REPORT

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MARINE FEEDSTOCK BASED BIOFUELS AND ECOSYSTEM SERVICES

Report from a project within the collaborative research program *Renewable transportation fuels and systems*

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Left: Cultivation of sea squirts (source: Marin Biogas AB). Right: Rope cultivation of sugar kelp (source: algolesko.com).

Authors: Karin **Hansen** (IVL), Roman **Hackl** (IVL), Susanne **Ekendahl** (RISE), Johan **Engelbrektsson** (RISE), Julia **Hansson** (IVL) and Anna-Sara **Krång** (IVL)

THE SWEDISH KNOWLEDGE CENTRE FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This project has been carried out within the collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system), Project no. 43679-1. The project has been financed by the Swedish Energy Agency and f3 – Swedish Knowledge Centre for Renewable Transportation Fuels.

f3 Swedish Knowledge Centre for Renewable Transportation Fuels is a networking organization which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities
- Carries through system oriented research related to the entire renewable fuels value chain
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

The project group has been supported by a reference group consisting of Fredrik Norén (N-Research), Jessica Hjerpe Olausson (Maritime Cluster of West Sweden, Region Västra Götaland) and Sofie Allert (CEO Swedish Algae Factory). The reference group has audited the report and provided valuable comments to both content and language. Also, the report has been audited by a researcher at IVL according to IVL's rules of auditing.

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SUMMARY

Ecosystem services are based on a human perspective and are among others defined as “conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life”. Sustainability assessments and numerous national and international policy decisions and action plans often prioritize climate change mitigation, particularly in relation to the transformation of the transportation sector towards sustainable modes of transport and fuel systems. Biofuels for transportation have the potential to provide sustainable alternatives to fossil fuels, if the links between biofuels production and ecosystems services and other environmental impacts are properly understood and considered.

Marine feedstocks are depicted as interesting alternatives to more traditional biofuels produced from agricultural crops or forest residues since they require little or no land area and thus do not compete with land based food production. However, prior to full-scale production, a complete sustainability assessment is needed, screening possible impacts of marine-based biofuel production. For this, there is a need to identify the different ecosystem services affected. This project aims at identifying and describing the ecosystem services which are affected by the production of marine feedstock based biofuels in Sweden and to pinpoint appropriate indicators for these.

Two out of several potential marine feedstocks for biofuels production that can be cultivated in Sweden, namely the macroalgae sugar kelp and sea squirts are investigated further. The report provides a summary of the potential impacts of the intensification of marine biomass production for biofuel production on ecosystem services from a Swedish perspective, identifying affected ecosystems services and defining appropriate indicators to measure changes. This is followed by a qualitative assessment of the consequences of large scale marine biomass cultivation on provisional, regulating and maintenance, and cultural ecosystem services.

The impact of intensified production of biomass from macroalgae and sea squirts on provisioning ecosystem services is overall positive. For example, the amount of wild fish and the production of feed, sustainable energy from biomass and fertilizers may increase. Cultures of macroalgae and sea squirts may however impact other aquacultures of for example mussels. The impacts of the biomass production on the regulating and maintenance ecosystem services are both positive and negative. For example microalgae and sea squirts have potential to counteract eutrophication by building up nitrogen and phosphorous in tissue which is removed by harvest. Also, climate change can be mitigated when biofuels from marine biomass replace fossil fuels. On the other hand, large scale aquacultures may lead to low resilience and the dispersal of pests. Lastly, the cultural ecosystem services such as recreation as well as physical and mental health may be affected negatively through for example decreased beauty around aquacultures. However, new jobs may be created having a positive influence on the coastal communities.

The qualitative and semi-quantitative valuation provided in this report helps to improve our understanding of the implications of biofuel production from marine feedstocks on ecosystem services. This is an important first step to enable informed and well-thought-out decisions regarding sustainable biofuel production based on marine feedstocks.

SAMMANFATTNING

Ekosystemtjänster betraktas ur människans perspektiv. En av flera definitioner på ekosystemtjänster är att dessa är ”förutsättningar och processer genom vilka naturliga ekosystem och arter som utgör dessa upprätthåller och fullgör mänskligt liv”. Hållbarhetsbedömningar och ett flertal nationella och internationella policybeslut och färdplaner prioriterar minskad klimatpåverkan, specifikt när det gäller transportsystemets omvandling mot hållbara transportslag och bränslesystem. Biodrivmedel har potential att utgöra hållbara alternativ till fossila bränslen inom transportsektorn om drivmedelsproduktionens påverkan på ekosystemtjänster och andra miljöpåverkan tas hänsyn till.

Produktion av biodrivmedel med biomassa från havet undersöks som ett intressant alternativ till biodrivmedel från skogsrester och jordbruksgrödor, eftersom odlingen inte utnyttjar odlingsbar mark i konkurrens med odling av livsmedelsgrödor. För att kunna fastställa den övergripande hållbarheten vid en eventuell framtida ökad produktion av havsbaserade drivmedel krävs dock en kartläggning av olika sociala följder och miljökonsekvenser kopplade till produktionen. I detta sammanhang är kunskap om de ekosystemtjänster som påverkas av produktionen av biodrivmedel viktig. Syftet med projektet är därför att kartlägga och beskriva dessa ekosystemtjänster, och de indikatorer som bäst beskriver dem, vilket kommer utgöra ett viktigt beslutsunderlag vid en eventuell intensifiering av havsbaserad biodrivmedelproduktion.

Två ut av flera potentiella marina råvaror för framställning av biodrivmedel som kan odlas i Sverige är makroalger (sockertång) och sjöpungar. Rapporten ger en sammanfattning av potentiell påverkan på ekosystemtjänster vid en intensifiering av marin biomassaframställning från dessa arter för biobränsleproduktion ur ett svenskt perspektiv. Detta görs genom att identifiera ekosystemtjänsterna som potentiellt påverkas och definiera lämpliga indikatorer för att mäta dessa förändringar. Därefter presenteras en kvalitativ analys av påverkan av storskalig odling av marin biomassa på försörjande, reglerande och underhållande samt kulturella ekosystemtjänster.

Konsekvenserna av ökad odling av makroalger och sjöpungar på försörjande ekosystemtjänster är huvudsakligen positiva. Till exempel kan mängden vild fisk och produktionen av foder, energi och gödsel öka samtidigt. Akvakulturer av makroalger och sjöpungar kan dock negativt påverka andra akvakulturer som till exempel av musslor. Effekterna på reglerande och stödjande ekosystemtjänster av odlingar av makroalger och sjöpungar i havet är både positiva och negativa. Odlingar har till exempel potential att motverka övergödning genom att ta bort kväve och fosfor från vattnet genom skörd. Däremot kan storskaliga odlingar leda till låg resiliens och spridning av skadedjur. Slutligen kan kulturella ekosystemtjänster som rekreation samt fysisk och mental hälsa påverkas negativt till exempel genom att odlingarna stör havsvyerna. Emellertid kan det skapas nya jobb som kan ha positiv inflytande på landsbygden.

Den kvalitativa och semi-kvantitativa värderingen av ekosystemtjänster som presenteras i rapporten leder till en förbättrad förståelse av hur biodrivmedelsproduktion baserad på marina råvaror påverkar ekosystemtjänster. Detta är ett viktig första steg till att möjliggöra genomtänkta beslut angående hållbar biodrivmedelsproduktion som är baserad på marina råvaror.

CONTENTS

ABBREVIATIONS

CICES	Common International Classification of Ecosystem Services
CO_2	Carbon dioxide
DME	Dimethyl ether
FAME	Fatty acid methyl ester
FAO	Food and Agriculture Organization of the United Nations
HTL	Hydrothermal liquefaction
MEA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment of Ecosystems and their Services
RED	Renewable Energy Directive
TEEB	The Economics of Ecosystems and Biodiversity

1 INTRODUCTION

A reduced use of fossil fuels within the transport sector is a necessity if we should meet exacerbating climate change. Climate change mitigation is prioritized in numerous national and international policy decisions and action plans, particularly in relation to the transportation sector. In Sweden, the use of biogas to replace fossil transportation fuels is widely adopted. In 2015, approximately 1.95 TWh (corresponding to 7,010 TJ) of biogas was produced in Sweden, of which approximately 63% was used as transportation fuel (Energigas Sverige, 2016).

The EU Renewable Energy Directive (RED) promotes the use of energy from renewable energy sources (European Union, 2009) and includes criteria for a sustainable production of renewable biofuels. A transition from fossil based fuels to more renewable energy sources and biofuels is thus prioritized and new renewable biomass products are being developed. The biofuel industry is constantly searching for sustainable and cost-efficient alternatives to fossil fuels in order to further intensify production and improve economic and environmental performance of biofuels.

Biofuels developed from waste or from lignocellulosic and aquatic biomass, offer promising performance in regards to economic, ecological and societal sustainability. They offer potentially interesting alternatives to more traditional biofuels produced from agricultural crops or forest residues since they do not compete with land based food production, require less land area and do not require use of fertilizers (Alvarado-Morales et al., 2013; Demirbas, 2010; Demirbas and Faith Demirbas, 2011; Radakovits et al., 2010). Today, a substantial amount of research is directed towards producing marine substrates for use as biofuels (Clarens et al., 2011), including marine macroalgae, green algae and diatoms, sea squirts, and sludge from fish cultivations systems (Tonderski, 2016). Marine cultivation systems that combine cultivation of different types of biomass (algae, sea squirts and fish farming) are also under development. The Swedish aquatic bioenergy potential from macro- and microalgae was estimated to approximately 0.6 to 1.5 TWh per yr (2,160-5,400 TJ per yr) by the year 2050 (Börjesson, 2016).

An increased production of marine biofuels could lead to less climate loads (Hackl et al., 2017). However, the risk that an intensified production of marine biofuels will have negative impact on marine ecosystems through changes of habitat and species abundance is currently being discussed (Fargione et al., 2010; Gasparatos et al., 2012; Hellmann and Verburg, 2010; Koh, 2007; Scharlemann and Laurance, 2008; Wiens et al., 2011). Therefore, prior to full-scale production, an all-embracing sustainability assessment is required, screening possible impacts of marine-based biofuel production (Bringezu et al., 2009). For this, there is a need to identify the different ecosystem services potentially being affected. This project aims at identifying and describing ecosystem services and appropriate indicators that are affected by production of marine feedstock based biofuels in Sweden.

2 AIMS AND TARGETS

The overall aim of this project is to synthesize and assess the current knowledge about potential impacts on ecosystem services as a result of an intensification of marine biofuel production.

The specific targets of the project are to:

- identify and describe the ecosystem services that may be affected by an intensified marine based biofuel production in Sweden;
- identify appropriate indicators to assess changes in these identified ecosystem services;
- identify knowledge gaps and recommend future scientific development;

This report presents the approach and outcome of the project. The focus is on impacts of marine biomass production for biofuel on ecosystem services in a Swedish perspective but with an outlook to the rest of the world. We concentrate on macroalgae and sea squirts as case studies. Marine feedstock may be cultivated in tanks on-land, but we only consider feedstocks grown in marine environments. As in the case of all environmental impact, the impact may be allocated between different products. However, allocation principles lie outside the scope of this project.

