materials which may not even originate from the sea, such as drift wood and polished glass, also commend value as e.g. souvenirs or decorative material. Resources are typically sold by small businesses in coastal areas. Buyers include tourists and artist.

The most precious decorative marine resource in the Baltic Sea region is amber. Amber is the fossilized resin from ancient forests and is often held in the same class as semi-precious gems because of its ornamental uses. In the dense forests of the Middle Cretaceous and Tertiary periods, between 10 and 100 million years ago, resin-bearing trees fell and were carried by rivers to coastal regions. There, the trees and their resins became covered with sediment, and over millions of years the resin hardened into amber. The sea is the oldest known source for amber. Prehistoric people picked up amber from the Baltic shore, when strong storms and winds brought the material up from amber-bearing strata under the sea. Sea amber has provided a livelihood for coast-dwellers for many centuries. Historically, it was considered to hold magical healing powers. Later it has been used to make varnish, incense and nowadays it is primarily used for decoration.

The main producer of amber worldwide is Russia. In fact about 90 % of the world's available amber is located in the Kaliningrad region of Russia, which is located in the south eastern Baltic. After a storm, amber collectors can be seen wading into the sea. For unemployed families, casual gathering of amber like this may be the only means of survival. Alternatively, they dredge for the precious fossil in shallow water or dive with scuba equipment to collect amber from the deeper waters. Yet, the bulk of the amber industry is mined on land, in areas once covered by the Baltic Sea.

Lithuania is the largest processor of raw amber. In Lithuania, amber has significantly contributed to the national economy and culture. Various amber jewelry and handicraft are offered to foreign tourists in most souvenir shops and an Amber Museum has been established in Lithuania's leading health resort, Palanga, near the Lithuanian coast. Palanga businessmen are the main suppliers of decorative amber to the western European market, but Poland is not far behind. The price of amber has grown by 25 % over the last three years. In Western Europe, interest in amber and admiration of the soft stone is growing. Yet, amber goods do not render large interest in the Scandinavian countries.

"Thousands of years ago people were fascinated by the extraordinary, inexplicable properties of the golden pebbles found on beaches and in coastal forests. The stone burnt when cast into the fire, exuding a pleasant resinous smell and aromatic smoke, and, when rubbed, attracted various small light items towards itself as if by magic"

Source: The Great Book of Amber by Elzbieta Mierzwinska

Interaction with other ecosystem services

The provision of ornamental marine resources is dependent on the distribution and abundance of the resources in question. The abundances of many ornamental resources are related to supporting and regulating ecosystem services such as maintenance of habitat, biodiversity and resilience. Amber, however, is a fossil and thus the distribution is not governed by recent action. In contrast, if living organisms (like urchins and star fish) are harvested, biodiversity, food webs and resilience may become affected. The exploitation of filter feeders like blue mussels for ornamental purposes, could promote the removal of nutrients from a potentially eutrophic environment, thereby mitigating eutrophication, while affecting e.g. food web dynamics and biogeochemical cycling.

Status, threats and consequences

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

In Sweden there is no immediate threat to this service due to unsustainable use. The collection of dead material such as driftwood or polished glass is harmless at almost any extent. On the contrary, there may be limit as to how many shells and sea urchins that can be harvested, at least if living specimen are collected. In comparison, the commercial use of decorative marine organisms has become a major

problem in tropical countries where endangered corals and shells are sold as curiosities and juvenile fish caught for the aquarium industry.

The amber industry in the south eastern Baltic Sea region is a different story. So far, it has caused many environmental problems. In addition to the damage done to the environment by amber mining in open pits, the processing of amber also harms the local ecology. Since mining started over a century ago, more than 100 million tons of waste has been discharged by the Kaliningrad amber mine into the Baltic Sea. The plant is considered one of the world's biggest culprits due to the expulsion of suspended material expulsion with consequences for turbidity and marine polluted. Although amber mining is an activity which severely threatens a large number of ecosystem services, it is questionable whether it can be regarded as a *marine* ecosystem service, given that the extraction of amber nowadays primarily takes place away from the marine environment.

How to strengthen the provisioning of ornamental resources

The harvest of living things should be evaluated in relation to present and local levels of threat. Any activity detrimental to the desired organisms is reducing the value of this service, including excessive harvest. For some species, cultivation may be a more sustainable option. Important for the protection of this ecosystem service is to promote awareness, ideally causing reduced demand, for species or products which are unsustainably exploited. Trade in red-listed species is regulated both by international and Swedish law (CITES, Species Protection Ordinance).

Examples of knowledge gaps

Generally there is limited information on the extent of this service, what is for sale and in which quantities.

Provisioning ecosystem services

P6: Provision of energy

Definition

Provision of energy refers to the acquisition of energy *directly* from the marine environment, for example by using wave or tidal power. Offshore wind power, oil extracted from marine sediments and biofuel derived from marine resources are not included in this particular service but dealt with in other chapters (offshore wind power in chapter P7; oil in chapter P2 and biofuel in chapter P4).

Extent of use and importance to society

Waves, currents and tidal movements represent an underused ecosystem service. It is renewable, its sustainability practically infinite, and thus it has enormous potential in the light of ongoing energy debate. In our part of the world, the use of tidal energy is limited. In contrast, wave energy, which is generated by wind passing over the sea, is a powerful source of energy, even in relatively protected waters such as the in the Baltic Sea. All ice-free sea floor < 100 m depth can be used to extract wave power, which currently includes most parts of Skagerrak and the Baltic Sea south of Stockholm. In general, wave energy is less irregular than for example energy derived from sun and wind power; scientists predict that wave plants in Sweden could run 35 - 50 % of the time. The resultant potential for wave energy in the Baltic Sea is 24 TWh (196). This corresponds to Sweden's scheduled increase in renewable energy within the next 10 years. In addition to the near-shore wave plants currently under development, there is potential for deep water power, where resources are enormous, although yet largely impractical to exploit. Provision of energy from the sea is non-extractive and renewable; once the plant has been built, it provides energy free of charge, needs no fuel and produces no waste or pollution. Given economic investment, wave power could be developed in Sweden and elsewhere, with great benefits to society and the environment.

Interaction with other ecosystem services

The provision of wave energy is primarily related to hydrographic factors and processes occurring in the atmosphere.

Status, threats and consequences

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

There are no threats to the provision of wave energy, nor can the use of this in any way diminish its value (i.e. become unsustainable).

Although wave power stations are still rare and mostly at an experimental or development stage, this energy sector is growing in Sweden and elsewhere. In Wales, for example, the construction of the world's biggest wave energy plant has commenced. At Islandsberg in Skagerrak a plant is currently set up by researchers from Uppsala University for a full scale test to run from 2008 to 2014. (197). In close cooperation with researchers at the Division for Electricity, Department of Engineering Sciences, at Uppsala University, Seabased Industry AB is planning to build a pilot plant in Skagerrak. At the completion of this plant in 2010, it may include as many as 2000 generators (using approximately 2 km²) with a maximal effect of 20 MW, thus producing 50 GW/year (198). Although the benefits of using energy from the sea as a resource of power are considerable, it is nonetheless easy to imagine how the large-scale distribution of such plants could impact the ecosystem through habitat alteration, possible sound pollution as well as other disturbances, particularly during construction. Meanwhile, new artificial underwater environments, like those presented by the wave plants, might in fact attract certain species (providing additional hard surfaces) while naturally offering local protection against fishing.

Examples of knowledge gaps

There is much to learn about wave energy and its potential. First, technological improvements are required. Efficiency has to be increased, as well as resistance to the detrimental effects of corrosion and severe weather conditions. Secondly, environmental consequences need to be extensively investigated, in the same way as environmental impacts of offshore wind farms are investigated. If wave energy is to become extensively exploited, areas have to be set aside for this purpose, based on sound knowledge about the distribution of benthic habitats. Finally, large-scale wave power can only become a realistic alternative if gaining economic strength.

Provisioning ecosystem services

P7: Provision of space and waterways

Definition

Provision of space and waterways refers to the use of the sea surface as medium for transport (shipping), as site for energy provision (offshore wind parks) as well as for other types of construction (e.g. harbours, bridges, artificial islands). Within this service, the use of sea water for industrial purposes is included.



Figure 16. Source Bernes 2005 (14)

Extent of use and importance society

Medium for transport

Shipping and ports play a vital role in international trade and commerce. Maritime shipping offers considerable cost advantages in many sectors involved in inter-regional trade. For example, sea transport represents 90 % of EU's external trade and 40 % of its internal.

The Baltic Sea, with more than 500 ports, is one of the busiest seas in the world and both the number of ships and the quantities of cargo afloat are growing rapidly. The amount of cargo handled in the Baltic Sea approximately doubled from 2000 to 2004. In 2005, 500 million tonnes were transported within the Baltic Sea and this figure is expected to have doubled once more in 2015 (199). The major ports are Helsinki and Kilpilahti (Finland), Tallin (Estonia), Ventspils and Riga (Latvia), Klaipeda (Lithuania) St. Petersburg and Primorsk (Russia), Gdansk (Poland), Lübeck and Rostock (Germany), Trelleborg and Gothenburg (Sweden). The port of Gothenburg ranks 15th largest port in Europe and handled 39.9 million tonnes of cargo (200).

The use of fossil fuel is increasing and the shipping of oil is predicted to become fourfold compared to present (Fig. 17). Primorsk in the Gulf of Finland constitutes one of the most important Russian ports for oil shipping. During 2008 oil shipping through the Gulf of Finland will reach 150 million tonnes (201). Although Finland receives 300 million yearly for the transit, the environmental risk to the Gulf of Finland is considerable.

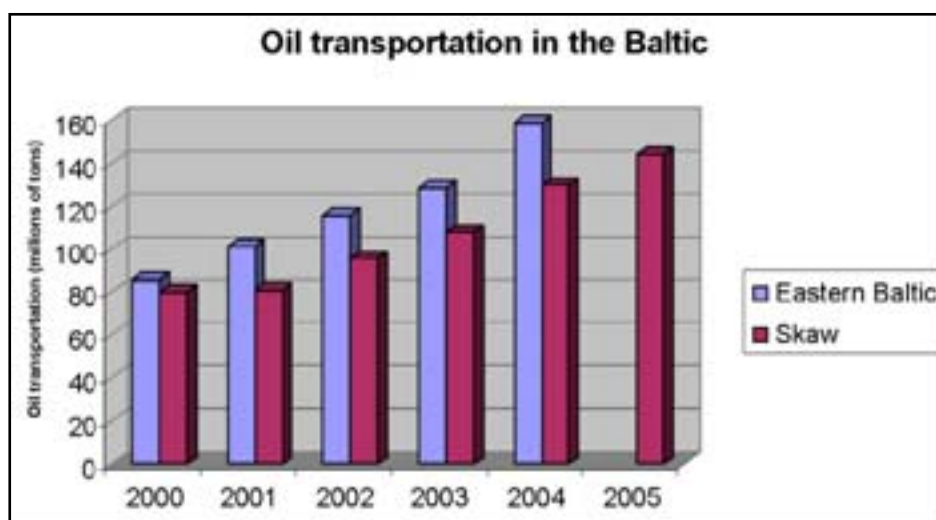


Figure 17. Amount of oil transported via 11 largest oil terminals in the East Baltic (Gdansk, Klaipeda, Ventspils, Muuga, Primorsk, Porvoo, Naantali, Riga, Butinge, St. Petersburg and Kaliningrad) and via the Skaw (in millions of tonnes). Source: HELCOM (202).

Besides cargo, the transport of passengers is extensive within the Baltic and Skagerrak. For example, the Tallinn-Helsinki sea-line is one of the busiest international passenger routes in the world. AS Tallink Group is one of the largest passenger and cargo shipping companies in the Baltic Sea region. In 2006/2007 the number of passenger was 6 873 339, the number of employees 6 227 and their net profit was € 670 000 000 (203). During 2006 the even larger shipping company Stena Line transported approximately 11 500 000 passengers within the Baltic Sea and Skagerrak (204).

Offshore wind power

Recent environmental awareness resulting particularly from the threat of global climate change has pushed renewable sources of energy towards the top of the power agenda. This has contributed towards promoting wind power as the most cost effective of the renewable technologies. Today 93.8 GW, or > 1 % of global electricity, is produced by wind power plants (205). However, if wind power is to become a significant source of energy, worldwide as well as in our region, single plants are not enough. Instead, large-scale wind parks located offshore are frequently discussed. Not only is space plentiful at sea, but wind energy is also significantly greater than inland. In order not to conflict with shipping, tourism and nature conservation interests, developers typically plan their parks tens of kilometres off the coast.

Among the countries bordering to the Baltic Sea and Skagerrak, wind power development varies. Denmark has the highest number of plants per capita acquiring 20 % of power from wind parks (with direct consequences for the emissions of CO₂). Six of Denmark's wind parks are situated offshore. Besides Denmark, Germany is investing considerably in wind power, including offshore wind farms. The German government estimates that the offshore capacity will have reached 3000 MW in 2010. However, out of 16 granted permits for offshore wind parks (including parks in the North Sea), none has yet been completed. In contrast to other countries, Germany aims to concentrate offshore wind power in the EEZ, located far beyond the coastal regions, which puts high technical demands on construction and operation (206).

In Sweden, investment in wind power has not been prioritized and currently only approximately 800 wind power plants are running. A power plant of 1 MW produces approximately the yearly household electricity for 500 Swedish houses. The equivalent amount produced by non-renewable sources would cause the mining of almost 1000 tons of coal/year, the emission of 2500 ton CO₂, 3 tonnes of SO₂ as well as 2.5 tons NO₂ (207). Given the EU objective that 20 % of Sweden's energy should be derived from renewable energy sources in 2020, and that this should be accommodated wind power, Sweden will need to increase its wind power capacity to 3000 - 6000 plants. This corresponds to 30 TW, among which one third might become situated offshore (208). For example, a 128-turbin wind park is currently under development at Kriegers Flak between Sweden and Germany. The Swedish

Energy Agency will promote increased support and management control measures in order to speed up the installation of offshore wind parks.

Industrial use of sea water

Many industries are situated in coastal environment in order to gain access to water. 27 % of industrial water originates from the sea (Table 5). Among users, nuclear power stations use 11 450 million m³ of sea water for cooling per year (209). This sea water is subsequently released back to the sea, approximately 10° C warmer.

Water district	Sea water use	Total water use (1000 m ³)
Bothnian Bay	70 757	312 687
Bothnian Sea	62 578	635 475
Baltic proper – north	99 697	263 095
Baltic proper – south	83 037	331 836
Kattegat & Skagerrak	299 765	711 769
Sweden total	615 834	2 254 862

Table 5. Sweden's use of industrial water. Source: SCB 2005 (210).

Coastal development

Recreational boating is increasing and consequently there is increasing pressure on the development of coastal marinas. Only in Bohuslän 13 000 boaters are waiting in line for a berth. Accommodating this need requires the construction of 25 km of jetties.

Interactions with other ecosystem services

Sea space is provided no matter the condition of the marine environment. In contrast, heavy maritime activity could, in regard to emissions of air-bound pollutants, contribute to global warming, eutrophication and pollution, with consequences for most aspects of the ecosystem, and the services provided to human society. However, it is typically not until a major shipping disaster like an oil spill occurs, that we are made aware of the risks of letting millions of tons of e.g. petroleum products pass in our seas and in proximity to our coasts.

Status, threats and consequences

Status	Good
Sustainability of use	Sustainable?
Level of threat	Low
Expected consequences	Limited

Modern human demands have generated many space-requiring activities at sea.

The majority of these activities are concentrated to coastlines. Examples of human activities, often in conflict with each other include marinas and artificial islands for residential development, offshore wind power plants, shipping lanes and gas pipes. Threats to the provision of space and waterways include all use of the service which jeopardizes the health of the marine environment. Although the foundation of this service, namely space and waterways, are not at stake, their usage may become increasingly regulated if considered too detrimental. In a long-term perspective, this service requires the goodwill that comes with thorough environmental consideration from the beneficiaries of this service.

Shipping

Despite being cleaner than some land-based alternatives, shipping is still responsible for a great deal of emissions, particularly of CO₂ and compounds of nitrogen and sulphur. This air pollution can be transported and does not only affect local marine ecosystems but also humans on distant land. In Sweden the estimated release of nitrogen oxide is estimated at approximated at 18 – 19 000 tonnes yearly, an amount approaching land-based sources. This release from shipping may compromise the Swedish Environmental Objectives of *Zero Eutrophication* (chapter R3), *Natural Acidification Only* and *Clean Air* (211). As for pollution from petroleum products, the amount of non-catastrophic oil spills have decreased in the last few years, despite increased shipping of oil. Still, the number of ship accidents has almost doubled in the Baltic Sea marine area since 2003, according to a new study by the Helsinki Commission (212) and thus large-scale oil spills remains an ever present threat where shipping is intense (Table 6).

Shipping has yet another major disadvantage. Large ships often carry millions of litres of ballast water. The total quantity of ballast water discharged annually from ships in international traffic into the Baltic Sea is estimated to be > 118 million tonnes, according to HELCOM (213). This water is taken from coastal port areas and transported with the ship to the next port of call, where the water is discharged or exchanged. Ballast water is considered the prime source of introduced species. There is plentiful evidence on the huge ecological and economic damages caused by invasive alien species discharged with ballast water (214).

Year	Name of ship	Oil spilled (tonnes)	Location
2003	Fu Shan Hai	1 200	Bornholm, Denmark/Sweden
2001	Baltic Carrier	2 700	Kadetrenden, Denmark
1998	Nunki	100 m ³	Kalundsborg Fjord, Denmark
1995	Hual Trooper	180	The Sound, Sweden
1990	Volgoneft	1 000	Karlskrona, Sweden

Table 6. Major oil incidents in the Baltic Sea 1990 - 2003 resulting in an outflow of more than 100 tons of oil. Source: HELCOM 2006 (212)

Offshore wind power

Offshore wind power is reported to have limited detrimental impacts on marine life according to a recent report (216). Artificial structures like wind plant foundations

affect not only benthic organisms also pelagic species; they may indeed supply new habitat for pelagic fish. Research on the environmental effects of offshore wind power has shown that foundations may function as combined artificial reefs and **fish aggregating devices (FAD)** for small demersal fish. (217). Nevertheless, the construction of wind plants is advised against in certain underwater environments, which may contain vulnerable habitats, e.g. the shallow offshore banks. An additional aspect of large-scale development of offshore wind power is the introduction of electric underwater cables. Certain species of fish may potentially become impacted by the electromagnetic fields induced by the electric currents in such cables. Although an impact has been noted on the movement of the red-listed eel, to date extensive empirical evidence of this effect remains limited (218). As the number of offshore wind farms increase, the question also arises if noise generated due to mechanical motion of the turbines and other vibrations which can be transmitted via the tower structure to the sea will become significant enough to harm sea mammals.

Industrial use of water

The effects of heated water from e.g. nuclear power stations include increased primary production and alterations in community compositions.

How to maintain maritime space and waterways

The sustainability of marine space provision can only be guaranteed if used with great care. The fact that the Baltic Sea recently became classified as **Particularly Sensitive Sea Area (PSSA)** should enable stronger regulation of all maritime activity.

Shipping

In order for society to profit from the medium of transport that the sea constitutes, human health and ecosystem fragility need to be considered when shipping routes are planned and maritime policies formulated. In response to the declaration on the safety of navigation and emergency capacity in the Baltic Sea area (219), countries around the Baltic have cooperated in mapping out new safer routes, by promoting the use of pilots, by regular hydrographic surveys of the main shipping routes and by extending Port State Control. Measures towards environmentally sustainable shipping further include reduced nitrogen and sulphur oxide (NO_x and SO_x) emissions from ships in the Baltic Sea (predicted to increase sharply). According to the HELCOM executive secretary Anne Christine Brusendorff "*The call for stricter IMO requirements is part of the HELCOM Baltic Sea Action Plan to drastically reduce pollution to the sea and restore its good ecological status by 2021*".

In terms of ballast water, proper handling is needed to prevent the introduction of aquatic plants, animals, bacteria, virus and fungi to areas to which these would not

spread in a natural way. If all ships were required to provide ballast water information (e.g. volumes and origin) then at least the amounts and origins of the water entering the Baltic Sea would be known. Increased regulation related to the handling of ballast water is furthermore to be expected once Sweden accedes to the **Ballast Water Convention** (220).

Offshore wind power

The Swedish Energy Agency is currently looking over the sites earlier appointed National Interest Wind Power. Concurrently SEPA is undertaking an ecological inventory of Swedish offshore banks. The results will become valuable when it comes to excluding sensitive areas from wind park development. Already, the geological mapping of 20 offshore bank, suggested as locations for wind parks, has been carried out by the SEPA (81), in co-operation with SMF/GMF/UMF (Stockholm, Göteborg and Umeå Marine Research Centres), SGU, SMHI, Swedish Coast Guard, SBF and the Swedish Species Information Centre (ArtDatabanken). At the completion of the mapping, seven of these banks were recommendation protection from human exploitation of all kinds. These recommendations have not yet resulted in protection and the planning of wind parks on offshore banks continues.

Construction and development

Regarding construction and development in the marine environment, all projects should be preceded by **environmental impact assessments (EIA)**. The EIAs should not only look at potential effects of the activity on particular species or populations; rather, it is important that they adopt an ecosystem approach, extending their impact assessment to the whole system, its functions, processes as well as its ability to continuously provide ecosystem services to humans.

Examples of knowledge gaps

Basic data on benthic habitat distribution constitutes the groundwork for physical planning. Equipped with ecological data on the structure and function of sea floor communities can guidance be provided to those who wish to build offshore wind parks, wave plants, pipe lines, bridges or any other artificial structure in the marine environment. Although geological information on the distribution of sandbanks, bedrock and hard bottom areas within Swedish territorial waters and EEZ exists, there is none or insufficient knowledge about habitat structure, ecosystem functions and processes and the values that they represent; generally speaking, there is a lack of coordination of existing data. However, an extensive national program for the mapping of Sweden's marine realm is underway. Ideally, the resulting data base will include **GIS** models with respect to both abiotic and biotic characteristics of the sea floor. Meanwhile, there are imminent gaps in our knowledge regarding the impact of maritime use on our surrounding marine ecosystems. For example, potential donor regions of ballast water released in the Baltic Sea remains largely unknown. Furthermore there are only few biological studies of donor and recipient

Baltic ports, and consequently species-specific risk assessments have not yet been undertaken. Also, there is a need for invasion capacity and risk analyses of target invasive species.

Cultural ecosystem services

C1: Enjoyment of recreational activities

Definition

Enjoyment of recreational activities refers to economic and societal values of activities carried out in the marine environment such as sport fishing, boating, diving, swimming and bird watching. The service further includes the use of coastal and marine environments to promote and sustain national and international tourism.