3 APPROACH

In order to identify and describe the ecosystem services that are affected by an intensified Swedish biofuel production based on marine feedstock, as well as appropriate indicators related to those, the following tasks were performed:

- A literature review was carried out in order to gain knowledge on ecosystem services related to marine biofuel production. Swedish and international literature was included.
- The ecosystem services concept is described in general terms (Chapter 4).
- Swedish marine ecosystem services are listed in general (Chapter 5), described in more detail and appropriate indicators capable of showing changes in these ecosystem services are identified (Chapter 5).
- The use of macroalgae and sea squirts for production of marine based biofuels for transport is introduced and described (Chapter 6).
- Potential changes in ecosystem services as an effect of intensified production of biomass of macroalgae and sea squirts are described with reference to zero production. Possible actions to mitigate these potential changes are suggested. Whether sufficient data exist to describe changes in ecosystem services is discussed (Chapter 7).
- Gaps in knowledge in order to enhance the future use of ecosystem services in planning, management and recommendations are discussed and conclusions are outlined (Chapter 8).

4 ECOSYSTEM SERVICES IN GENERAL

As part of the national environmental goals, the Swedish Government has established a milestone target to considerably improve the knowledge about ecosystem services and promote their integration in political and economic decisions by 2018 (SOU, 2013). As a result of the increased political interest, in 2013, the Government commissioned the Stockholm Resilience Centre to investigate how ecosystem services should be valued and integrated in economic resolutions as well as political and societal decisions (SOU, 2013). This further led to a Governmental proposition in March 2014 (Regeringen, 2014), where a strategy for strengthening biodiversity and ecosystem services was presented. The actions taken by the Swedish Government is in line with the global work on tackling changes in biodiversity and ecosystem services according to the Aichi biodiversity targets and the strategy on biodiversity and ecosystem services in EU (European Union, 2011).

The increasing relevance of ecosystem services in Sweden, and more broadly in the EU, will likely have a strong impact on the biofuel sector in the future since it is already influenced by sustainability criteria. It is, therefore, of paramount importance for the biofuel sector to reach an improved understanding of the link between biofuel production and ecosystem services, in order to be better prepared for potential future challenges and move to an efficient and sustainable production and use of biomass.

This chapter shortly summarizes background knowledge on ecosystem services. We otherwise refer to previous reports by Hansen et al. (2014, 2016a, b) and the SOU (2013) where the concept of ecosystem services is described in more detail.

4.1 DEFINITION OF THE CONCEPT

The ecosystem services approach is used increasingly in environmental sciences. It is becoming a common concept used to describe all goods and services provided by nature. In the Millennium Ecosystem Assessment report (MEA, 2005) the concept is described as “the benefits people obtain from ecosystems”. Earlier, Daily (1997) specified the concept in more detail as “conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life”. Several other definitions exist; hence, the concept is not defined with one precise agreed definition (Nahlik et al., 2012).

The term ecosystem services initially appeared in a peer-reviewed paper 1983 (Ehrlich and Mooney, 1983). More than 10 years went by before the concept was again brought up in scientific publications (Costanza et al., 1997; Daily et al., 1997) stressing the importance of all services we receive from different ecosystems that often are taken for granted. The publication of the MEA (2005) managed to raise further awareness on ecosystem services through a reexamination of the status of the global ecosystems and pointing to how changes influence human life. Henceforward, an almost exponential increase in publications on the concept of ecosystem services took place (Vihervaara et al., 2010; Dick et al., 2011; Potschin and Haines-Young, 2011; Tuvendal, 2012). The dicussions and use of the ecosystem services concept are therefore a relatively new focus area and the knowledge on how to quantify the services, analyze synergies and trade-offs between services as well as economically price ecosystem services is relatively limited.

4.2 CLASSIFICATION OF ECOSYSTEM SERVICES IN MARINE ECOSYSTEMS

Different classification systems, or frameworks, are used to sort ecosystem services into classes to supply a logical identification. Considerable efforts have been made in order to classify ecosystem services at different scales (Yang et al., 2013; Nelson et al., 2009; Power, 2010). However, there are diversified opinions on how ecosystem services are best categorized. Four main efforts of classification have contributed to advance the assessment of multiple ecosystem services at the global scale: MEA (2005), TEEB (2009), CICES (Haines-Young and Potschin, 2013) and FEGS-CS (Landers and Nahlik, 2013; see list of abbreviations). Basically, they are not widely different and they build on to each other. They all include provisioning, regulating and cultural ecosystem services. The frameworks mainly differ on the practice for defining supporting services. Nahlik et al. (2012) review some additional frameworks described in literature and points at the wish for a unified classification.

Hansen et al. (2016b) previously reviewed the four major frameworks in order to identify the most appropriate one to address the impacts of biofuel production on ecosystem services. We here follow their example and work with the CICES (v. 4.3) classification scheme (Table 1) incorporating the Cascade model (Figure 1). This since its hierarchical structure allows detailed specification of impacts for each level of the chain of biofuel production; from ecosystem structure to benefits and value to human beings, using indicators for each level. Moreover, the CICES classification scheme is currently the most used framework internationally. We use the existing CICES classification scheme, but have adapted it to fit a Swedish perspective which is common in national ecosystem assessments (Brouwer et al., 2013).

Table 1. The CICES (v. 4.3) classification of ecosystem services (after Haines-Young and Potschin, 2013).

Section	Division	Group
Provisioning	Nutrition	Biomass
		Water
	Materials	Biomass, Fibre
		Water
	Energy	Biomass-based energy sources
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota
		Mediation by ecosystems
	Mediation of flows	Mass flow
		Liquid flows
		Gaseous/air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
		Pest and disease control
		Soil formation and composition
		Water conditions
		Atmospheric composition and climate regulation
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes (environmental settings)	Physical and experimental interactions
		Intellectual and representational interactions
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes	Spiritual and/or emblematic
		Other cultural outputs

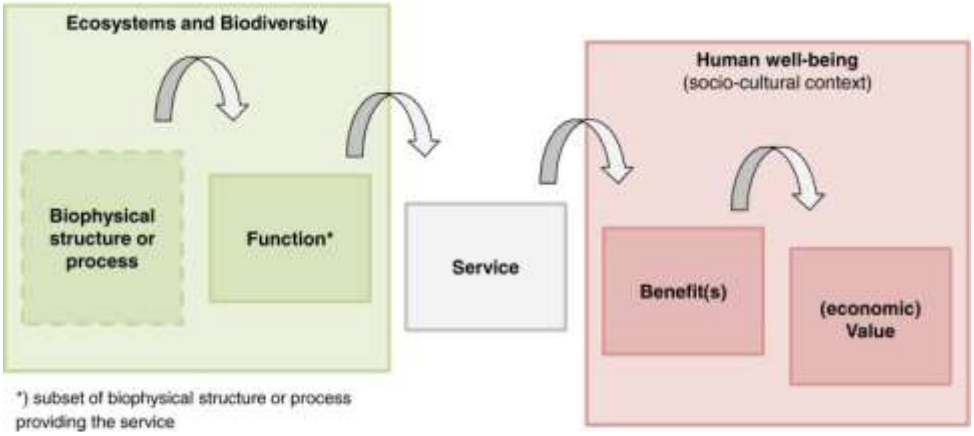

Figure 1. The connection between biodiversity, ecosystem function and human well-being in the Ecosystem Service Cascade model used in CICES (Hansen and Pauleit, 2014 who adapted it from Haines-Young and Potschin, 2013).

4.3 THE CICES CLASSIFICATION AND THE ECOSYSTEM SERVICE CASCADE MODEL

The CICES classification was developed in close cooperation with the European Environment Agency (EEA) between 2009 and 2011 alongside and shortly after the TEEB classification was published. CICES attempts to use the same nomenclature as in MEA (2005) and TEEB (2009). CICES divides services into three sections: provisioning, regulating and maintenance, and cultural services having eight divisions and 20 groups (Table 1). The last version of the CICES (v.4.3) classification is described by Haines-Young and Potschin (2013) and on the CICES web site (https://cices.eu/). CICES has been adopted at the EU level by the Mapping and Assessment of Ecosystems and their Services (MAES) which forms part of the European Union’s Biodiversity 2020 Strategy (Maes et al., 2013).

Haines-Young and Potschin (2010, 2013) presented the ecosystem services in an organization scheme called the Ecosystem Service Cascade Model (Figure 1). The sequence is described as biophysical structures (and processes) produced by organisms in ecosystems, which create possibilities for the ecosystems to function in a way that generate concrete services, which again leads to benefits for beneficiaries and the monetary values that these benefits might have to people.

4.4 INDICATORS FOR ECOSYSTEM SERVICES

We use the Ecosystem Service Cascade Model to define indicators for all ecosystem services. A suitable indicator for an ecosystem service is a measurable or quantifiable variable which makes it possible to compile important and appropriate data providing facts and statistics on the condition of a given ecosystem service. It also supplies information on possible changes in a service, for example as an effect of climate change, or changes in management strategies (Efroymson et al., 2013; Dale et al., 2013; Dale et al., 2015). In the following chapter we identify ecosystem services for marine ecosystems and suggest suitable indicators for each of the ecosystem services through a qualitative description of each of the services using the Ecosystem Service Cascade Model.

5 MARINE ECOSYSTEM SERVICES

The seas are rich in biodiversity and food and provide a large part of the global oxygen production. They supply recreation possibilities and offer a range of other ecosystem services. Thus, the seas are a central and crucial provider of ecosystem services with large values for the population and the sustainability of these services are crucial for humanity at large. In Europe, good environmental status across Europe's marine environment is regulated as part of the Marine Strategy Framework Directive (European Union, 2008) which was partly revised in 2017 to include criteria and methodological standards to help Member States implement the Marine Directive. The Marine Strategy Framework Directive does not, however, mention marine ecosystem services.

We have based our analysis on the lists of ecosystems services provided by the sea, which were identified by the Swedish Environmental Protection Agency (2008, 2009) and the Swedish Agency for Marine and Water Management (2015). These reports base their comprehensive discussions on ecosystem services in the Swedish seas on the MEA (2005) framework. We adapted their lists of marine ecosystem services using the CICES classification, separating them into provisioning, regulating and maintenance, as well as cultural services according to Haines-Young and Potschin (2010). We did this since the CICES framework is more used in global and European work on ecosystem services today than the MEA framework. As such the updated ecosystem list adapted to CICES can be used in marine feedstock based biofuels issues internationally in the future.

Based on a literature review of reports and scientific peer-reviewed articles, accessible knowledge on ecosystem services in connection to marine feedstocks and production of biofuels is summarized. The quest for literature was performed querying science direct, google, and google scholar mentioning keywords such as "ecosystem services", "ecosystem service valuation" as well as "ecosystem service framework" both in combination with and without the search words "marine", "biofuels", "algae", "tunicates" and "sea squirt".