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Extent of use and importance to society

Recent research claims that the most commonly, although often unconsciously, used ways among people to ameliorate life, reduce stress, prevent occupational fatigue and increase quality of life, is to seek nature experiences and/or to get involved in outdoor activities (221-224). Nature may in fact increase human capacity concentrate, shorten time spent in hospital and provide cost-efficient opportunities for rehabilitation. Moreover, it has been proven that nature-based activities and environments reduce medical costs and promotes rehabilitation (224). It has further been demonstrated how nature based activities mitigates the development of cardio-vascular problems and depression while increasing muscle and skeleton function and boosting the immune system (221-223).

Almost 90% of all Swedes live within 100 km of the coast and more than half of all Swedes swim occasionally in the Baltic (60). The Swedish coastline, including islands, offers 43 400 km coastline (5), which is more than the Earth's diameter

(40 000 km). Some of the archipelagos in Sweden are among the largest in the world harbouring more than 60 000 islands.

Tourism is said to be the world's largest business (226) and non-degraded coastal zones and marine ecosystems are undoubtedly of huge importance for its economy. For example, two thirds of all Europeans prefer coastal holidays (227). In northern Europe, coastal settings are particularly attractive for visitors in summer. The importance of this industry is substantial at both local and regional level. Some of the obvious beneficiaries include tourists, tourism operators, and people engaging in marine recreational activities as well as those who operate, market or sell recreational activities including marinas, dive operators, boat owners and boat constructors. Furthermore, coastal tourism and a rich supply of recreational activities bestow a wide range of benefits to coastal communities including e.g. increased revenues for food suppliers, suppliers of recreational goods as well as for the transportation sector. It should be noted that in addition to the economic input, tourism, per se, can in turn generate increased job opportunities, investments and other services of benefit for the local region. Quantification of recreational services provided by marine ecosystems can be made by calculating the number of visitors or hotel nights, by employment in the tourism sector, by the number of people engaging in the various recreational activities, as well as by all commerce related to local tourism and recreational activity including shopping, boat construction, fishing gear, advertising and infrastructure.

In monetary terms, the output in the tourism industry in the Baltic Sea region as a whole (not only in coastal areas) is estimated to about € 90,000 million per year, providing jobs for about 2 million people (228). In Poland, for example, the number of beach visitors reaches 8 million per year (228). The extent of the benefit related to coastal tourism is likely to differ among countries, partly in relation to the length of respective coastlines (for the purpose of this report limited to Baltic Sea and Skagerrak). Thus, in countries like Sweden, Denmark, Finland, Estonia, Latvia and Lithuania, the proportion of tourism revenues related coastal tourism is likely to be significant. When considering climate predictions, there is reason to believe that coastal areas of northern Europe will increase in popularity as tourist destinations.

Ecotourism is about diminishing any negative impact of the activity and preserving what the visitor has come to see and experience. It may seem obvious to conserve the conditions upon which the activity is based. Nevertheless, this is not always the case. The Swedish Ecotourism Association approves ecotourism operators or services with the **Nature's Best** label, which guarantees to both customers and stakeholders that the activity in question takes place with maximal caution and minimal impact on local nature and culture (229).

Sport fishing

Sweden has a unique water resource for sport fishing. Not surprisingly, sport fishing is one of the major recreational activities in Sweden, with approximately one million recreational fishers. Along 2000 km of Swedish coastline anyone can fish with hand tools without a permit. The net value of this activity has been estimated at almost 79.5 million EUR (230) and willingness to pay at 265 million EUR. Current revenues from the recreational fishery largely exceed those from the commercial fisheries. The net value of each kilo of fish caught by a recreational fisher is estimated at 4.2 EUR. In fact, it might add economic value if part of the commercial fishing quota was transferred to the recreational fishery.



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Recreational boating

Recreational boating is experiencing a steady growth (5 - 6 % within the EU; 231). Boaters typically agree that there is no other form of participative recreation which covers such a diversity of ages, social groupings, interests and locations (232). Altogether Swedish households own approximately 718 000 boats (233). 250 000 Swedish boaters organized in 100 boat clubs and the number of recreational boats has doubled in the last 20 years. Not surprisingly, Sweden is found among the countries with highest number of boats per capita; in Sweden, as well as in Finland, there are seven people to each recreational boat. In comparison, the number of people to each recreational boat is significantly greater in e.g. Denmark (155) and Germany (182). Each day of the Swedish summer, 90 000 recreational boats are used and over a season, at least 5 million Swedes have travelled with recreational boats at least once. Today there are 1500 ports for recreational boats in Sweden, which together receive 20 000 visits from foreign boats. In total, the recreational

boat industry generates approximately 276 million EUR in 2004 (233). Moreover, Sweden holds 2 % of the world market in terms of boat production (3). Increased boating also generates increased need for shipyards, marinas, service and craftsmen.

Diving

Within the Baltic Sea region the number of divers are roughly estimated at 235 000 (234) and the number is believed to be increasing. Regarding the extent of Swedish recreational diving there is no reliable statistics. Nevertheless, the main actor, PADI, sees that the industry is growing (235). The number of dive centres is increasing (65 PADI centres in Sweden) and so are the number of employed in this industry. PADI certifies ca 20 000 people in the Nordic countries each year. An even larger group of Nordic divers are certified abroad (30 000). Among these, 60 - 65 % are new to the sport. Besides PADI, there are two more actors, NAUI and CMAS, which (albeit to lesser extent) certify in Nordic countries and abroad. The Swedish Diving Association (SSDF) includes approximately 200 dive clubs, among which most are likely to offer dive opportunities in coastal waters (236).

Bird watching

The Baltic Sea is considered important for birdlife, particularly along coastlines, on islands and in shallow lagoons. In Latvia for example, more than half of the best locations for bird watching are situated on the coast. Numerous so called *Important Bird Areas* (IBA) are situated along the coast; their aim is to identify, monitor and protect key sites for birds. The Bird Directive from 1979 aims to protect valuable bird populations and today many of the IBAs are legally protected within nature reserves or included in Natura 2000 areas. The rich birdlife attracts recreational bird watchers and tourism related to bird watching. According to the Swedish Ornithological Society (237), bird watching is a rapidly growing recreational activity in Sweden and elsewhere. In Sweden, bird watching is particularly important along the southern coasts including Öland, Gotland and the peninsula of Falsterbo. The bird sanctuary on Stora Karlsö, where 9000 pairs of guillemots breed, is a major attraction. Furthermore, bird tourism typically has limited ecological impact. Besides recreational values and tourism revenues, the presence of accessible seabird colonies, like that of Stora Karlsö (Gotland), generates scientific information and contributes towards public education (chapter C3). The Swedish Ornithological Society has approximately 12 000 registered members and the number of registered members in the 24 regional, and almost 100 local organisations are estimated to be similar in size. The Danish Ornithological Society has 13 000 members (238), and in Finland, 10 000 ornithologists are organized in 30 local agencies under Bird Life Finland (239).

Seal safari

Various companies offer seal safaris both in the Baltic Sea and Skagerrak. In some cases, the safaris are run by commercial fishermen. Some operators are certified within the **Nature's Best** programme (229).

Interaction with other ecosystem services

Enjoyment of recreational activities related to the marine environment is primarily dependent on the presence of attractive scenery both above and below water. Diving, for example, is particularly boosted by underwater diversity. The use of beaches for sunbathing and swimming activities is related to the presence on clean, attractive beaches devoid of putrid algae, rubbish and toxic substances such as oil. Various supporting and regulating ecosystem services are needed to fulfil these requirements, including mitigation of eutrophication, regulation of pollution and biological regulation. Sport fishers, on their hand, demand big fish, preferably fit for consumption, which is typically related to healthy stocks of target species, high biodiversity, high habitat quality and efficient nutrient cycling and resilience. Bird watchers and participants on seal safaris are also ultimately dependent on biodiversity, habitat and resilience. The enjoyment of recreation can in turn positively affect other cultural ecosystem services such as the use of nature for education, the experience of cultural heritage and inspiration and finally it might strengthen the belief that ecosystems have to be preserved for ethical reasons. Tourism may also become an incentive for conservation and sound management practices which then in turn might increase most other ecosystem services.

Status, threats and consequences

Status	Moderate
Sustainability of use	Unsustainable?
Level of threat	Moderate
Expected consequences	Moderate

Excessive development related to tourism and recreational activity is in many areas around the Baltic Sea threatening its own existence. Unless the services that provide the basis for tourism and recreational activities are acknowledged and sustainably managed, future value may be diminished. In summary, most threats to e.g. biodiversity, habitat and resilience (dealt with in respective chapters) could indirectly affect the enjoyment of recreational activities in marine and coastal settings. The predicted increase interest for Baltic Sea tourism due to global warming could be seen as an incentive to promote conservation measures. There is reason to make sure that such opportunity promotes sustainable use - rather than imperils - ecosystem services provided by our coasts and seas.

Over-fishing

Along major parts of the Baltic and Skagerrak coasts, sport fishing is not considered meaningful today, due to reduced catches and environmental degradation in general. Although recreational fishing has been shown to add more value, over-fishing for commercial purposes is still a substantial threat to sport fishing. Mean-

while, eutrophication and other human-induced disturbances exacerbate the situation. Due to the current status of the marine environment few communities along the Baltic coast choose to develop fishing tourism (240-241). Instead, Swedish sport fishermen leave the country and spend their money elsewhere, particularly along the coasts of Norway.

Eutrophication

Eutrophication is believed to increase the presence of filamentous algal mats, as well as blooms of blue-green algae (cyanobacteria), which can sometimes be toxic. The commonly occurring increase in filamentous algae in shallow coastal areas results in unattractive malodorous shores. In order to maintain recreational values, these algal mats have to be removed. The cost of cleaning the shores of the municipality of Strömstad (Skagerrak) was estimated at 70 000 EUR per year (152). A survey of 1 600 tourism operators in Sweden revealed that intense algal blooms in the Baltic 2005 caused substantial decrease in bookings on Gotland during the following summer (242). On Öland, algal blooms during the 2005 summer resulted in losses of approximately 11 million EUR in the tourism and fishing sectors (243). The organism primarily responsible for toxic blooms in the Baltic Sea is *Nodularia spumigena* (a cyanobacterium). It can cause liver damage and although no human fatalities have been recorded so far, cattle and other domestic animals have deceased from this poisonous organism.

Pollution

The Baltic Sea is already one of the world's most trafficked seas and maritime activity is expected to increase in coming years (chapter P7). Despite large numbers of old and less secure tankers, no truly catastrophic oil spills have not yet occurred. It should however be noted that the tanker *Prestige*, which in 2002 lost tens of thousands of tonnes crude oil off the Galician coast in Spain, had travelled through the Baltic Sea on its way to the scene of the accident. The spill had severe consequences for tourism, fisheries and the marine environment. The Swedish Rescue Services Agency has presented a hypothetical scenario in which a similar tanker catastrophe (hypothesised spill of 30 000 tonnes) occurs in the Baltic Sea at the location where the *Fu Shan Hai* released 1 500 tonnes in 2004. Among others, this scenario results in an estimated loss of 42.3 million EUR in tourism revenues (244).

Coastal development

Tourism is already having a major environmental impact on many coastal areas. Besides land-grab, its demand for resources such as water and need for waste disposal facilities cause pressure on water resources and natural coastal habitats and structures such as wetlands and sand dunes. In Poland, for example, most coastal habitats are threatened by coastal development, excessive garbage disposal and coastal abrasion (245). Meanwhile, many visitors and operators are unaware of the consequences their activities might have on nature and ecosystem processes. In the Eastern Baltic, Russian Kaliningrad is becoming an increasingly popular tour-

ism destination. For wealthy Russians, Kaliningrad offers cheap opportunities. As a consequence, coastal land is bought for the construction of holiday homes, often with detrimental effects on the environment and with loss of potential development of local tourism (246).

Invasive alien species

During the last decade two long-tailed water fleas have spread rapidly in the Baltic Sea. Besides threatening food web dynamics (chapter S3), the long tail spines of these water fleas are a nuisance to anglers because they tend to accumulate on fishing lines and nets. Some anglers have reported needing to cut their fishing lines because there were so many water fleas attached they could not reel in their lines. Invasive species do not always constitute a threat; the round goby has become an appreciated target for sport fishers in e.g. Poland.

How to strengthen the ability to enjoy recreational activities in marine environments

It is clear that the many tourist destinations that owe their popularity to their proximity to the sea are dependent on environmental quality. A high level of protection of the coastal and marine environment (above as well as below water) is therefore essential for the sustainability of tourism. For example, an international demand for sport fishing on natural fish populations in a clean environment is believed to provide great opportunities for our region (126). A current campaign from the Swedish Federation of Fishing Rights Owners highlights the potential for recreational fishery to become a major tourist attraction. Meanwhile, the association demands better water management in areas, including coastal regions, with potential for this business (247). Regarding the current state of eutrophication in the Baltic proper, BSAP work in progress appears promising. But is the tourism industry patient enough to wait for the results to become evident? When it comes to water transparency, it may take decades for the huge water masses that are the Baltic to respond to altered farming practices. If too slow, preventive measures could possibly be complemented by the cleaning of filamentous algae from shores and the gathering of algal slicks at sea (248).

" Feel the white sands and the sea salt on your skin. Listen to the call of the seagulls gliding on proud wings over the bay. Look for amber, the gold of the Baltic, sparkling in the morning sun"

Promotion for a sea side hotel in Rügen, Germany

In order to promote Swedish dive tourism, underwater dive parks including specific dive trails could be developed. Underwater parks are a sustainable and educative way to display maritime finds. Examples from different parts of world have shown

that underwater parks are useful in protecting and promoting maritime historical inheritance. For example, the underwater park at the wreck site of the Kronprins Gustav Adolf off Helsinki in Finland was created at the initiative of the National Board of Antiquities, in order to promote sustainable use of a historical site. Divers can view the wreck following a leading line with twelve information boards about various details of the wreck. The park opened in the summer of 2000 and has been well visited since (249). Similar initiatives have been taken in Latvia by the Jurmala Town Museum and in Lithuania by the Maritime Museum at Klaipeda.

Finally, providing information and raising awareness is a first step towards responsible actions among recreational users of the coastal and marine environment. Generally though, environmental awareness is only likely to bring about changes in behaviour, if consequences of behaviour are immediate and clear.

Summarized in the list below are some important measures to be considered in areas of extensive tourism development:

- Habitat restoration and protection, particularly in sensitive and highly valued areas
- Adaptive management of biodiversity with clear action plans for vulnerable organisms
- Increased regulation for coastal development
- Make users/visitors/operators aware of the ecosystem services they are using
- Where suitable, make users/visitors/operators pay for the services they are using

Examples of knowledge gaps

Enjoyment of recreational activities is one of the most obvious ecosystem services provided by the Baltic Sea and Skagerrak. Therefore, it is vital to value this service in monetary terms and try and link it to the state of the marine environment or to alterations in the marine environment, achieved by particular measures (amelioration) or particular human-induced disturbances (deterioration).

Cultural ecosystem services

C2: Enjoyment of scenery

Definition

Enjoyment of scenery refers to aesthetic values of benefits to individual humans and society. This service includes the appreciation of beauty and silence.

Extent of use and importance to society

Human society has a significant need for environmental variation. Enjoyment of an attractive, rich and varied nature is believed to have significant impact on health and well-being. Attractive marine and coastal scenery may be a particularly important service for residents, property owners and real estate agents. It is also of utter importance to the tourism industry. Hence, the importance of this service is greatest in residential and touristic areas, or at least limited to where there is infrastructure. On the other hand, the undisturbed coastal areas in between developed areas are due to their undeveloped setting - and thus attractive scenery - likely to be the next areas of development. To get an estimate of the importance of a scenic coastal environment to residents, 120 000 buildings are situated within 100 m from the Swedish coastline (Fig. 18 illustrates Swedish coastal development). These include 30 % of all existing holiday residential homes (1). The value of both permanent and holiday residential homes increases with proximity to the sea (250). Examples of how reduced water quality can negatively affect prices on coastal real estate have been reported (251). Included in the enjoyment of scenery is the appreciation of silence and sense of freedom. Both of these values were found to be of major importance to Swedish recreational boaters, for example (233).

Shoreline protection in Sweden

The protection of shorelines is established in the Environmental Code. The objective with shoreline protection is to maintain environmental quality and potential for recreational activities. Shoreline protection is granted to all aquatic environments protecting them from essentially all disturbing development.

Interaction with other ecosystem services

The enjoyment of scenery is naturally dependent on the existence of a visually attractive coastline without disturbing development as well as on relatively clear waters. Naturally, the definition of attractive is subjective, yet certain factors appear important for increasing scenic values. Included among aesthetic values is the presence of variety of attractive wildlife like birds, seals and shells on the beach.



Figure 18. In Sweden there are almost 120 000 buildings within 100 m of the coast or of the shores of islands in the sea. *Source: Bernes 2005 (14)*

The enjoyment of scenery can therefore be considered dependent on a variety of supporting and regulating services such as the mitigation of eutrophication and the maintenance of habitat, particularly for species of widespread human interest. In addition, the appraisal of scenic beauty may affect the extent to which we wish to protect the marine environment for ethic reasons (chapter C6). In other words, although we do not know what is contained within the sea, we wish to protect whatever is there because of the overall impression of beauty.



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The enjoyment of scenery is an ecosystem service which conflicts with the use of various others. For most people, the definition of beautiful scenery is related to the absence of development, which means that most provisioning services as well the enjoyment of recreation and touristic activities may have a negative influence on the enjoyment of scenery. Take for example, the construction of a wind park; while it becomes feasible by the provision of space and is beneficial for atmospheric regulation, it is nevertheless detrimental to the appreciation of local scenery, which in turn may have consequences for the enjoyment of recreational activities, and the strengthening of cultural identity and heritage.

Status threats and consequences

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

Determining the status of aesthetic value of coastal and marine environments around the Baltic Sea and Skagerrak is difficult due to regional differences. However, overall status is considered moderate due to excessive development in many coastal regions. As this development is ongoing, current level of threat is also stated as moderate. It should be noted that use of this service can only be sustainable.

Loss of scenic value is associated with coastal development and large construction activity such as the bridge between Sweden and Denmark and offshore wind parks but also with environmental deterioration like the presence of putrid algal mats, loss of sand dunes, beach erosion, litter, pollution and decrease in rare spectacular marine fauna like harbour porpoises and white tailed sea eagle. The mitigation of impact may be costly. For example, the cost of cleaning the shores of Bohuslän from litter is 1.3 - 1.6 million EUR per year (82). The loss of scenic values has negative consequences for property value and taxation as well as for local tourism revenues. Scenic values contribute greatly to national identity as well as international reputation. Hence, they are difficult to replace and should not be overlooked.

How to strengthen marine aesthetic values

In order to maintain enjoyment of scenery and profit from the economic and societal benefits it may infer, this ecosystem service should be considered in all development issues and marine planning. A recent example in which aesthetic values have indeed been considered, is the setting aside of two areas protected from human-induced noise pollution along the Skagerrak coast. These areas are the first of their kind, but if this pilot experiment is considered successful, three more areas are waiting in turn. The revised Swedish environmental objective regarding noise and other disturbances include a target of noise-free areas in all counties by 2015 (82).

Examples of knowledge gaps

There is limited knowledge regarding the values of scenic beauty, silence and undeveloped coastal marine environments. In order to strengthen the appreciation of aesthetic values, more information is needed regarding what constitutes attractive scenery and the consequences of alterations in scenery. Summarized, investigations are welcomed in the following fields:

- Identification of the factors which contribute to an attractive coastal scenery
- Understanding how the impression of an aesthetic scenery best maintained, despite coastal development
- Linking scenery to tourism
- Economic valuation of coastal and marine sceneries
- Possible benefits of scenery for health and well-being

Cultural ecosystem services

C3: Contribution to science and education

Definition

The existence of a varied marine life and a rich coastal environment is likely to stimulate various activities such as school excursions, the establishment of museums and aquaria, but also scientific research. Aspects of the marine coastal environment can also motivate the general public to engage in voluntary work, thereby raising environmental awareness. Furthermore, the marine environment provides historical records of environmental change, environmental indicators and early warnings of change.

Extent of use and importance to society

Human society currently faces numerous environmental challenges. We have entered an age where humans have the predominant impact on the world's ecosystems. To battle what we are faced with, environmental education and public awareness are critical. Moreover, tangible management advice, based on sound scientific knowledge and reasonable predictions, has to be given to those with managerial responsibilities.

Indicators of environmental health

Ecological indicators and early warning signs provide marine resource users with vital information about the system upon which they depend. Indicators typically allow managers to track progress with respect to reference points. For example, the Swedish Environmental Objectives Council (Miljömålsrådet) has used indicators to estimate success in reaching the Swedish Environmental Objectives. For the two foremost objectives relevant for the marine environment, *Zero Eutrophication* (chapter R3) and *A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos* (chapter S5), there are nine and 11 indicators respectively (with some overlap), from which the proximity to the desired objective can be determined.

The commercial fishery constitutes a sector in which indicators are commonly used. Indicators provide managers with information regarding size, growth and reproductive capacity of respective fish stock. Faced with environmental deterioration or over-extraction, certain populations will exhibit clear responses well before the whole ecosystem is affected. Examination of e.g. physiological condition, presence of so called **indicator species** and size of **reproductive stock** can identify potential environmental impact and help guide managers to assign appropriate

fishing quotas. Ecophysiological responses of marine organisms to environmental alteration are referred to as **biomarkers** and can provide significant information for development of early warning systems for environmental degradation (252). The extent to which we choose to pay attention to early warnings signs does, however, differ.

Environmental monitoring

When dredging was carried out in the port of Gothenburg, blue mussels were used in order to monitor the release and spread of contaminants. Mussels filter large amounts of water (3 - 5 L/h) when they feed (chapter R3) and by looking at substances caught in the tissue of previously clean (translocated) mussels, the amount of contaminants in the water could be calculated (253).

Historical environmental records

The study of ancient coastlines, fossil content and geochemical variation in sediment cores aid today's scientists in understanding how the environment has changed in the past, thus enabling them to predict future change. For example, sediment cores from the Baltic Sea contain records of the historical events, including the development of the Baltic Sea from the Baltic Ice Lake to the present post-Litorina Sea stage. This is of particular relevance to current concerns about climate change. In the case of amber found in the Baltic Sea, the presence of organisms within the fossil can provide information about the environment in which they lived and where the resin was deposited, million years ago.