We identified 28 marine ecosystem services and developed indicators for each of the four cascade-levels for all services (Table 2). This comprehensive matrix of services and indicators for marine environmental state and human well-being can be used to relate the production of marine feedstock based biofuels to ecosystem services.

Table 2. Ecosystem services in Swedish marine ecosystems and relevant indicators categorized using CICES v4.3 and the Ecosystem Service Cascade Model.

CICES			CASCADE Indicators			
Class	**Division**	**Ecosystem service**	**Structure (spatial)**	**Function (temporal)**	**Benefit**	**Value [SEK]**
Provisioning services	**Nutrition**	Wild fish, mussels, oyster, shellfish	Area for catch [ha]	Population [n/km^2]; Annual production [t/yr]	Annual landings [t/yr]; Consumption [t/yr]; Employment in fishing industry [n]	Market value; Health value; Value of employment in fishing industry
		Cultivated fish, mussels, oyster, shellfish	Area for catch [ha]	Population [n/km^2]; Annual production [t/yr]; Annual use of feed [t/yr]	Annual yields [t/yr]; Consumption [t/yr]; Employment in production [n]	Market value; Health value; Value of employment in production; Feed value
		Algae, sea weed	Area of habitats [ha]	Population [n/km^2]; Annual production [t/yr]	Annual yields [t/yr]; Consumption [t/yr]	Market value; Health value
		Seabird	Area of habitats [ha]	Population [n/km^2]; Annual production [t/yr]	Annual yields [t/yr]; Meat consumption [t/yr]; Employment [n]	Market value of meat; Health value
		Feed (fish meal, mussel powder, other by-products etc.)	Area of habitats [ha]	Annual production [t/yr]	Protein feed produced [t/yr]	Market value; Meat production
	Materials	Reed for fertilizers, building materials	Area of habitats [ha]	Annual production [t/yr]	Annual yields [t/yr]	Market value;
		Algae for agar-agar production and beauty treatments	Area of habitats [ha]	Population [n/km^2]; Annual production [t/yr]	Annual yields [t/yr]	Market value; Health value
		Chemical resources (antibiotics, glue, plastic)	Area of habitats [ha]	Annual production [t/yr]	Annual yields [t/yr]	Market value; Health value
		Driftwood, mussels, shells, amber used in art, handicraft and decoration	Productive area (beach, sea bottom, coast) [ha]	Annual feedstock production (raw driftwood, etc) [t/yr]	Annual yields [t/yr]	Market value; Value of employment in production
		Genetic resources	Area of gene reserve habitat [ha]	Amount of red-listed species [n/yr]; Variety in species [n/yr]	Breeding; Discovery potential; Genetic variance for future use	Market value for resources
	Energy	Biomass for energy	Area for production [ha]	Annual growth of biomass [t/ha]	Harvest [m^3/yr]; Yields of energy crops [t/ha or MJ/ha]; Employment in bioenergy sectors [n]	Value of employment in bio-energy sectors; Health value when fossil fuels are substituted; Avoided costs of air quality im-

						provement; Intrinsic value through contribution to a sustainable society
	Fertilizers	Biomass for bio-fertilizers	Area for production [ha]	Annual growth of biomass [t/ha]; Amount of N, P, K	Mineral fertilizer replacement [t/yr/]; Crops production [t/yr]	Market value for fertilizer
Regulating and maintenance services	**Mediation of waste, toxics and other nuisances**	Regulation of toxic substances (denitrification, stabilisation of toxins)	Endangered sea area [ha]	Annual toxin uptake [t/yr]	Volume of sea water cleaned [m^3/yr], Avoided mass of contaminated sediment [t/yr]	Avoided cost of water/sediment treatment
	Mediation of flows	Regulation of eutrophication (uptake of nutrient surplus; Counteract oxygen depletion)	Sea area/volume in danger of eutrophication [ha], [m^3]	Annual N/P uptake [t/yr]	Volume of sea water cleaned [m^3/yr]	Avoided cost of water treatment
		Regulation of erosion (sediment retention, existence of eelgrass)	Undisturbed sediments [ha]		Avoided erosion [t soil/yr]; Improved sediment retention	Avoided costs of sediment and erosion control
	Maintenance of physical, chemical and biological conditions	Biogeochemical cycling	All marine areas [ha]	Mass balances - removal rates slower than supply rates [N, C, P]; Amount of acidified marine areas [ha]	Optimal pools and fluxes of nutrients to supply final ecosystem services; Increased nutrient uptake	Avoided costs of eutrophication and acidification of waters; Avoided costs with impacts on human health
		Climate regulation (uptake of C)	All marine areas [ha]	C sequestration rate [t/ha/yr]; C balance	C stocks [Mg/ha] and C sequestration [Mg/ha/yr]	Avoided costs of climate related impacts
		Primary production - Photosynthesis	All marine areas [ha]	C sequestration rate [t/ha/yr]; C balance, O_2 generation	C stocks [Mg/ha] and C sequestration [Mg/ha/yr]	Avoided costs of related impacts
		Food web dynamics			Change in feed, change in species	
		Biological pest regulation			Number of invasive species; new pests	Avoided costs of pest damage
		Maintenance of habitats	Area of nursery habitats [ha]; Non-exploited area [ha]	Reproduction success [n/yr]; Indicator species [n/yr]	Access to a wide variety of species; Shelter and nutrition	Willingness to pay to protect threatened species; Avoided cost of management measures; Intrinsic value
		Stability and resilience	Area affected [ha]	Number of species [N/ha], Number of individuals per species [N/ha]	Stability and resilience	Avoided human regulatory actions

Cultural services	**Physical and intellectual interaction with biota, ecosystems and landscapes**	Recreation and training	Preferred recreation areas [ha]; Area of hunting and fishing [ha]; Boat trails [km]; Beach area [ha]; Bird density [n/ha]	Visitors in marine areas [n/yr]; Number of hunting licenses [n/yr]; Hunting activities [n/yr]; Number of competitions associated with sea activities [n/yr]; Number of beach visits [n/yr]	Opportunities for recreational activities [n/yr]; Improved health	The willingness to pay for recreation and training; The willingness to pay for hunting licenses; The willingness to pay for bathing and boating; Avoided health costs
		Tourism	Preferred marine areas for tourism [ha]	Tourists in marine areas [n/yr]; Number of enterprises offering tourist services [n]; Number of ecotourism operators [n]	Number of jobs created by the tourist sector [n]	The willingness to pay for tourist activities and a stay in the area; Total turnover in the tourist sector; Value for tourist visits
		Mental and physical health	Areas offering varied and interesting marine landscapes [ha]	Sickness caused by cyano bacteria growth [n/yr]; Health problems avoided due to recreation and training [n/yr]	Improved or impoverished health – Sick days [n/yr]; Pulse and blood pressure decrease; Stress hormone decrease in blood	Health value; Avoided costs for health care, sickness leave and decline in production
		Aesthetics (unspoiled nature)	Preferred marine landscapes [n, ha]	Change in preference	Aesthetic experiences	Willingness to pay for trips to aesthetic areas, beautiful and infinite views
		Knowledge and information	Areas used for scientific studies and education [ha]	Excursions, School ships [n]; Marine research infrastructures [n]; Number of scientific studies [n/yr]; Number of publications [n/yr]	Increased knowledge and awareness of marine science and education; Source of knowledge	Value for science and education; Funding for research activities
	Spiritual, symbolic and other interactions with biota, ecosystems and seascapes	Natural and cultural heritage	Marine area [ha]	Number of monuments (lighthouses and bridges) in marine areas [n/ha]; Interaction and preservation of areas	Cultural continuity; Folk belief; Inspiration for art and design	Story tradition; The willingness to pay for a visit

5.1 PROVISIONING SERVICES

Provisioning services provided by the Swedish seas comprise nutrition, materials, energy and fertilizers; services that can be traded and consumed. We distinguish between wild and cultivated marine fish, mussels, oysters and other shellfish. Furthermore, the sea provides algae, seaweed, seabirds and products to be used as feed.

Nutrition

Wild marine fish provide both food for human consumption, feed used for production of food and employment opportunities. The extent of harvest of wild fish in Sweden is relatively small and continues to decrease, employing approximately 4,000 people (year 2005) with a total of 1,880 licensed commercial fishermen and 1,550 ships with commercial fishery permission. The main fishery species are cod, herring and spratt. The most important commercial shellfish in Sweden include pink shrimp (*Pandalus borealis*), Norway lobster (*Nephrops norwegicus*), edible crab (*Cancer pagurus*) and European lobster (*Hommarus gammarus*). The total catch of fish and shellfish in 2013 was 192,000 tons landed (Swedish Environmental Protection Agency, 2008; Swedish Agency for Marine and Water Management, 2015).

The conventional fishing industry has launched developments in order to optimize the landings of wild fish per area. For example, larger fishing boats and more advanced methods of trawling have been introduced in order to optimize catch, running the risks of overexploitation and unwanted bycatch of undersized individuals and unintentional species. For several years, the harvest of many important fishery species has been way above the populations' ability to reproduce (ICES, 2014; The Board of Agriculture, 2014), leading to overexploited fish stocks. In Sweden, several fish stocks are below the biological reference points, partly due to the high capacity fishing fleet (Swedish Environmental Protection Agency, 2008). For example, there has been a 70% reduction of cod stocks in the last 15 years in Swedish waters. Excessive landing of fish not only jeopardizes particular species but will negatively affect the maintenance of food web dynamics and the continued provision of nutrition.

As a response to overexploited fish stocks and increased demands for marine food, humans modify ecosystems to increase their provisioning production of services through for example fish and mussel farming in inshore and offshore aquacultures (FAO, 2014). Aquacultures are expanding rapidly in the world as well as in Sweden. Inshore aquacultures, which are more common, are situated in sheltered waters as opposed to more rare offshore aquacultures situated in deeper and less protected waters where currents are stronger. Approximately two hundred fish farms exist today in Sweden according to the Swedish Board of Agriculture, where ca. half is producing fish for consumption and the other half is for so called put and take. Approximately 13,400 tons of fresh weight fish were cultivated for consumption in 2016 (compared to 5,000 tons in 2007), corresponding to a total economic value of 487 million SEK (SCB, 2017). Rainbow trout constitutes the main part (86%) of the farmed fish, followed by arctic char (SCB, 2017). Cultivations are mainly situated near the northeastern coasts of the Gulf of Bothnia, in the Baltic Sea and in the North Sea (Swedish Agency for Marine and Water Management, 2015). Farmed fish are typically fed by fish meal and fish oil originating from wild fish stocks. Mussels are most often farmed on ropes, with approximately 2,300 tons of mussels being farmed annually for human consumption along the west coast of Sweden (SCB, 2017). There are rising concerns on leaking nutrients and discarded feces settling on the seafloor originating from aquacultures. In addition the use of antibiotics and other drugs as well as the possibilities of cultivated fish escaping and spreading disease among wild fish can have severe consequences on the marine environment.