Environmental education

Generating interest and promoting environmental education are important ambitions of most museums and aquaria. In aquaria, marine living organisms provide stimulus for cognitive development, including education and research. The aquaria furthermore generate jobs and revenues. Well known examples of marine aquaria or exhibitions in our region include *Aquaria Water Museum* in Stockholm, *Universeum* in Gothenburg, *Havets Hus* on the Skagerrak coast, *Denmark's Aquarium*, *Gdynia Aquarium* in Poland, *Sea Life* in Helsinki, Finland and the *Sea Museum* on Fehmarn, Germany. Apart from museums, visitor centres are commonly set up in protected areas or areas of special interest. Among the 28 Swedish visitor centres (*Naturum*) supported by SEPA, eight are situated in coastal protected areas, while a number of other additional coastal centres are under development (including one in the future *Kosterhavet National Park*). These include a new Baltic Sea Education Centre on Gotland, *Forum Östersjön*. The centre which is to be completed in 2009 is to provide user-friendly information to the public about the current status of the Baltic Sea. In summary, the visitor centres exhibit local coastal and marine ecosystem characteristics and offer various activities to the general public (254). An example of a more specific site promoting public education is provided by the Bergeforsen salmon farm. It is open to the public and harbours a salmon aquarium. In august visitors can witness and take part of the annual catch of specimens that will be squeezed for roe.

It is difficult to quantify the benefit of education and public awareness, and even more so to assign monetary values to it. To illustrate the extent of use, Universeum in Gothenburg is used as an example. Half a million people visited Universeum in from January to November 2007. Among them, almost all passed through their water exhibition and the aquaria; 20 000 were participants of school excursions. Among the school children, approximately 5 000 received specific guidance related to '*water and the marine environment*' (255).



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Information can be distributed in many ways. Apart from exhibits and education centres, natural history, ecology and conservation issues are often communicated in nicely packaged coffee table books and films with impressive footage. For example, documentary director Folke Rydén and renown photographer Mattias Klum have taken on the Baltic Sea as their next project, which is likely to generate an increased awareness in local marine environmental issues. The project is a 10-year production with the first film to have its premiere during 2009.

Interaction with other ecosystem services

The processes or services required for the marine environment to contribute to education and scientific information have not been investigated. It might be easier to consider whether it would be more difficult to promote awareness and attract attention to marine conservation, were habitats severely degraded and biodiversity largely decimated. At least, it seems probable that nature centres would be much less visited, were the scenic or recreational values of coastal and marine environments significantly reduced (with the possible exception of the last cod on exhibit).

Meanwhile, the contribution to marine environmental awareness and education is likely to promote recreational activities. In a long-term perspective, public awareness and opinion might also contribute to improved management and conservation, with consequences for almost all services. As for the provision of environmental indicators and historical records, they might contribute to a better understanding and even improved management of ecosystem processes and resources. Thereby they may contribute to the continuous supply of most regulating, provisioning and cultural ecosystem services.

Status threats and consequences

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

The provision of educational opportunities and scientific interest is not easily reduced. Nor can this service be used unsustainably. However, it is likely to experience limited threats from of e.g. biodiversity habitat loss. Museums and aquaria ultimately depend on nature to provide it with organisms, habitats and information.

How to promote future contribution to science and education

The Swedish visitor centres (Naturum), founded by SEPA are good examples of a measure towards promoting awareness and education regarding local marine and coastal ecosystems. Another example includes the introduction of dive parks with particular dive trails (256), offering more than merely a dive experience. In preparation of diving along a set trail, the diver is provided with information about the marine habitats and life forms that he or she is about to encounter.

Examples of knowledge gaps

The development of visitor centres in coastal areas calls for feedback from attending visitors. What are the lessons learned? How does this effort contribute to overall awareness regarding marine ecosystems? In terms of marine indicators much work lies ahead. Taking a step away from the traditional single-species models, SBF (in co-operation with ICES, HELCOM and EU) is currently investigating ecological indicators that may better represent fish community structure and dynamics (all according to the ecosystem approach). Interesting topics related to the use of ecological indicators include the identification of functional roles (not least

among commercial fish), analyses of trophic levels and the identification critical thresholds and factors contributing to ecosystem resilience.

Cultural ecosystem services

C4: Maintenance of cultural heritage

Definition

Maintenance of **cultural heritage** refers to the use of the marine and coastal environment for spiritual, sanatory or historical purposes.

Extent of use and importance to society

Sanatory and spiritual use of nature in general

Nature worship often replaces traditional religious beliefs and reduced family ties among modern humans. According to Carl Reinhold Bråkenhielm, professor in Philosophy of Life at Uppsala University, many people lack roots and history today. Rapid development creates opportunity but also stress and restlessness (257). Under such circumstances, nature can provide tranquillity, energy as well as a sense of meaning and being part of a bigger picture. Bråkenhielm refers to the forest as being of particular value to Swedes. It is however likely that the focus of nature worship differ among regions; the sea is likely to replace the value of forests in coastal regions. Whichever biotope is appreciated, researcher Bråkenhielm compares it to a religion. He refers to how Swedes view nature as a source of power, inspiration and an escape from heavy social and economic burdens, characteristics typically use to define religions (257).

Maritime history and coastal cultural identity

Throughout history, the sea has been an important feature linking people and nations while enabling trade and cultural exchange. Maritime activity is, for example, considered to be the force driving the development of colonialism and capitalism, resulting Europe constituting the centre of global development between the 1500s – 1800s. In a historic account of the Baltic Sea region, the North Sea and the Baltic Sea are described as the main culture promoting factors in Northern Europe (258). Already millennia before Roman times, Baltic Sea amber had been traded across western and central Europe. Then, in early mediaeval times, the Vikings developed shipping and used the Baltic Sea as a corridor from Scandinavia to what is now Russia and - via the Russian rivers - to the Black Sea and Byzantium. The authors Gerner and Karlsson conclude that in a historical perspective, the Baltic Sea has constituted “*an element creating continuity*” (258). The interest in maritime heritage in the region can be illustrated by the fact that some 3.4 million people visited

maritime museums in the Baltic Sea region in 2004 (234).

Abundant natural resources, like fish, typically play an important role in community formation as well as in the development of peoples' attitudes and identity. The resources thus become part of the community heritage. Not only do the resources provide the economic foundation of the community, but also the cultural definition. Today, the economic significance of e.g. fishery has decreased in all traditional fishing communities, yet many attach symbolic values to the preservation of goods and services related to their heritage.

One species of fish, the herring, has played a particularly important role in the development of Swedish coastal settlements in historical times. Enormous herring schools arrived from the North Sea to the Skagerrak to spawn and along the coasts of Bohuslän, particularly in the 18th century, herring fishery generated richness and a multitude of job opportunities and trade. Numerous settlements along the coast of Skagerrak have been listed as important cultural heritage sites, with long-term records of shipping and fishing, such as Fiskebäckskil, Gullholmen, Klädesholmen and Marstrand (259). The herring industry on the island of Klädesholmen (Skagerrak), for example, goes back to the 18th century. To a community like Klädesholmen, the relatively recent loss of fishery resources may strike hard even though the economic dependence has long ceased to be of importance.



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Ship building is another industry with old traditions, many of which live on. The Swedish Association of Traditional Boats (Föreningen allmogebåtar) aims to conserve old Nordic boats as well as the traditional industries concerned. The association has 3 200 members in all Nordic countries (260).

Marine archaeology

The Baltic Sea has a unique underwater cultural heritage (UCH). Few regions can compete in terms of the number and condition of their UCH sights. The impressive wrecks from large 17th century naval ships like Vasa and Kronan are world famous, but the underwater heritage extends much farther. Besides an impressive number of wrecks, sunken Stone Age villages as well as remains from the Viking and Middle ages are to be found. The Baltic Sea is one of our last 'Wild West', claims the director of the Archaeology Unit at the Swedish National Maritime Museums. Today, 12 000 wrecks have been found, but there is reason to believe that there are many more. The Baltic Sea has a unique capacity to conserve the remains of sunken ships. Due to the low salinity, ship worms are absent and in addition there is widespread distribution of wreck-conserving sandy substrates. The cooperative project RUTILUS, in which all nine countries around the Baltic participated, aimed at describing Baltic marine cultural heritage (234). RUTILUS identified the top 100 wrecks in the Baltic, 12 among which have made it to the top 100 list of wrecks worldwide. For more detail on the Swedish part of the Baltic underwater treasure, the National Maritime Museums have compiled a list of the 25 most valuable submarine cultural heritage sites spread around Swedish coasts (256).

Not surprisingly, wreck diving is the foremost reason for Baltic Sea diving. According to Swedish National Maritime Museums, the newly acquired awareness of our marine treasures may bring about new legislation as well as an increase in underwater tourism around the Baltic. This is welcomed by the tourism industry (chapter C1). To facilitate accessibility and promote wreck diving in the Baltic Sea, the installation of dive parks in Sweden has been discussed. The concept of dive parks has already been introduced in Germany, Finland and Denmark. Countries like Russia, Estonia, Latvia and Lithuania have yet not investigated their waters for wrecks, but it is likely that their waters too contain treasures and potential for dive tourism.

Interaction with other ecosystem services

The maintenance of traditional maritime practises and the conservation of coastal settlement and cultural heritage related to the coastal and marine environment are primarily dependent on the historic use of ecosystem services. Nevertheless, continued harvest from the sea is important when it comes to maintaining fishing traditions. Therefore, cultural heritage in traditional fishing villages may still be related to the provision (albeit limited) of food and other goods from the sea. As for the sanatory aspect of the marine and coastal environment, it is related to scenic and inspirational services as well as to the enjoyment of recreational activity.

Status threats and consequences

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

Cultural heritage is being lost, particularly due to resource loss and consequential loss of small-scale industries along our coastlines. Moreover, deteriorated environmental conditions in the Baltic Sea reduce the potential for divers to experience our spectacular underwater heritage sites. The use of this service does typically not in itself threaten its value (unless UCHs are impacted by increased visitor numbers). It is difficult to assign a value to this service, and the impacts of current threats are considered relatively minor.

Many coastal settlements with traditions of marine resource use have been depopulated as a result of reduced viability of resource extraction or other traditional industries, but also to urbanisation and reduced willingness of people to retain tradition and cultural values. Cultural heritage cannot be replaced. Nonetheless it is dynamic and future generations are likely to possess a different cultural identity; perceiving the sea in a different way. Moreover, certain traditional use of the sea may only remain as history account. As for submarine cultural heritage sites, they are in part threatened by the same disturbances as are natural environmental values (Table 7).

Threats	Natural environments	Cultural environments
Oil spill	x	?
Hazardous substances	x	?
Eutrophication	X	?
Fishing (trawling)	X	X
Aquaculture	X	X
Shipping	X	X
Alien species	X	?
Development and construction	X	X
Diving	?	X

Table 7. Comparison of threats to natural and cultural underwater environments. *Source: Naturvårdsverket 2007 (256)*

How to maintain coastal, marine and maritime cultural heritage

Under the Swedish Environmental objective No 10 (chapter S5), a new interim target for 2015 is proposed (82). The target promotes the sustainable use of cultural, social and natural values in the coastal environment. Suggested measures include marine planning and regional development programmes for coastal areas.

Cultural reserves can be established under the 1999 Swedish Environmental Code. Twenty five cultural reserves have so far been established in Sweden, among which two include coastal cultural heritage sites (Brottö skärgårdsjordbruk and Sandvikens fiskeläge). According to the Swedish National Heritage Board, the number of cultural reserves needs to be extended. By receiving legal protection, sites could become both sustainably used while gaining increased reputation among the public; tourism benefits may constitute a welcomed spin-off effect (chapter C1). To date no UCH per se has received this status (256). In 2001, the UNESCO *Convention on the Protection of the Underwater Cultural Heritage* was introduced, opening up for international recognition of UCH. The Swedish National Maritime Museums has declared UCH in the Baltic Sea extremely rich (234), and thus it deserves rightful attention and good management.