Materials

Marine fish also provide materials in the form of feed for terrestrial animals like poultry and pigs as well as for farmed fish. A rather large proportion of the total landed amount of fish (54%) is converted to fish meal and used as feed (SCB, 2014). There are ongoing, promising trials with feed based on invertebrates like mussels to be able to replace unsustainable use of feed based on wild fish, for example in the production of organic egg and chicken (Forum Skagerrak, 2004; Stadmark and Conley, 2011).

Another material produced from marine feedstocks is agar from red algae. Agar has several uses as a laxative, as a vegetarian substitute for gelatine and for the production of agar media in petri dishes to grow and identify microorganisms. The cosmetics industry has furthermore successfully used marine algae as thickening agents.

Birds, specifically of the order Anseriformes (ducks), live and thrive around the seas and represent a natural source of food for human consumption. Approximately 133,000 ducks were hunted 2006/2007 (Elmberg, 2009).

The sea may provide chemical resources in the form of new biochemical substances and for example produce sustainable plastics. There is also a constant search for new active substances for pharmaceuticals. This search for new noteworthy organisms in pharmacology and biotechnology is a rapidly expanding sector and the bioprospecting progression is unequivocally related to biodiversity. Marine algae for example include hypotensive agents found in kelp. However, the production of such products from Swedish seas is currently insignificant (Hanning, 2013).

Marine resources are used in ornamental art and handicraft by artists in commercial production of decoration and crafts as well as human beings for recreational purposes. Mostly used are objects like shells, amber, driftwood and pieces of glass.

Genetic resources are all forms of genetic material from marine areas. These resources are important to sustain the biodiversity. Furthermore, a wide span of genetic resources is essential in the technological development of new products from the sea.

Energy and fertilizers

Energy extraction through sea-based wind power, wave, current and tidal movement may reduce the dependence on fossil fuels and mitigate climate change. However, it is only biomass for energy in the form of for example biofuels produced from mussels, fish parts, reed, algae, sea weed and sea squirts that are considered ecosystem services.

Due to high nutrient content, marine species such as algae and shellfish may possibly be used as agricultural fertilizers especially if the levels of contaminants are low. In earlier days, the use of macroalgae as fertilizers was common but today the use is insignificant. Organic farmers on the island of Orust on the Swedish west coast have tested the use of mussel scraps as fertilizers in agricultural fields; however, unpleasant smell is a draw-back (Olrog and Christensson, 2003; Swedish Environmental Protection Agency, 2008).

5.2 REGULATING AND MAINTENANCE SERVICES

The regulating and maintenance services in Swedish seas are as mediators of flows of for example toxic substances, nutrients and sediment retention as well as maintenance of physical, chemical and biological conditions such as biogeochemical cycling, climate regulation, primary production, food web dynamics, pest regulation as well as maintenance of habitats and resilience (Swedish Environmental Protection Agency, 2008).

Mediation of waste, toxics and other nuisances

Toxic content of mussels and other marine resources may cause problems. Mussels may locally contain high concentrations of different pollutants (Länsstyrelsen, 2014a) that may transfer directly to human consumers or via crops when mussels are used as feed and fertilizer. Mussels may also contain toxic substances from harmful algal blooms and intoxication from shellfish containing algal toxins is one of the most serious problems for the aquaculture and fisheries industries worldwide (Shumway et al., 1995). However, mussels sold commercially are routinely controlled by the National Food Administration for algal toxins. Rates of toxin accumulation is species specific and blue mussels (*Mytilus spp.)* typically show higher toxin uptake rates and attain higher concentrations than other bivalves such as oysters and clams (Lassus et al., 1989; Hurst and Gilfillan, 1977).

Mediation of flow

Eutrophication is caused by an excess of nutrients, mainly nitrogen (N) and phosphorous (P). Coastal areas are especially affected when nutrients carried by streams and rivers eventually reach the sea. Also, eutrophication is caused by restricted exchange of water in more shallow and sheltered areas. In coastal waters, N inputs are often the main reason for marine eutrophication (Howarth and Marino, 2006). Nitrogen originates mostly from agriculture, atmospheric decomposition, waste water treatment plants and run-off from forests and pasture lands (Haamer et al., 1999; Helcom, 2017). Eutrophication may be observed through plankton blooms, excessive macroalgal biomass and oxygen depleted bottoms. In 2015, the Swedish Marine and Water Authority suggested a number of measures to improve the marine environment in the North Sea and the Baltic Sea. One suggested action involves financial support for measures that increase the removal of nutrients from the water e.g. by harvesting marine organisms that feed on plankton organisms utilizing nutrients for their growth (Swedish Agency for Marine and Water Management, 2015). To cultivate and harvest marine organisms in this way could be a cost- and energy efficient way to counteract eutrophication of coastal waters, utilising the biomass for food or feed production, bioenergy and biofertilizers.

Sediment retention is the ability of the sea to naturally stabilize and retain sediment and avoid erosion, both at sea beds in the open sea and along the coastline (Swedish Environmental Protection Agency, 2008). Winds, waves, currents and sediments interact continuously mainly in the coastal zone. The coastal erosion is estimated to be most serious in south Sweden primarily on a local scale (Swedish Geotechnical Institute). Deeper sea bottoms are less influenced by waves and wind, but more influenced by trawling which causes turbidity and damage to the seabeds (Tjensvoll, 2014). Living biomass such as sea-grass meadows and their root systems as well as algal beds reduce waves and wind and stabilize the sediment (Fonseca, 1989; Rosqvist, 2010; Grabowski et al., 2011) and thus counteract erosion.

Maintenance of physical, chemical and biological conditions

Biogeochemical cycling is the movement of energy and materials within the sea and it is thus the pathway by which chemical elements move through the physical and biological compartments of the ocean. The most important biogeochemical cycles in the sea are the oxygen cycle, the hydrological cycle, the carbon (C) cycle, the N and P cycles and finally the salt cycle. The cycles are all coupled to each other. Biogeochemical cycles are dynamic and non-static. In many seas, human activities have distorted the nutrient cycles since nutrients have become over-abundant.

Human activities cause a continuously increasing concentration of greenhouse gases in the atmosphere. The oceans act as sinks and store C from the atmosphere (Swedish Agency for Marine and Water Management, 2015). The rate of global climate change would be devastating without these marine C sinks, causing yet more heating of the planet. In addition to the seawater, carbon dioxide (CO_2) is incorporated in living tissue such as sea-weed and phytoplankton which therefore also play a significant role in climate regulation and facilitate the build-up of C in sea bed sediments. The climate regulation is directly related to biogeochemical cycles and primary production and thus supports a range of other ecosystem services. However, an increased storage of CO_2 in the oceans has led to decreased pH of the seawater (IPCC, 2013) with negative consequences for many marine organisms sensible to acidification (Dupont et al., 2010) but also to other organisms through ecosystem changes.

The basis of all primary production in ecosystems is photosynthesis where nutrients are converted to living biomass by means of solar energy and carbon. In marine environments the main primary producers are phytoplankton, benthic algae and sea-grass as well as vegetation such as reed. The two ecosystem services foremost impacting the extent of primary production are biogeochemical cycling of nutrients, mostly N, and climate regulation as availability of CO_2. Marine primary production of phytoplankton and marine plants is the basis for food web dynamics and habitat. An increased primary production is typically a sign of eutrophication.

Food webs structurally describe links between organisms in the marine environment. Simplified, it describes who eats who in the food chain. Organisms in a food web can be separated by function into producers, consumers and decomposers. The numbers of producers, consumers and decomposers are regulated by the availability of food in a delicate balance. Changes in food webs might happen for example through extraordinary high fishing pressure of certain species or through changes in primary production caused by eutrophication (Håkanson et al., 2010). The best way to cater food webs is to avoid overexploitation of individual nodes in the web.

Biological regulation of pests, pathogens and detrimental processes is another service where one organism regulates the abundance of another organism often through feeding. An example of such biological control is when filter feeders like blue mussels decrease the amount of phytoplankton and cyanobacteria in the water column (Swedish Environmental Protection Agency, 2008) and hereby help keep the water acceptable for recreational activities such as swimming.

A habitat is basically defined as the environment in which an organism lives. An optimal habitat has proven essential to maintain the diversity in and the function of an ecosystem. Habitats not only influence the species distribution; the habitat is also altered by marine organisms through for example, grazing, filtering, and defecating. Key marine habitats in Sweden are sea-grass meadows, algal beds, mussel beds, soft bottom seafloors, and offshore banks. Essentially all ecosystem services are dependent on the maintenance of the habitat one way or the other. Coastal habitats seem particularly central for preserving biodiversity, resilience and options for present or future human use. Chemical circumstances such as eutrophication and oxygen-deficiency will cause adequate habitats to diminish, with consequences for food webs, biodiversity, resilience and consequently also for fish stocks.

Ecological resilience is normally defined as 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 (Holling, 1973). High marine diversity, food web dynamics and habitat maintenance facilitate stability and resilience, thus ensure plasticity and capability to adapt to changes and regulate disturbances (Worm et al., 2006). Environmental change in a biodiverse system will likely have fewer consequences since a range of species has similar functions and the response changes vary between species.

5.3 CULTURAL SERVICES

Physical and intellectual interaction with biota, ecosystems and landscapes

The Swedish seas provide cultural services which add benefit to human well-being. Many Swedish inhabitants are active in nature and use the sea for training and recreation (Fredman et.al., 2008a,b; 2013) such as snorkeling, diving, hunting, wind surfing, sailing, bathing, fishing, bird watching, and photographing. The most common recreation activity related to the sea is coast-near walks (Fredman and Hedblom, 2015). Especially, sport fishing is a large leisure interest in Sweden including 1.6 million private recreational anglers, catching approximately 7,000 tons of fish along the coastline and in the sea (Swedish Agency for Marine and Water Management, 2015). The Swedish coastline is long (2000 km) and the net value of recreational fishery exceeds those from commercial fisheries. Recreational fishers request large fish naturally related to healthy stocks, high diversity, high quality of habitat and resilience.

Bird watching is another example of activity attracting recreational bird watchers to visit the numerous important bird areas located along the Swedish coastline. Bird watching is a quickly increasing activity in Sweden which is largely reliant on high biodiversity, habitat conservation and resilience. Even the extent to which the area is undisturbed and situated peacefully will largely matter. Other recreational activities, as for example diving, are related to the marine environment through the presence of eye-catching scenery both above and below water, particularly diversity below the surface. Eutrophication and climate change may disturb human experiences of the sea environment (Söderqvist et al., 2012)

Tourists enjoy marine services in likewise ways. Further interests in Swedish marine areas are whale and seal safari, and motor-boating. Untouched coastal zones and marine ecosystems are unquestionably of large importance for tourism. In Sweden, especially coastal waters are appealing for visitors during the summer and the tourist industry has large economic importance both locally and regionally.

Enjoyment of an attractive, rich and varied nature is believed to have significant impact on health and well-being. The most frequently used ways to improve life, reduce tension and stress, prevent work-related exhaustion and increase the quality of life, is to pursue experiences in nature and participate in outdoor activities (Adevi and Grahn, 2011). In this way, nature offers the capacity to concentrate, reduce time spent in hospitals and provide cost-efficient opportunities for rehabilitation. Additionally, it has been established that nature-based activities reduce medical costs and promote rehabilitation. Areas offering varied and interesting marine landscapes thus supply mental and physical health when visited. Also, marine food is supposed to possess highly nutritious qualities and is promoted in diets and supplements (D vitamins, omega-3 etc.).

Individuals often enjoy coastal scenery and aesthetic values and appreciate beauty, silence and a sense of freedom. The assessment of scenic beauty may affect the extent to which we wish to protect the marine environment. In general, beautiful scenery is for many people related to the absence of development, and therefore provisioning services such as commercial fishing, aquaculture as well as recreational and touristic activities may have conflicting negative influence on the enjoyment of scenery.

Education and information as well as inspiration for art are other examples of cultural services. Activities such as school excursions, museums and scientific research are intensified when marine life is diverse and the interest in the sea environmental questions increase. Education is needed to avoid over-exploitation, eutrophication, littering, release of chemicals etc.

Spiritual, symbolic and other interactions with biota, ecosystems and seascapes

Cultural and natural heritage in the Swedish seas are often well preserved but many are yet to be detected. Common heritage at the bottom of the sea are traces from former shipping and from the former world wars.

6 MARINE FEEDSTOCKS AND BIOFUELS

Algae are one of the most interesting marine feedstocks for biofuels production. Algal biomass is considered as 3rd generation bio-based feedstock for biofuels due to the higher growth yield as compared to earlier generations of feedstock from plants (the Ellen MacArthur Foundation, Neufeld et al. 2016). Another promising feedstock for marine bioenergy production is sea squirts (*Ciona intestinalis)* which recently have been considered an interesting feedstock for mainly biogas production.

Both macroalgae and sea squirts can be cultivated along the Swedish west coast. The suitable areas for aquaculture mainly exist in the northern half of the Swedish west coast, the Västra Götaland Region (Figure 2). In order to maximize yield and decrease production costs, co-cultivation of macroalgae and sea squirts can be applied. In this case macroalgae are cultivated in the upper parts of the sea where more light is available and sea squirts are cultivated below the algae as they don't need light and grow best a few meters below the surface and downwards.

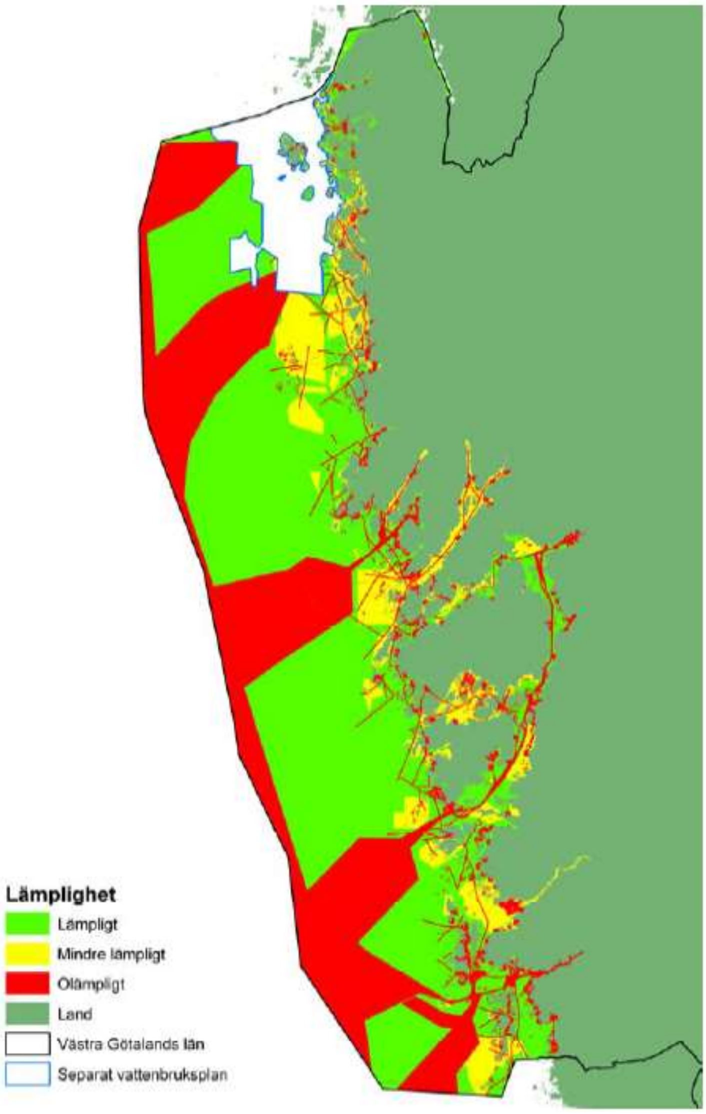

Figure 2. Map of suitable areas for aquaculture in the Västra Götaland Region (Länsstyrelsen, 2014b). Bright green areas are suitable, yellow areas are less suitable, red areas are not suitable, dark green areas are terrestrial land.

6.1 MACROALGAE

Algae in general dominate primary production and CO_2 fixation on earth and are the origin to the fossil oil we use for a majority of fuels today. Compared to algae cultivation on land, algae grown directly in sea water, for example for biofuel purposes, will probably influence marine ecosystem services more, regardless of whether these are micro- or macroalgae. We have chosen to concentrate on macroalgae as marine feedstock because they are abundant in seawater, in some cases easy to cultivate at large scale and relatively easy to harvest in large volumes.

Macroalgae are defined as algae consisting of more than one cell, or unicellular non-planctonic cells combined into visible colonies or filaments (Tolstoy and Willén, 1997). If they are perennial, they are commonly called seaweed. Algae need sunlight, CO_2 and nutrients to grow and proliferate. They are thus photosynthetic and produce oxygen, but unlike plants, they do not have root, stem or leaves. Instead, they take up light and nutrients directly through the whole body. They are often attached to solid surfaces or to the rocky sea floor and can reproduce with spores, sperms and eggs, or by asexual reproduction through cloning where parts of the algae separate and then settle and grow in a new location.

Macroalgae occur in both marine and freshwater environments across the globe. The algae are pigmented in green, brown or red depending on adaptation to the wavelengths of light occurring at the depths in which they grow, from the surface down to about 40 m. Species diversity found along Swedish shores often reflect differences in salinity among other physical factors. For larger seaweed production, the west coast in Sweden constitutes the preferred location due to comparatively more stable and relatively high salinity and less problem with winter icing compared to the Baltic Sea. In addition, productive species can show growth inhibition in brackish waters such as the Baltic Sea (Bergström, 2005).

Macroalgae contain many interesting substances for different applications. The main constituents are carbohydrates with contents varying from 34 to 76% of dry weight (Nielsen et al., 2016), proteins make up 7-12%, while lipids occur in low amounts (0-2%). The mineral ash content can be 33–55% (Jard et al., 2013). Lipid contents vary with season, from around 0.6-0.9% in July to 3.3-3.4% in November (Marinho et al., 2015). The lipids are mainly composed of polyunsaturated fatty acids. In this report we focus only on those traits that are important for biofuels production and associated ecosystem services.

The brown algae sugar kelp, *Saccharina latissima (*class *Phaeophyceae)* (Figure 3) was chosen for a more detailed case study. In Sweden, sugar kelp grows along the west and south coast. The reasons for choosing this particular species are that it is commonly occuring, can be cultivated easily on ropes (Oirschot et al., 2017) on-site in sea water, grows fast (Broch and Slagstad, 2012) and is a possible candidate for co-cultivation with fish farms (Handå et al., 2013). Practical cultivation of the species is being tested in the research project Seafarm (www.seafarm.se) on the Swedish west coast, thus bringing relevant and available data for this study.

Figure 3. Rope cultivation of sugar kelp. Photo source: algolesko.com.

6.1.1 Cultivation of biomass

The potential to cultivate macroalgae on the Swedish west coast depends on available sea surface area. The total water surface area from the shore line of the Västra Götaland region to the Swedish territorial border is 5,604 km^2 (Länsstyrelsen, 2008). Of this, 2,400 km^2 is potentially suitable for aquaculture (Figure 2).The coastal area available and theoretically possible to cultivate is 555 km^2 with regards taken to competing activities and after downscaling to realistic cultivation areas (Fredrik Gröndahl, KTH Royal Institute of Technology, Sweden, pers. comm., manuscript in publication process). In practice, the cultivation area will probably be considerably smaller. The water depth should preferably be approximately 10 m and up to 30 m for a good cultivation area (Smale et al., 2013).

The production potential for cultivation of sugar kelp is reported as 170 tons per ha fresh (wet) weight over a 10 months cultivation period from August to June in Norway (Broch et al., 2013). In Spain, the potential for sugar kelp production is 45.6 tons per ha (Peteiro et al., 2014) and the Swedish Seafarm project has reported 22-28 tons per ha fresh weight over 8 months of cultivation under Swedish conditions (Pechsiri et al., 2016). An optimal yearly production potential of 220 tons per ha was suggested Henriksson and Egeskog (2015), which seems comparatively high, being ten times higher than the actual production achieved in the Seafarm initial tests. However, 221 tons per ha was calculated from cultivation near fish farms (Handå et al., 2013).

6.1.2 Prospects and possibilities for production of biofuels

The basis for biofuels production is the extraction of the desired biomass which is then converted into biodiesel, biogas or via fermentation into bioethanol, butanol or hydrogen. Summaries of relevant publications on this subject were made by Coelho et al. (2014) and Milledge et al. (2014), who reviewed currently available methods. For biofuels production from macroalgae, the content of carbohydrates is especially interesting. Of the carbohydrates, laminarin and mannitol can constitute 55% of the dry weight (Adams et al., 2009). These are storage compounds that can be converted to glucose and fructose with the help of enzymes and subsequently fermented to ethanol by yeast. Alginate is a polysaccharide which functions as a structural compound in macroalgae with a content ranging between 6 and 27% (Handå et al., 2013). Alginate is well known as a thickener. Macroalgae also contains cellulose almost free of lignin, making them easier to ferment than other cellulose feedstocks.

In general, the energy content of algal biomass can be used to estimate the potential biofuel production capacity. Biocrude extracted via hydrothermal liquefaction (HTL) from sugar kelp was shown to have an energy value of 36.5 MJ per kg (Anastasakis and Ross, 2011), which is similar to crude fossil oil. Before HTL treatment, the higher heating value in the macroalgae was 12 MJ per kg. Another HTL treatment of the same macroalgae species showed an energy recovery of 63% (Milledge et al., 2014).

Biodiesel production from macroalgae might not be a good option due to their low lipid content (Milledge et al., 2014). Few studies have been performed on this subject. However, 0.10 g diesel per g of algae has been reported (Ahn et al., 2012).

Few studies have also been made on fermentation of macroalgae extracts for butanol production. In studies of *Saccharina spp*. a yield of 0.12 g butanol per g algal extract was obtained (Huesemann et al., 2012). The macro alga *Ulva* produced 0.045 g butanol per g algae (Frank et al., 2013).