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Examples of knowledge gaps

The valuable work of mapping cultural values in the marine environment has only commenced. According to the Swedish National Heritage Board it is far from complete and needs to be sustained (256).

Cultural ecosystem services

C5: Inspiration for art and advertisement

Definition of the service

Inspiration from the coastal and marine environment and maritime activity has given rise to numerous art works including books, films, paintings, folklore, architecture as well as advertisement.

Extent of use and importance to society

Inspiration is a treasure of unknown value; the extent to which the marine environment is appreciated by artists is hard to estimate. Use is typically private, with thousands of amateur artists using our marine environment as a source of inspiration. Although inspiration can arise in many environments, it is generally difficult to replace one source of inspiration with another in case of environmental deterioration leading to reduced quality of inspirational worth. The significance of this service may be local, for example when local artist sell paintings to tourists, but may extend to regional, like in the case where an art community contribute to the fame of an entire region, a famous example being the Skaw, Denmark. On rare occasions, art projects inspired by the marine environment have reached global fame, like the example of the award-winning and globally distributed movie, the *Big Blue*, depicting a fictionalized account of the sporting rivalry between two famed free divers in the Mediterranean. A few examples of how the marine environment in our part of the world provides inspiration for art and advertisement are presented below.

Art

At the web gallery of the National Museum of Fine Art in Sweden, 26 % of all displayed paintings made by Swedish artists 1900 to contemporary are characterized by coastal, marine or maritime motives (261). One of the most famous art communities in our region is the aforementioned *Skagen Painters*, situated in the Skaw. As such it contributes to the overwhelming popularity of this tourist village. Painters like Krøyer, Krohg and the Anchers came to the area in the late 1800s to escape the city and to record artistically a way of life they realized was soon to disappear. The *Skagen Painters* encompassed not only painters, but also writers, composers and other influential people on that time's cultural area. They all came to be influenced by this picturesque and at this time unspoilt village at the entrance of the Baltic where Kattegat and Skagerrak meet. Until today, the *Skagen Museum* and the residents of famous painters constitute important tourist attractions, and

reprints of their paintings, of which many of which have coastal motives, are sold worldwide.

Film

The Swedish television series *Saltön*, based on books by author Viveca Lärn, takes place in a small coastal community by the Skagerrak. Both the books and subsequently the film, received considerable attention. When *Saltön* was broadcasted on Swedish national television (2005 and 2007), it was watched by approximately 2.5 million viewers and ranked among the top ten programs of the year (262). Documentary film can be considered both art and education. A documentary broadcasted on national television in 2007 investigated the rich treasures of Baltic shipwrecks from a marine archaeological perspective. The Baltic Sea is also the current focus for documentary director Folke Rydén and renowned photographer Mattias Klum. The project is a 10-year production with the first film to have premiere during 2009.

Literature

In a compilation of Swedish poetry from 600 years, 4 % of the poems appeared inspired by the sea or maritime activity, most of them originating in the last two centuries (263). In Finland, a writer's competition with the title "*the Sea and Us*" was arranged in 2007 by among others the Finnish Maritime Society and the Finnish Science Centre. Students were encouraged to write songs, poems or short stories from a various marine themes, including "*A clean Baltic – only a dream*" and "*What significance does the sea have for me?*" The contest received 522 contributions and the winners of the competition were awarded cruises within and outside the Baltic (264).

Music

In a compilation of Swedish songs (265) 9 % of all lyrics have clearly been inspired by the marine environment or by activities carried out at sea such as fishing, sailing or other maritime activities.

Advertisement

In 2009, the well known Swedish beer *Pripps Blå* is celebrating its 50th anniversary. Among everyday commodities, *Pripps Blå* is the most commonly purchased beer with a market share of 12.5 % (volume). The beer has been the subject of many commercials set in coastal environments and investigations have demonstrated that Swedes associate this product with summer, seas and archipelagos. Herein lies the secret of its popularity, according to the manufacturer (266).

Interaction with other ecosystem services

Typically, inspiration for art and advertisement is related to the scenery, above as well as below water. What constitutes an inspiring marine environment is naturally

subjective, yet there is reason to believe that visual aspects like beauty, abundance and variety are of importance. Generally a visually attractive environment will receive more visitors and will thus have the capacity to inspire more people. Like enjoyment of scenery, inspiration for art and advertisement is typically related to biodiversity, habitat, resilience, mitigation of pollution and eutrophication but also to cultural heritage and education. In addition, art and advertisement is often inspired by marine and maritime activity such as fishing, shipping and recreation. In turn, art and advertisement related to the marine environment may contribute to environmental education as well as to the identity and heritage of coastal populations.

Status threats and consequences

Status	Good?
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

Overall, little is known about the value of this service. Whether current deterioration of environmental conditions in for example the Baltic Sea is reducing its potential to inspire artists and advertisers, is questionable. Although the use of this service is sustainable by definition, its status could possibly worsen with increasing threats.

How to ensure that the marine and coastal environment remains a source of inspiration

Careful marine planning in regard to scenic values as well as sustainable management of coastal and marine resources are likely to constitute the best insurance for maintained inspirational value. In addition, providing access to the potentially inspiring environments is a prerequisite to this service. For example, measures which promote close encounters with a scenic environment, like current and future investments in National Parks, visitor centres, nature trails and dive trails, might further promote the sea and coastal environment as sources of inspiration.

Cultural ecosystem services

C6: The legacy of the sea

Definition

The legacy of nature is a non-use benefit. The service refers to an appreciation of nature for ethical reasons (**existence value**), which is often accompanied by a willingness to preserve the intrinsic value of nature for future generations (**bequest value**). In this context, the legacy of *nature* is replaced by the legacy of the *sea*, referring to all aspects of the coastal and marine environment.

Extent of appreciation and importance to society

The legacy of nature cannot be quantified, nor can the legacy of the sea. Nevertheless, its importance to humans can be evaluated, even in monetary terms (24). The beneficiaries of this service are believed to be numerous. They are limited neither to coastal residents, nor to recreational users or visitors to seaside communities. The legacy of the sea may be equally important to an inland resident who has never visited the coast. To many people, nature does not need to be generating measurable services or providing goods; it just needs to *be*, in order to deserve concern and good management. Take for example the harbour porpoise or the white-tailed sea eagle. The number of people that have seen these animals is minimal, yet many of us are prepared to invest in their conservation, and many of us would even experience a sense of loss were they to disappear. It would signal that our generation has failed to protect the legacy of sea for future generations. Although the ethical values responsible for our appreciation certain animals are typically considered less worth, they may in fact constitute the foundation for our wish to maintain biodiversity and conserve our natural environment. Assurance that all components of nature will persist, for no other reasons than ethical, adds to the well-being of many people. The extent of appreciation and thus its importance are strictly individual. How this service is valued is nevertheless likely to vary with economic development and levels of welfare; the value of participation in the conservation of nature for ethical purposes is, after all, a luxury. If one is poor, the main incentive for conservation is likely to be related to nature's capacity of producing food or generating income.

Interaction with other ecosystem services

The more nature is degraded, the less value does this service provide. The extent to which individuals recognise this legacy of the sea is, however, strictly individual and the factors affecting it remain unknown. However, the appreciation of the sea

for ethical reasons may (or may not) result in action promoting sustainable management or protection, which could be anything from joining a local NGO to cleaning a beach from litter. The combined influence of many such actions may affect the maintenance and provision of various ecosystem services.

Status threats and consequences

Status	Moderate
Sustainability of use	Sustainable
Level of threat	High
Expected consequences	Limited

As awareness of the marine and coastal environment is rising, the value of this service may become reduced. Yet, its use is inherently sustainable. Threats to this service include loss of biodiversity and deterioration of ecosystem processes and function. However, in relation to other ecosystem services, the consequences to this ecosystem service are limited.

Examples of knowledge gaps

Attitudes and ethics in regard to the marine environment remains a largely unexamined field of research.

Glossary

2nd law of thermodynamics A general statement of the idea that there is preferred direction for any process.

Abiotic compartments All physical and nonliving chemical factors, such as soil, water, and atmosphere, which influence living organisms.

Adaptive management A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

Agar and agarose Gelatinous substances obtained from some species of red algae. Agar can be used as a laxative, a gelatin substitute, a thickener for soups, ice cream and as a clarifying agent in brewing, among others.

Algal toxins The cyanobacterium *Nodularia spumigenia* can produce a toxin which causes liver damage. Although no human fatalities have occurred, domestic animals have died from *Nodularia* poisoning. Some dinoflagellates phytoplankton may contain diarrhetic shellfish toxins (DST). In addition, there are other toxic dinoflagellates which can impact both wild and farmed fishes.

Alginate A viscous gum that is abundant in the cell walls of brown algae.

Alkaline Having a relatively low concentration of hydrogen ions, thus a pH greater than 7.

Alternate states Substantial ecosystem change which may be stable or unstable, and which is typically offset by great disturbance.

Anaerobic Without oxygen or not requiring oxygen.

Anthropogenic Created, caused or affected by human.

Anoxic/ anoxia Absence of oxygen. Organisms die when oxygen concentration is below 1mg/l.

Autotrophs An organism capable of synthesizing its own food from inorganic substances. Rather than depending on other organisms for energy, (photo)autotrophs obtain energy from the sun and CO₂ from the atmosphere.

Benthic Occurring at the base of bodies of water: lakes, oceans, and seas. *Benthos* refers to life attached to the bottom or moving in the bottom mud.

Bequest value Refers to the value of maintaining some aspect of the environment for future experience or use.

Bioaccumulation The build-up of toxins in the tissues of individual organisms.

Biomagnification Because organisms at each successive trophic level must consume more biomass to meet their energy requirements, they experience an increase in contamination.

Biomarker A specific physical trait used to measure or indicate the effects or progress of a disease or detrimental condition.

Biotic compartments Factors which are living; sustaining or having sustained life.

Biodiversity The number, variety and variability of living organisms. It includes variability within species (genetic diversity), among species (species diversity) and among ecosystems (ecosystem diversity).

Bioturbator Organisms, often burrowing or boring, which stir or mix sediments.

Byssus threads Mussels use byssus threads to attach to rocks and other surfaces. The byssus is made of keratin and other proteins and constitutes a remarkable adhesive that is neither degraded nor deformed by water as are synthetic adhesives.

Carbon offsetting The act of mitigating - or offsetting - greenhouse gas emissions. A well-known example is the purchase of carbon offsets to compensate for the greenhouse gas emissions caused by personal air travel.

Carnivores A flesh-eating animal.

Carrageenan Gelatinous substance obtained from some species of red algae. Agar can be used as a laxative, a gelatin substitute, a thickener for soups, ice cream and as a clarifying agent in brewing, among others.

Chromatography Any of various techniques for the separation of complex mixtures.

Chronic anthropogenic stress Ongoing, or background human-induced stress, often resulting in less susceptibility towards acute disturbance.

CITES The Convention on International Trade in Endangered Species of Wild Fauna and Flora An international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. The CITES B-list or Appendix II includes species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival.

Convention on Biological Diversity (CBD) An international treaty that was adopted in 1992 with the goals to conserve biodiversity, promote sustainable use of its components as well as fair and equitable sharing of benefits arising from genetic resources.