In a test of hydrogen production from several macroalgae via anaerobic fermentation a maximum production yield of 28 ml hydrogen per g dry *Laminaria japonica* was obtained (Park et al., 2009). Through heat pretreatment another study obtained 83 ml per g with the same macroalgae (Liu and Wang, 2014). The macro alga *Gelidium* was reported to give ca. 54 ml hydrogen/g algae (Chader et al., 2011). *Saccharina latissima* was tested and a hydrogen production of ca. 15 mol per kg or 338 mL per g with NaOH pretreatment was shown (Onwudili et al., 2013.

There are yet no figures of actual ethanol production from macroalgae in the Seafarm project (Eva Albers, Chalmers University of Technology, Sweden, pers. comm.) and there are only few studies performed. Pretreatment methods were tested and did not increase ethanol production from macroalgae (Adams et al., 2009). A theoretical yield of 0.56 g bioethanol per g starch with conversion rates of 30-40% was calculated for algae with high starch content (John et al., 2011). Bioethanol production from macroalgae was investigated and yielded 0.281 weight ethanol per dry weight macroalgae, or about 80% of the theoretical yield from the algal sugars, within a new microbial platform for direct biofuel production (Wargacki et al., 2012). The ethanol yield from macroalgae is low (90 L ethanol per ton of dry algae) compared to crops like corn, but also that the energy return on energy investment (EROI) is about the same for these two feedstocks (Milledge et al., 2014).

The potential for biogas production from macroalgae was reported to be 180 Nm^3 CH_4 per ton volatile solids (VS) from the Seafarm algae project, containing 77% VS of the dry weight (Pechsiri et al., 2016). Another study reported a CH_4 potential of 209 ± 15 mL CH_4 per g VS with a VS fraction of 502 g per kg (Jard et al., 2012). Bacteria taken from sheep feeding on macroalgae and thereby being adapted to this kind of feedstock, was shown to increase the biogas production from *Laminaria hyperborean* to 256 ml methane (CH_4) per g VS (Milledge et al., 2014). Based on data from the Seafarm project on biomass production per ha, dry weight of the algae, and biogas production, the potential CH_4 production range from macroalgae cultivation corresponds to 580-760 Nm^3 per ha and year. Calculated for the whole 555 km^2 possible cultivation area on the west coast, this value corresponds to a yearly production potential of 32-42 million Nm^3. One Nm^3 of CH_4 has a heat value of approximately 10 kWh. An average energy demand for a biogas bus driving in actual traffic is ca. 56 kWh per 10 km (Anderson, 2014). Thus, the production could support 57-75 million km of travel for a bus or 750-1,000 buses each year (75,000 km average distance traveled per year for buses in Sweden 2015) (Trafikanalys, official statistics). Compared to the total energy usage for transport purposes in Sweden (87.2 TWh 2015, Energimyndigheten, official statistics) the biogas production potential corresponds to approximately 0,4% of the energy demand. Note also that the maximum sustainable production of biomass, with regards to nutrient availability, is only a fraction of the theoretical maximum (chapter 7.2).

At present, macroalgae are mainly cultivated for feed and alginate extraction. Challenges in algal biofuels production include energy efficiency in cultivation and harvesting (Soratana et al., 2012) as well as the cost efficiency compared to cheap fossil oil. Information about prices and costs for production of macroalgal biofuels is hard to find and profitability is yet to come for liquid fuels, following improvements in biotechnological methods. Hughes et al. (2012) report that prices for macroalgal biogas are highly uncertain due to many unconstrained parameters such as scale, location and how mechanized the cultivation process is. To be competitive with fossil fuels, the production cost would have to be less than €450 per ha based on a biomass production of 20 tons of dry algae per ha (€24 per ton) for biogas. A theoretical study of a process in which macroalgae produced biogas, which subsequently was used for electricity and heat production, found that the breakeven electricity selling price was €120 per MWh (Dave et al., 2013). In Sweden, the electricity prices are relatively cheap. For industrial customers in Sweden January to June 2017, the price was €38-130 per MWh depending on size of the industry (Statistics Sweden, official statistics).

6.2 SEA SQUIRTS - TUNICATES

Sea squirts (*Ciona intestinalis*) are filter feeding animals with a cylindrical, gelatinous body, belonging to the ascidians evertebrates within the phylum Tunicata (Figure 4). Ascidians occur both as single organisms and in colonies. In the larvae stage sea squirts have a notochord, which is used when moving to their settling location. Larval dispersal in a population of sea squirts is limited and rather local, which suggests locally, isolated populations (Petersen and Svane, 1995). After settling the notochord is absorbed during the maturation process. The adults filter phytoplankton and other microorganisms from the seawater and are thus independent of light conditions. Sea squirts are hermafroditic and produce eggs and sperms as soon as water temperatures rise above approximately 8 °C. They have been reported to live in water with salinity between 12 and 40‰ (Norén et al., 2012). Sea squirts often form colonies and may completely cover certain surfaces.

Naturally, sea squirts can be found from 0.5 meters down to several hundred meters depth. Sea squirts growing at 0-20 meters depth are known to produce larvae twice per year while sea squirts in deeper areas only produce larvae once per year. Also, the life length depends on the depth they live, where sea squirts living in the deeper areas may live twice as long as animals living in more shallow waters (Dybern, 1965). Sea squirts seem to favour locations with moderately flowing water and they are normally growing on steep rocks and cliffs, bridge piles and other construction parts and boat chains. They are also reported to live in beds of eelgrass (Härkönen, 1983). The lifecycle is characterised by high growth rates, approximately 20 mm per month, early sexual maturity (within eight to ten weeks) and a high production of more than 10,000 eggs per individual. The number of eggs produced per day has been observed to be more than 500 (Carver et al., 2003) to 2,000-3,000 eggs every two to three days (Yamaguchi, 1975).

Sea squirts are native in northern European waters (Christiaen et al., 2009), but have also been introduced via shipping to Africa, Australia, New Zealand, China and North and South America. In Sweden, sea squirts can be found naturally and may thus be cultivated along the west coast. The most southern occurrence is reported from Kullaberg located in the northwestern part of the Skåne region. In order to obtain high yields, nutrient and plankton rich, flowing waters are preferable. In order to limit negative impacts of sea squirt excrements on sea bottoms, leading to oxygen depletion, deeper areas are preferable, so that excrements from cultivation are distributed over a larger area to promote their degradation (Odhner et al., 2013).

Sea squirts consist of a protein rich inner part and the tunic which consists of proteins and complex carbohydrates, e.g. cellulose. Chemical analyses show that the main constituents in sea squirts on a dry basis (ash content 47.5%) are 27% C, 6% N, 10% oxygen (O) and 0.5% P. The same analysis shows a raw protein content of approximately 52% of the ash-free dried sample weight and a carbohydrate content of approximately 37% (Zhao and Li, 2016).

Figure 4. Long line cultivation of sea squirts (Marin Biogas AB, 2015).

6.2.1 Cultivation of biomass

Sea squirts are currently cultivated in Sweden using conventional mussel farming techniques. Long ropes held afloat by buoys (Figure 4) are submerged on which the sea squirts larvae settle and grow. Other, large scale cultivation techniques are being developed to e.g. enable cultivation further off-shore. Sea squirts filter the seawater and hereby nutrients like N and P are incorporated in the organism tissue. Sea squirts are harvested by boat. The largest growth has been observed from August to November (Gulliksen, 1972). On board they are scraped off from the cultivation ropes using conventional mussel harvesting techniques and directly dewatered via a filter press to avoid the unnecessary transport of water. Today, sea squirts are harvested from mussel farms inside the island Tjörn. The standing stock of sea squirts in the one hectare culture is estimated to 1,350 tons wet weight and 69 ton dry matter. At full scale cultivation of approximately 10,000 tons wet weight per ha is expected (Odhner et al., 2013).

The company Marin Biogas AB is driving the development of cultivation and potential areas of commercial application of sea squirts in Sweden. In terms of technology development, cultivation in-shore and off-shore are being developed as well as different harvesting and dewatering techniques. The use of sea squirts as substrate for large scale production of biogas in a commercial co-digestion plant in Falkenberg, Sweden has been tested and deemed feasible. Also, the use of sea squirts as biofertilizers has been tested. No obvious negative effects were observed, but more testing is needed in this field (Odhner et al., 2013). Other applications such as use as fish feed are currently being investigated. Another potential business area is the cultivation of sea squirts as a nutrient emission compensation measure around fish farms or from other point sources of nutrients.

6.2.2 Prospects and possibilities for production of biofuels

In theory, the sea squirts can be used to produce a variety of biofuels. Biofuels production routes are especially bio-oil production via HTL treatment and ethanol production via fermentation which are also applicable for sea squirts, even though no detailed studies have been conducted.

The biofuels route currently investigated in most detail is the production of biogas. On-shore the sea squirts slurry is directly fed or loaded and transported by trucks to the biogas production facility. In order to convert sea squirts to biogas in an efficient way, co-digestion with other substrates has been shown to result in a higher CH_4 yield compared to conversion of sea squirts alone. Approximately two times higher biogas yield is achieved when using sea squirts together with conventional substrates like the separated fraction of organic household waste (Carlsson and Henningsson, 2015), compared to only using sea squirts substrate. In a co-digestion process approximately 14 MJ biogas per kg of sea squirts (dry mass) can be produced.

The three steps of the biogas production process are: hygienization, anaerobic digestion and biogas upgrading. Pasteurisation of the substrate is done by heating the feed to approximately 70 °C for one hour. After this the substrates are sent to the digestion chamber, where they are converted into biogas, consisting mainly of CH_4 and CO_2 (Jarvis and Schnürer, 2009). During upgrading, CO_2 and other impurities are removed from the CH_4, in order to achieve a gas quality suitable for use as transportation fuel (Holmgren, 2012).

The methane production potential of sea squirts was reported to be 640 Nm^3 CH_4 per ton VS (VS=50% of dry weight) if co-digestion with substrate from a conventional Swedish biogas plant is applied (Carlsson and Henningsson, 2015). Laboratory analysis showed that sea squirts contain approximately 63% volatile solids of the dry weight (Carlsson and Henningsson, 2015). The upgraded biogas is compressed and transported to fuel distribution stations and used as a transportation fuel. As a by-product from the anaerobic digestion process biofertilizer is produced, that can be used in agriculture.

Presently, sea squirts are not used as feedstock for biofuels production. With current biogas prices and support schemes, solely using sea squirts for biogas production is not feasible. This situation might change if policy instruments promoting the implementation of measures to counteract marine eutrophication are introduced (Fredrik Norén, pers. comm.).

7 IMPACT OF BIOFUEL PRODUCTION ON MARINE ECOSYSTEM SERVICES

An intensified removal of marine biomass will influence a range of ecosystem services and biodiversity. In this chapter, we describe the effects that an intensified production of marine biomass in the form of macroalgae and sea squirts will have on the marine ecosystem services (Chapter 5).

In the valuation guide published by the Swedish Environmental Protection Agency (2015), instructions to valuation of ecosystem services are given. The valuation is described in four different succeeding levels; i) description in qualitative terms through words, ii) semi-quantitative description based on a scale (e.g. 1-5, +/-, yes/no), iii) quantitative description of indicators through the use of biophysical units, and iv) description in monetary terms. It is further specified that all four ways of valuation are not always necessary in an analysis of ecosystem services.