Cultural environment An environment created or modified by humans. Includes anything from a building to a landscape.

Cultural heritage Includes not only the above, but also folklore, tales, tradition and any immaterial value that is passed from generations back.

Cyanobacteria Also called blue-green algae, these are prokaryotic photosynthetic organisms. Cyanobacteria may be unicellular or filamentous and some may form cells or filaments into colonies. Many species of cyanobacteria can fixate atmospheric nitrogen - that is, they can transform the gaseous nitrogen of the air into organic compounds. Under favourable conditions, cyanobacteria can reproduce at explosive rates, forming dense (surface) accumulations called blooms. Cyanobacterial blooms can colour a body of water. Cyanobacterial blooms are especially common in waters that have been polluted by phosphorus.

Decomposer An organism, often a bacterium or fungus that feeds on and breaks down dead plant or animal matter, thus making organic nutrients available to the ecosystem.

Denitrification The conversion of biologically available nitrogen to atmospheric nitrogen (N₂) by bacteria under hypoxic conditions.

Desirable and undesirable states A coarse indication of collective human attitudes and expectations towards particular system configurations.

Detritivore An organism that consumes dead organic matter.

Diatom Any member of the algal class Diatomophyceae. Tiny planktic and benthic, unicellular or colonial algae. Among the most important and prolific sea organisms, diatoms serve directly or indirectly as food for many animals.

Dinoflagellate Any of numerous microscopic, chiefly marine protists of the class Dinophyceae. Dinoflagellates characteristically have two flagella and a cellulose covering and form one of the chief constituents of plankton. They include bioluminescent species and species which form blooms. The blooms are often called red tides due to their tendency to discolour the water.

Dive park Underwater dive parks are one way to display maritime finds and ecosystem attractions.

Dolastins Compounds derived from sea squirts with potent antitumor effect.

Ecological greenlash A situation in which human action aimed at increasing the supply of a desired ecosystem service (e.g. provision of food) inadvertently degrades other ecosystem services (e.g. nutrient regulation, food web dynamics) that are essential for the provision of the desired ecosystem service; as a consequence the supply of the desired ecosystem service is reduced as well.

Ecological integrity or ecological health The capability of ecosystem to support a balanced, integrated and adaptive, community of organisms, displaying species composition, diversity, and functional organization comparable to that of natural habitats of the region, while maintaining services of value to humans.

Ecological/ energy pyramid A graphical representation of the numbers of organisms, energy relationships, and biomass of an ecosystem; numbers are high for the lowest trophic levels (plants) and low for the highest trophic level (carnivores).

Ecological memory During a disturbance – whether natural or human-induced - ecological memory is necessary to the reorganization of the ecosystem. In the marine environment ecological memory may be preserved in e.g. fish and act between distant ecosystems and over long periods of time. For example, as a result of a disturbance fish may be able to move to another ecosystem. After the disturbance has passed the fish can return with their supply of energy, nutrients and genes and contribute to the rebuilding of the system.

Ecological surprise Unexpected – and often disproportionately large – consequences of changes in the environment.

Ecosystem A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Ecosystem approach A holistic approach to ecosystem management, recognizing that humans and our socioeconomic systems constitute an integral part of ecosystems and striving to achieve sustainable use of ecosystem goods and services while maintaining ecosystem integrity.

Ecosystem services Defined as ecological processes or functions that have value to individuals or society. Many definitions stress the way in which ecosystem services both *sustain* and *fulfil* human life (267). Yet others restrict the services to originate from *natural* ecosystems (268).

Ecosystem shift A major shift in community composition, typically from being dominated by one species to being dominated by another species.

Ecotourism Travel undertaken to witness sites or regions of unique natural or ecologic quality, or the provision of services to facilitate such travel that have the least impact on biological diversity and the natural environment.

EEZ Exclusive Economic Zone The maritime zone adjacent to the territorial sea that may not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured. Within the EEZ, the coastal state has sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources, both living and nonliving, of the seabed, subsoil, and the subjacent waters.

EIA or environmental impact assessment A process applied to development proposals whereby technical studies are undertaken in order to predict the likely impact that the scheme will have on the local, regional, and global environment. The aim is to better inform the decision-making process, allow alternative proposals to be compared, and, where appropriate, promote the development of acceptable mitigation measures.

Endemic Native to or confined to a certain region.

Epiphyte Any plant that grows upon or is in some manner attached to another plant or object merely for physical support.

Essential amino acid Amino acids are organic compounds made of carbon, hydrogen, oxygen, nitrogen, and (in some cases) sulphur bonded in characteristic formations. Strings of amino acids make up proteins. The 20 essential amino acids are indispensable for the optimum animal growth but cannot be formed in the body and must be supplied in the diet.

EU Habitats Directive (92/43/EEC) The Directive dates from 1991 and constitutes the backbone of the EU's internal policy on biodiversity protection.

EU LIFE LIFE is the EU's financial instrument supporting environmental and nature conservation projects throughout the EU, as well as in some candidate, acceding and neighboring countries. Since 1992, LIFE has co-financed some 2,750 projects, contributing approximately €1.35 billion to the protection of the environment.

Eukaryote A single-celled or multi-cellular organism whose cells contain a distinct membrane-bound nucleus.

The EUROSION Project A project commissioned in 2002 by the General Directorate Environment of the European Commission. The overall objective of EUROSION was to provide the European Commission with a package of recommendations for policy-making and information management practices to address coastal erosion in Europe.

Eutrophication The deterioration of water quality due to abundant phosphorus, nitrogen, and organic growth substances. Commonly, primary production becomes excessive, resulting in a sequence of environmental problems including shading, algal blooms and spread of anoxic sea floors.

Evapotranspiration Water transpired from plants and evaporated from the land and water surfaces.

Exchange pool In this sense an exchange pool is where an element is held for a limited amount of time (as opposed to in a sink). In the biogeochemical cycle of e.g. nitrogen exchange pools include different living organisms as well as water and air.

Existence value

Refers to the value of a species or ecosystem simply by existing, without being used by society.

FAO The Food and Agriculture Organization of the United Nations.

Fish aggregating device (FAD) Any man-made object used to attract pelagic fish.

Food web dynamics All processes by which nutrients are transferred from one organism to another in an ecosystem.

Functional diversity Refers to the diversity of ecological processes.

Functional group A functional group refers to a group of organisms, regardless of taxonomic identity, that carry out the same ecological function such as grazing of epiphytes, decomposing, nitrogen fixation or filter feeding.

Functional redundancy The presence of multiple species that provide the same function.

Genetic diversity Variation within a species. Genetic diversity is the 'raw material' permitting species to adjust to a changing world, whether these changes are due to natural or human factors.

Genetic manipulation Removing, modifying or adding genes to the DNA of an organism, in order to change the information it contains, with the objective to produce desired characteristics and to eliminate undesired ones. Organisms modified by genetic engineering are referred to as *bioengineered* or *genetically modified*.

Gene probe A single-stranded DNA or RNA sequence that is specifically labelled (e.g. radioactively) and used to detect or identify another substance in a sample.

Genetic screening Testing to enable the identification of vulnerabilities to inherited diseases.

Genome The complete set of genes of an organism. The human genome for instance contains 30 000 to 40 000 genes.

GIS Geographic information system A computer application used to store, view, and analyze geographical information, especially maps.

Greenhouse gases Heat-trapping gases emitted from earth to the atmosphere. Among the greenhouse gases released by anthropogenic activities, CO₂ has received most attention.

Habitat The arrangement of objects in space – or the environment suitable for spawning, breeding, feeding or growth to maturity.

Habitat restoration The return of a habitat to its original community structure, natural complement of species and natural functions.

HELCOM The **Helsinki Commission**, or HELCOM, works to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. HELCOM is the governing body of the **Convention on the Protection of the Marine Environment of the Baltic Sea Area** - more usually known as the Helsinki Convention.

Herbivore An animal that feeds chiefly on plants.

Heterotroph An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.

High-grading Landing high-priced fish while discarding the less priced part of the catch.

Hypoxia Dearth of oxygen < 1-2 mg/l. Hypoxia makes organisms flee (if they can).

ICES International Council for the Exploration of the Seas The organisation that coordinates and promotes marine research in the North Atlantic, including the Baltic Sea and Skagerrak. 1600 scientists from 20 countries working through ICES gather information about the marine ecosystem which is then developed into unbiased, non-political advice.

Intraspecific Among individuals of the same species.

IMO International Maritime Organisation The specialized agency of the United Nations. IMO's main task is to develop and maintain a comprehensive regulatory framework for shipping.

Indicator species Organisms that, by their presence, abundance, or chemical composition, demonstrate a distinctive aspect of the character or quality of the environment.

Integrated multi-trophic aquaculture (IMTA) A practice in which the by-products (wastes) from one species are recycled to become inputs (fertilizers, food) for another. Fed aquaculture (e.g. fish, shrimp) is combined with inorganic extractive (e.g. seaweed) and organic extractive (e.g. shellfish) aquaculture to create balanced systems for environmental sustainability and economic stability (product diversification and risk reduction) and social acceptability (better management practices).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments The convention was adopted in 2004 and comprises all ships in international traffic. On board these ships the ballast water shall be exchanged in areas where the depth is at least 200 m at a minimum distance of 50 nautical miles from shores, or treat the ballast water by approved treatment systems preventing harmful species and pathogens to exceed stipulated limits. Due to limited depth in both the Baltic Sea and Skagerrak, Sweden cannot fully comply with the requirements of the Ballast Water Convention until 2016, when all ships are required to provide internal systems of ballast water handling.

Invasive alien species A non-indigenous species that, by movement by human agency, has been introduced outside its natural distribution and whose introduction and/or spreading threatens indigenous species or habitats.

IPCC Intergovernmental Panel on Climate Change Established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988. IPCC's role is to determine the impact of and possible responses to climate change. In 2007 the IPCC shared, with Al Gore, the Nobel Peace Prize for disseminating knowledge about man-made climate change.

IUCN International Union for the Conservation of Nature and Natural Resources The world's main authority on the conservation status of species.

IUCN Red List of Threatened Species (1963) The red list is the world's most comprehensive inventory of the global conservation status of plant and

animal species. The list is based upon precise criteria to evaluate the extinction risk of thousands of species and subspecies. These criteria are relevant to all species and all regions of the world. The aim is to convey the urgency of conservation issues to the public and policy makers, as well as help the international community to try to reduce species extinction.

Keystone Species The keystone in an archway is a wedge-shaped stone at the top of the arch. Its position is extraordinarily important: if the keystone is removed, the arch will collapse. In ecology, the term keystone species has become an often-used metaphor referring to a species playing a critical role in the food web or ecosystem.

Kyoto protocol The **Kyoto Protocol to the United Nations Framework Convention on Climate Change** The international treaty from 1997 that aimed to reduce the emission of gases that contribute to global warming. In force since 2005, the protocol called for reducing the emission of six greenhouse gases in 36 countries to 5.2 % below 1990 levels in the commitment period 2008 - 2012.

Life cycle analysis (LCA) A systematic tool addressing environmental impact throughout the entire life cycle of a product, process or activity.

Littoral Coast- or shore-.

Marine vs. maritime Marine refers to anything native to, inhabiting, or formed by the sea. Maritime refers to matters related to marine shipping or navigation.

Marine sediment extraction The removal of sand, gravel, stones and other sediments from the sea bed for purposes such as construction, beach nourishment, landfill or as industrial raw material.