In this report we describe the effects that an intensified, full scale cultivation of marine macroalgae and sea squirts for use as feedstock for biofuel production will have on the marine ecosystem services. Qualitative description of changes as well as a semi-quantitative description (scale: -/--/---/0/+/++/+++) are provided (Table 3). The sea is a complicated, multifaceted ecosystem with complex relationships which at times makes it hard to generalise about changes.

Table 3. Potential changes in ecosystem services as an effect of intensified marine algae and sea squirt production. Positive impacts are indicated with + to +++, with increasing intensity, indicated from light green to stronger green. Likewise, negative impacts (-, --, ---) are indicated in pink. When increased macroalgae and sea squirt production influence ecosystem services in the same way, there is one row describing this for each ecosystem service. If their influence on ecosystem services differs there is an upper row for macroalgae and common impacts, and a lower row for impacts from sea squirts. The CICES framework is used to structure the ecosystem services as outlined in Table 2.

Class	Division	Ecosystem service	Qualitative description of changes in ecosystem services as an effect of intensified marine production for fuels	Semi-quantitative description of importance of change (0/+/-)
Provisioning services	**Nutrition**	Wild fish, mussels, oyster, shellfish	Cultivation areas will provide shelter and hiding places and thus produce protected areas which may act as fish nurseries or artificial reefs. Such areas limit the opportunities for commercial fishing.	++
			Temporary negative impact on sea bottom due to sea squirt excrements, which potentially impacts bottom fauna. Increased competition for food with other filter feeding animals (mussels, oyster etc.).	0
		Cultivated fish, mussels, oyster, shellfish	Nutrient uptake from algae and sea squirts production allows more cultivation of these food sources. Co-cultivation of algae, sea squirts and fish is an opportunity in order to compensate for nutrient emissions from fish farming.	+
			Sea squirts can contaminate existing mussel cultivations as larvae settle and replace mussels.	-
		Algae, sea weed	There is no current production of algae for nutritional purposes to compete with.	0
		Seabirds	Cultivation areas might attract seabird populations due to increase of fish fry and preferred foraging in cultivation areas.	++

		Feed (fish meal, fish oil etc.)	It is possible to use the protein fraction of macroalgae for feed (but only 3% protein) but competition is rather unlikely.	0
			Protein rich feed can be produced from the inner parts of sea squirts, while the outer layers can be used for biofuels production. No major impacts on other feed production from fuel production expected.	+++
	Materials	Reed for fertilizers and roofs	Macroalgae and sea squirt cultivation for fuels do not influence the production of reed.	0
		Algae for agar-agar production and beauty treatments	There might be competition between macroalgae and sea squirts for fuels and algae for other purposes. Agar-agar is however not currently produced from algae in Swedish marine areas.	0
		Chemical resources (antibiotics, glue)	Phenols can be extracted from macroalgae, possibly also organic acids as a byproduct. Also, production of plastics may evolve. Development of antibiotics from marine species is ongoing. Cultivation of algae is unlikely to undermine such development due to the comparably small scale of cultivation. Even other chemicals can potentially be produced from macroalgae.	+
			Tunicates, such as sea squirts, are discussed as a potential source of antibiotics. Cultivation of sea squirts for biofuels is unlikely to undermine production of antibiotics due to the comparably small scale of cultivation.	+
		Driftwood, glass, mussels, shells, amber used in art, handicraft and decoration	Increased cultivation is unlikely to have an impact on the amount of material for handicrafts.	0
		Genetic resources	Cultivation of macroalgae will create new habitats allowing a wider diversity of organisms. Monocultures in general results in a higher risk for pests.	+
			There is a risk of sea squirts and other organisms following it to become invasive species outside their habitat. Cultivation of specialized sea squirts that withstand harsher conditions might pose a threat for species in areas where sea squirts currently can't thrive. The plankton consumption by sea squirts is unlikely to pose a threat to genetic resources.	-
	Energy	Biomass for energy (mussels, fish parts, reed, algae, sea weed, sea squirts)	Cultivation provides a resource that can be used for biofuel production: Biocrude via HTL, bioethanol, biogas, possibly hydrogen and butanol, combustion of residuals. An impact on other species that are specifically used for energy production is not expected.	+++
	Fertilizers	Biomass for biofertilizers	Cultivation of macroalgae and sea squirts provides a resource as biofertilizer, e.g. digestates from biogas production.	++
Regulating and maintenance services	**Mediation of waste, toxics and other nuisances**	Regulation of toxic substances (denitrification, stabilisation of toxins)	Both algae and sea squirts potentially take up heavy metals. Algae are often high in Cd, while sea squirts contain large amounts of Vanadin. It is not expected that the regulatory potential of the sea to degrade toxic substances is influenced by the cultivation of macroalgae or sea squirts, but there might be an influence of metal remediation.	+
	Mediation of flows	Regulation of eutrophication (uptake of nutrients)	Cultivation leads to an increased uptake of nutrients such as N and P from the sea, which contributes to positively regulating eutrophication. Large scale cultivation of algae may be limited by nutrient supply.	++

		Regulation of erosion – Sediment retention (e.g. eelgrass)	High density cultivation could lead to reduced flows and currents thereby contributing to sediment retention and less erosion. Limitations imposed on boating and similar activities would also reduce sediment transport.	+
	Maintenance of physical, chemical and biological conditions	Biogeochemical cycling	Nutrients and trace metals are recycled. A larger proportion of primary production is bound in the algae and sea squirt biomass, leading to less organics and nutrients in sediment and water.	++
		Climate regulation (uptake of C)	Using algae and sea squirts as substrate for biofuels production to replace fossil fuels has a negative C footprint thereby supporting climate regulation.	+++
		Primary production - Photosynthesis	Increased production of algae greatly increases primary production, but could reduce light and nutrient availability for other photosynthetic species.	++
			Not relevant for the cultivation of sea squirts.	0
		Food web dynamics	Cultivation areas are attractive hiding places providing new habitats for younger and small fishes and different kinds of animals. This could allow for larger diversity and food web interactions.	++
			Plankton consumption by sea squirts might increase competition for feed with other filtering organisms. At the same time sea squirt excrements increase nutrient availability and organic growth. Sea squirts are not an attractive food source for other species and are therefore not likely to attract predators to feed on them. Sedimentation of organic material to sea beds from sea squirt cultivation may lead to oxygen depletion and species composition precisely under the cultivation area.	-
		Biological pest regulation	Large scale cultivations are monocultures which are likely to increase the vulnerability to biological pests, but it is unclear how large a problem this is. This might lead to spreading of pests to others species in proximity to the cultivation site. Large scale cultivation might lead to increased competition and thus decreased population of other species settling in similar areas.	--
		Maintenance of habitats	Cultivations create protected habitats for fish fry and higher abundance of fish is observed. Changes in nutrient cycling could impact lower productivity habitats.	+
			Sea bottom fauna might be impacted by excrements from sea squirts leading to lower species density. However, the feces may be feed for crustaceans.	-
		Stability and resilience	Monocultures might increase the vulnerability of algae and sea squirts or other species in close proximity to the cultivation site. Pests are more likely to occur. This probably depends on scale and harvesting techniques employed.	-
Cultural services	**Physical and intellectual interaction with biota, ecosystems and landscapes**	Recreation and training (snorkeling, diving, hunting, wind surfing, sailing, bathing, fishing, bird watching etc.)	The area available for recreational activities will be reduced, since the biomass production will compete with areas for e.g. boating, wind surfing, diving, snorkeling and similar activities. Other recreational activities as e.g. bathing will only be affected to a minor extent since cultivations are further out at sea. Fishing should improve with protected habitats carrying increased abundance of fish, though fishing within cultivations areas might not be feasible. Cultivation sites might attract sea birds leading to positive impact on bird populations and bird watching. Noise from harvesting boats disturbs fishing, bird watching and	-

			other recreational activities. However, in the summer period when recreation at sea is at its highest, boat traffic is high, thus the harvest boat is considered neglectable.	
		Tourism (fishing tourism, whale- and seal safari, motor-boating)	Competition with boating activities for large scale cultivation, the best areas for cultivation are typically also attractive for recreational activities. Since aesthetics might be influenced negatively at large scale cultivation it may have negative impacts on tourism. Fishing tourism might however be impacted positively. The number of professional visitors and bioenergy enthusiasts might increase and can to some extent outweigh the negative impact on tourism.	-
		Mental and physical health	Noise and emissions from harvest boats can impact health but again the harvest boat is neglectable in comparison to usual summer boats. Job creation by cultivation and biofuels production activities will have a positive impact.	0/+
		Environment and aesthetics (unspoiled nature)	Aesthetics might be influenced negatively at large scale cultivation areas mainly due to visible buoys.	-
		Knowledge and information	Development of algae and sea squirts based industry will most probably be linked with research and educational activities. This is especially advantageous in remote coastal communities. Also, the interest from the public to visit farms will increase.	+
	Spiritual, symbolic and other interactions with biota, ecosystems and seascapes	Natural and cultural heritage	Cultivations could provide ways to preserve the culture of the local population (coastal), living, small scale fishing as well as creation of job opportunities.	+

Impacts of an intensified marine biomass production of macroalgae and sea squirts on the different ecosystem services are described below in the order of how they are presented in Table 3.

7.1 IMPACT ON PROVISIONING SERVICES

Nutrition

Macroalgae and sea squirts cultivation areas will provide shelter and hiding places and thus produce protected areas which may act as fish nurseries or artificial reefs and be positive for future fish populations (Norén et al., 2012; Smale et al., 2013). Such areas, however, limit the opportunities for commercial fishing. Sea squirts excrements may lead to temporary negative impact on sea bottom fauna although the effect of sedimenting excrements is highly dependent on the local conditions such as water depth and current. Directly beneath a cultivation area, reduction in population numbers, biomass and species diversity have been observed (Loo and Petersen, 2013). Also, Norén et al. (2012) found noticeable changes of the sea bottom directly under cultivation areas, with anoxic sediment and flourishing of the sulphur bacterium *Beggiatoa*, allowing for no other macro fauna. However, observations showed that the affected sea bottom went back to pre-cultivation conditions after 6 months without cultivations. Besides effects on seabeds, increased competition for food with other filter animals (mussels, oyster etc.) may occur.

Co-cultivation of algae, sea squirts and fish is an opportunity in order to compensate for nutrient emissions from fish farming. The remediation potential for N is extensively investigated by Broch et al. (2013) in a case where algae are cultivated next to a fish farm. The authors claim that such production will create a net removal of 0.36 ton of NH_4-N per ha of algae cultivation next to a 5,000 tons salmon farm. However, there is a time discrepancy since algae are rapidly growing in spring while fish farms mainly discharge nutrients in late summer and autumn (Handå et al., 2013). There is a risk that sea squirts may contaminate existing mussel cultivations as larvae settle and replace mussels. Sea squirts compete with mussels (*Mytilus edulis*) both for feed and settling space. In Scandinavian waters, sea squirts spawn simultaneously or even slightly prior to mussels and can therefore occupy space and take over mussel cultivations sites, which results in major losses for mussel farmers (Loo and Petersen, 2013). This could however be prevented by using a safety distance between cultivation sites of the different species, avoiding larval dispersal between them.