Metabolism The chemical processes occurring within a living cell or organism that are necessary for the maintenance of life. In metabolism some substances are broken down to yield energy for vital processes while other substances, necessary for life, are synthesized.

Methionine An essential sulphur-containing amino acid.

Nature's Best (Naturens Bästa) A quality labelling of tourism developed by the Swedish Ecotourism Association, Swedish Society for the Conservation of Nature and VisitSweden.

Nitrification The oxidation of an ammonia compound into nitric acid, nitrous acid, or any nitrate or nitrite, especially by the action of bacteria.

Nutrients The necessary building blocks of various cell components that certain organisms cannot synthesize and therefore must obtain preformed.

Omega-3 fatty acids Polyunsaturated fatty acids found in leafy green vegetables, vegetable oils, and fish such as salmon and mackerel, capable of reducing serum cholesterol levels and having anticoagulant properties

Omnivores An organism with wide food-preferences including both plant and animal resources.

Oslo-Paris Convention (OSPAR) The 1992 OSPAR Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. The work under the convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 countries as well as the European Commission, representing the European Community.

Otolith Fish hearing organ.

Petri dish A shallow circular dish with a loose-fitting cover, used to culture bacteria or other microorganisms.

pH A quantitative measure of the acidity or basicity (alkalinity) of water. A solution with pH less than 7 is considered acidic; a solution with pH greater than 7 is considered basic, or alkaline.

Photosynthesis

Solar energy + CO₂ + H₂O + nutrients => organic material + O₂

Phylum – phyla One of the major divisions of the kingdoms of living things; the second-largest standard unit of biological classification. The best known animal phyla are the Mollusca, Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Arthropoda, Echinodermata, and Chordata, the phylum to which humans belong. Although there are approximately 35 phyla, these nine include the majority of the species.

Phytoplankton (Photo)autotrophic microscopic marine algae including diatoms, dinoflagellates and coccolitophorids.

Plankton Plankton is a common name for marine organisms (plants, animals and bacteria) living in the water column which can not actively move to any great extent. Some plankton are unicellular (one cell only) while others are multicellular. They vary in size from microscopic phytoplankton (belonging to the plant kingdom) to large jellyfish and drifting sunfish (*Lumpus lumpus*). A number of marine organisms, like mussels, crustaceans and fish, start their life as plankton, only to become mobile, and often benthic, with increasing size.

Precautionary approach places the burden of proof on the proponents of an activity, i.e. it is not appropriate to assume that environmental impacts are negligible until proved otherwise.

Precautionary Principle “Where there are threat of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (269).

Predator An organism that lives by preying on other organisms.

Predatory release Decrease in predation pressure leading to increased abundance.

Primary production The production of organic compounds from CO₂, principally through the process of photosynthesis. Measurements of primary production are typically expressed as the weight of carbon per square meter (mg C/ m²). Primary production can also be estimated from the amount of chlorophyll-a (a pigment present in all phytoplankton) in the water, typically expressed as mg Chl/ m² or µg Chl/ litre.. Finally, comparative measures of production can be inferred from water clarity – typically measured with an instrument called the Secchi disc.

Primary productivity A measurement of the amount of carbon incorporated into cellular material per unit area of ocean *per day*.

PSSA Particularly Sensitive Sea Area According to IMO, an area sensitive to the potential impact of maritime activity. Furthermore it is of ecological, socioeconomic and/or scientific importance. The PSSA label enables strict rules on maritime safety. All release of toxic substances is for example illegal. Some areas in a PSSA may become closed to shipping while others require the use of pilots. However, the PSSA classification cannot address safety aspects of ship construction.

REACH EU's chemical legislation, REACH, came into force on 1 June 2007. REACH is a European Community regulation and applies directly in Sweden. It replaces a great number of other EC rules, which in main have had the form of directives and, thus, been implemented into Swedish legislation. These rules will be changed or abrogated concurrently with the step-wise entry into force of the various parts of REACH.

Reproductive stock The amount of reproductively mature individuals within a defined fish stock (often expressed in biomass).

Reservoir or sink Where an element is kept for an extended period of time, like deposits of fossil carbon and sediments harbouring e.g. phosphorus.

Resilience The ability of a system to absorb disturbance, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance.

Selective breeding The breeding of animals or plants with desirable characters.

Sequencing In genetics and biochemistry, sequencing means to determine the primary structure (or primary sequence) of DNA.

Species diversity A function of the number of species and individuals (of respective species) per given area.

Species Protection Ordinance (1998:179) This ordinance contains provisions governing capture, killing, taking from the wild, trade and other actions involving specimens of animal and plant species in need of protection or that may constitute a threat to live specimens of such species.

The Swedish Taxonomy Initiative (Svenska Artprojektet) The Swedish Species Information Centre (ArtDatabanken) was in 2001 commissioned by the government to develop keys for the identification of all Swedish multisel-

lular organisms, approximately 50 000 species. This project, designed to run for 20 years, will result in a considerable improvement of the infrastructure of Swedish taxonomy.

Sustainability To meet the needs of the present without compromising the ability of future generations to meet their own needs. Definition from the 1987 *Brundtland report*.

Synergy effects Two or more discrete influences or agents acting together create an effect greater than that predicted by knowing only the separate effects of the individual agents.

Threshold A breakpoint between two regimes or states of a system.

Top-down versus bottom-up control In some ecosystems the structure is controlled by the top predators (top-down). In others the ecosystem is regulated by the primary producers (bottom-up).

Top predator As adults, top predators are not normally preyed upon in the wild in significant parts of their ranges.

Trophic cascades Effects on various levels of the food chain due to the alteration at one level.

Umbrella service Like the umbrella species, the umbrella service is one, which if carefully managed can result in the maintenance of others.

Umbrella species A wide-ranging species whose requirements include those of many other species. Thereby the protection of umbrella species automatically extends protection to other species.

VMS or Vessel Monitoring System uses electronic transmitters, placed on fishing vessels that transmit information about the vessel's position to enforcement agencies via satellite. This allows someone on land, monitoring such transmissions, to determine if a vessel is in a closed area.

List of abbreviations

CBD Convention on Biological Diversity
CITES Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMAS World Underwater Federation
GDP Gross Domestic Product
BRF Brominated flame retardants
BSAP Baltic Sea Action Plan
DDT Dichloro-Diphenyl-Trichloroethane
EEZ Exclusive Economic Zone
EIA Environmental impact assessment
EU European Union
FAD Fish aggregating device
FAO Food and Agriculture Organization of the United Nations
GIS Geographic information system
GIWA Global International Waters Assessment
GMF Gothenburg Marine Research Centre
HELCOM Helsinki Convention
ICES International Council for the Exploration of the Seas
IMO International Maritime Organisation
IMTA Integrated multi-trophic aquaculture
ITQ Individually traded quota
IPCC Intergovernmental Panel on Climate Change
IUCN International Union for the Conservation of Nature and Natural Resources
LCA Life cycle analysis
MA Millennium Ecosystem Assessment
MW Megawatt
N Nitrogen
NAUI National Association of Underwater Instructors
NO_x Nitrogen oxide
OPAB Oljeprospektering AB
OSPAR Oslo-Paris Convention
P Phosphorus
PADI Professional Association of Diving Instructors
PCB Polychlorinated biphenyls
PFC Perfluorinated substances
PSSA Particularly Sensitive Sea Area
SBF Swedish Board of Fisheries
SEPA Swedish Environmental Protection Agency
SGU Geological Survey of Sweden
SMF Stockholm Marine Research Centre
SMHI Swedish Meteorological and Hydrological Institute
SO_x Sulphur oxide
STD Sexually transmitted disease

SWOT Strengths, Weaknesses, Opportunities and Threats

TAC Total allowable catch

TBT Tributyltin

TW Terawatt

TURF Territorial use right in fisheries

UCH Underwater Cultural Heritage

UMF Umeå Marine Research Centre

UNDP United Nations Development Programme

UNEP United Nations Environmental Programme

VMS Vessel Monitoring System

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Appendix I. Summarized status of all considered ecosystem services

SUPPORTING SERVICES

S1: Biogeochemical cycling

Status	Moderate
Sustainability of use	-
Level of threat	Moderate
Expected consequences	Severe

S2: Maintenance of primary production

Status	Good
Sustainability of use	-
Level of threat	Low
Expected consequences	Limited

S3: Maintenance of food web dynamics

Status	Poor
Sustainability of use	-
Level of threat	High
Expected consequences	Severe

S4: Maintenance of biodiversity

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Unknown

S5: Maintenance of habitat

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Severe

S5: Maintenance of resilience

Status	Moderate
Sustainability of use	-
Level of threat	High
Expected consequences	Unknown

REGULATING SERVICES

R1: Climate and atmospheric regulation

Status	Good
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Severe

R2: Sediment retention

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Moderate

R3: Mitigation of eutrophication

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

R4: Biological regulation

Status	Good
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

R5: Control of hazardous substances

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Moderate

PROVISIONING SERVICES

P1: Provision of food fit for consumption

Status	Poor
Sustainability of use	Unsustainable
Level of threat	High
Expected consequences	Severe

P2: Provision of inedible goods

Status	Good?
Sustainability of use	Unsustainable
Level of threat	Moderate
Expected consequences	Moderate

P3: Provision of genetic resources

Status	Unknown
Sustainability of use	Sustainable
Level of threat	High
Expected consequences	Unknown

P4: The provision of marine resources for the pharmaceutical, chemical, and biotechnological industry

Status	Unknown
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Unknown

P5: Provision of ornamental resources

Status	Good
Sustainability of use	Sustainable
Level of threat	Limited
Expected consequences	Limited

P6: Provision of energy

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

P7: Provision of space and waterways

Status	Good
Sustainability of use	Sustainable?
Level of threat	Low
Expected consequences	Limited

CULTURAL SERVICES

C1: Enjoyment of recreational activities

Status	Moderate
Sustainability of use	Unsustainable?
Level of threat	Moderate
Expected consequences	Moderate

C2: Enjoyment of scenery

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

C3: Contribution to education and scientific information

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

C4: Maintenance of cultural heritage

Status	Moderate
Sustainability of use	Sustainable
Level of threat	Moderate
Expected consequences	Limited

C5: Inspiration for art and advertisement

Status	Good
Sustainability of use	Sustainable
Level of threat	Low
Expected consequences	Limited

C6: The preservation of nature for ethical reasons

Status	Moderate
Sustainability of use	Sustainable
Level of threat	High
Expected consequences	Limited

Ecosystem services provided by the Baltic Sea and Skagerrak

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What are ecosystem services? Which services are provided by our marine and coastal environment? To which extent do we use them? How do our activities threaten them? And what can we do to maintain or restore them?

Many of us know little about ecosystem services, let alone are we aware of their values or the extent to which we use them. The perception that the benefits obtained from nature is for free has no doubt resulted in an under-estimating and over-using natural resources. Yet, some ecosystem services are life-supporting; others create major economic opportunities for vast numbers of people. Least recognised are those, not readily quantified, which add to our sense of place, our health and our cultural identity. What they all have in common is that they, at large, are likely to be irreplaceable.

This report defines and describes the extent to which we use 24 benefits, or services, obtained from the Baltic Sea and Skagerrak. Translating marine biodiversity, and its prerequisites, into services or functions of economic or societal value, makes it more readily understood and hence more likely to be incorporated into decision-making processes. Provided with increased knowledge stakeholders are better prepared to make the best possible use of our marine and coastal resources.

The report is part of the project Economic Marine Information assigned by the Swedish Government