There is currently no production for nutritional purposes to compete with. At locations with low excrements concentration, for example in the outskirts of the cultivations site the growth of sea weed and other organisms could be increased due to improved nutrient access from excrements. Furthermore, sea squirts settle on sea weed and other macroalgae which might disturb these populations. On the other hand, sea squirts feed on suspended biomass, which could lead to clearer water. This in return leads to better growth conditions for e.g. macroalgae (Loo and Petersen, 2013).

Cultivation areas might attract seabird populations due to an increase of fish fry. Scottish kelp forests are preferred foraging habitat for many sea birds (Smale et al., 2013).

It is possible to use the protein fraction of macroalgae for feed but competition is rather unlikely. Due to the low protein content around 10% (Jard et al., 2013), processing of this fraction is unlikely to be cost and energy effective. However, whole macroalgae have been used directly as feed (Smale et al., 2013). Protein rich feed can be produced from the bodies of sea squirts, while the outer layers can be used for biofuels production. There is however no major impacts on other marine feed production (Ayre, 2013). Both macroalgae and sea squirts have a valuable content of omega-3 fatty acids.

Materials

Macroalgae cultivation for fuels requires larger depth than reed for growth and therefore does not influence the production of reed. For similar reasons, sea squirt cultivation does not compete with reed production close to shores. Reed is not thriving in marine environments and usage of reed is limited in Sweden.

There might be competition between macroalgae and sea squirts cultivated for production of fuels and harvest and extraction for other purposes. Agar-agar or extracts for cosmetics are however presently not produced from macroalgae in Swedish marine areas and therefore competition has no considerable impact.

Development of antibiotics from marine species is ongoing (Doshi et al., 2011). Cultivation of algae and sea squirts are unlikely to undermine such development due to the comparably small scale of cultivation required for pharmaceuticals. Polyphenols can be extracted from algae and act as antioxidants (Jard et al., 2013), possibly also organic acids as a byproduct (Barbot et al., 2016).

Increased cultivation is unlikely to have an impact on the availability of driftwood, glass, mussels, shells, amber which can be used in art, handicraft and decoration. It is interesting to note that kelp ash has been used in older days for manufacture of glass and soap and for glazing of pottery (Smale et al., 2013).

Macroalgae cultivation can be compared to natural kelp forests and these have been shown to act as "habitat-forming engineers" similar to coral reefs and provide an increase in genetic resources (Smale et al., 2013). Outside Europe, where sea squirts as well as certain kinds of algae are not native species, there is a risk that they become invasive but that risk is insignificant here in Sweden. Cultivation of specialized sea squirts to withstand harsher conditions might pose a threat for species in areas where sea squirts currently can't thrive. However, Petersen and Svane (1995) demonstrated evidence that the larval dispersal is insignificant under Danish conditions. The plankton consumption by sea squirts is unlikely to pose a threat to genetic resources.

Energy

Cultivation of macroalgae and sea squirts provide resources that can be used for biofuel production. Bioethanol, biogas, possibly hydrogen and butanol can be generated, as well as heat from the combustion of residuals (for macroalgae see section 6.1.2.). Impacts on other species which are specifically used for energy production are not expected. Using algae and sea squirts as substrate for biogas production to primarily replace fossil fuels has a negative C footprint compared to the use of fossil fuels as on a global scale GHG emitted during the combustion of biogas produced from algae and sea squirts is absorbed during the cultivation of these substrates. This is supporting climate regulation. A sea squirt cultivation system to produce biogas and biofertilizer was shown to result in reduced global GHG emissions if fossil transportation fuels and mineral fertilizers are replaced (Andersson et al., 2014; Hackl et al., 2017).

Fertilizers

Cultivation of macroalgae and sea squirts provide resources as biofertilizers, e.g. digestates from biogas production (Odhner et al., 2013). The mineral fertilizer application to Swedish arable land was approximately 196,000 tons N per year (107 kg per ha) and 29,400 tons P (19 kg per ha) in 2016 (SCB, Statistics Sweden, www.scb.se). This can be compared to 70 kg N per ha applied 1996 (Gustafson, 2007). A fertilizer composed of dry macroalgae produced at 555 km^2 could replace the nutrients corresponding to 1.4% of the agricultural usage of N or 3% of the P.

7.2 IMPACT ON REGULATING AND MAINTENANCE SERVICES

Mediation of waste, toxics and other nuisances

Macroalgae may contain metals and are known to be able to adsorb heavy metals from polluted waters (Davidsson, 2007). Metals usually are in the ppm range, for example 0.64 ppm Cd (var 0.07-2.64), 0.34 ppm Pb (var 0.07-1.66), 55.4 ppm As (var 29-88.3), 1.23 ppm Cu (var 0.29-11.75), 0.33 ppm Cr (var 0,12-1,97) and 1.37 ppm vanadin (var 0.57-3.0) (Nielsen et al., 2016). Arsenic content is relatively high and may preclude large scale usage as fertilizer or limit regions where the algae can be cultivated. Also, sea squirts contain metals. Analysis of cultivated sea squirts at the Swedish west coast showed the following metal contents: 0.22 ppm Cd (± 15%), 2.9 ppm Cr (±25%), 10 ppm Cu (±15%), <0.049 ppm Hg (±30%), 2.5 ppm Pb (±15%), 140 ppm V (±15%) according to elementary analysis conducted by Eurofins for N-Research AB (Eurofins Environment Sweden AB, 2010). Especially arsenic in macroalgae and vanadium in sea squirts are high but this is always relative to what they will be used for. The regulatory ability of the ocean to deal with toxic substances is expected to be influenced positively to some extent due to macroalgae and sea squirts ability to adsorb metals. The ultimate effect of this is dependent on the subsequent use of the marine biomass.

Mediation of flow

Nutrient removal from the marine coastal water in the form of nutrient uptake from algae and sea squirts production is of importance. During sea squirts cultivation, N and P are incorporated in the animal tissue during growth, mainly as N rich proteins and P rich metabolites. The nutrients are removed from the sea when the biomass is harvested, which makes cultivation of macro algae and sea squirts for biofuels production interesting as a measure to decrease the concentration of nutrients in the marine environment, which contributes to counteract eutrophication. Henriksson and Egeskog (2015) point out that the effluents of nutrients are quite low from the northern part of the Swedish west coast compared to other parts of the coast and that the yearly N released into Skagerrak 2013 was 2,036 tons (Swedish Environmental Protection Agency, 2014). The released amount of P into Skagerrak was 116 tons during 2015 (www.miljomal.se, 2017). Nitrogen remediation is estimated to be 120 kg per ha and year based on 2.13% N (dry weight) or 6,500 tons per 555 km^2 and year. Phosphorous remediation is similarly estimated to be 40 kg per ha and year with a P content of 0.79% or 2400 tons per 555 km^2 and year. While these figures are likely an upper estimate, nutrient availability might be the limiting factor for algae cultivation. Uptake of marine nutrients from cultivation of sea squirts was estimated to 25 kg C, 2.5 kg N and 0.2 kg P per ton of wet sea squirts (Loo and Petersen, 2013). The dry weight content of sea squirts is approximately 4.5%, which gives a dry weight nutrient fraction of 5.6% N and 0.44% P. Based on the same available area for cultivation as for macro algae and a productivity of 1,350 tons wet weight biomass per year, this corresponds to a nutrient remediation capability for N of 187,000 tons per 555 km^2 and year or 3.4 tons per ha and year. Nutrient remediation capability for P under the same conditions is estimated to 14,800 tons of P per 555 km^2 and year or 270 kg per ha and year. In the case of sea squirts the total productivity is highly likely to be limited by available nutrients rather than available area for cultivation, i.e. the total yearly release of P into Skagerrak from Swedish sources would support only 430 ha or 0.8% the theoretical productivity in the 555 km^2 of area available for cultivation.

High density cultivation could lead to wave damping, reduced water flows and currents, thereby contributing to sediment retention and reduced erosion (Smale et al., 2013).

Maintenance of physical, chemical and biological conditions

The C content over the whole season for sugar kelp grown in Swedish waters was 28±0.5%, with the highest value (31.4±0.6% of the dry weight) obtained in late summer (Henriksson and Egeskog, 2015). The P content was 7.9 kg per ton and the N content 21.3 kg per ton (Pechsiri et al., 2016). The mass of the C in the algae can be recalculated into equivalents of CO_2 in order to estimate the amount of fixed atmospheric CO_2 as one important regulating service. In the case of cultivation under Swedish conditions, with 28% C, 22% dry weight and approximately 25 tons harvested per ha (wet weight), the amount of sequestered CO_2 fixed into the algae would be 313,000 tons per 555 km^2 and year or 5.6 tons per ha and year. Sweden's CO_2 emissions was 43.1 million tons 2015 (Swedish Environmental Protection Agency, 2017) which corresponds to 138 times the 555 km^2 of theoretically available cultivation area or that 10 million ha (100,000 km^2) of cultivation area would be needed to sequester all the CO_2 i.e. ca. 17% of Sweden's total area. The CO_2 uptake by the macroalgae will however be better than by rapeseed and soybean (Yanfen et al., 2012). At the same time as 5.6 tons per ha and year of CO_2 is fixed in the photosynthesis process, 4.1 tons per ha and year of oxygen is produced based on the theoretical 1:1 (CO_2:O_2) molar conversion.

Sea squirts are not primary producers and therefore do not directly sequester CO_2. The dry matter content of sea squirts is approximately 4.5%. The methane yield during co-digestion of sea squirts with other substrates is estimated to approximately 14.6 MJ of methane per kg dry matter. Accounting for GHG emissions in the process of producing transportation fuel grade bio-methane approximately 29 g CO_{2eq} per MJ fuel are emitted. Assuming that the bio-methane replaces fossil transportation fuels (84 g CO_2 per MJ fuel) (Hackl et al., 2017) GHG emissions savings of approximately 36 g CO_{2eq} per kg of wet sea squirt substrate can be achieved.

Macroalgae cultivation could lead to an increased production of primary marine biomass, since kelp forests are some of the most productive habitats on the planet reproducing successfully and providing shelter and food for a range of other organisms, for example fish (Smale et al., 2013). Cultivation could also cause reduced light levels and nutrient availability for other species. Since sea squirts can be grown at greater depths, the effect of sea squirt cultivation on primary production might be less significant.

Sea squirts in cultivations filter for microorganisms and could be seen as purifying the water from for example parasites. Monocultures might increase the vulnerability of algae and sea squirts or other species in close proximity to the cultivation site. Pests are more likely to occur. This probably depends on scale and harvesting techniques employed. Monocultures in the same growth stage will be most vulnerable. Ineffective harvest methods leaving biomass will increase the risks. However, rich habitats will typically reduce the risk for pests and increase the stability and resilience.

The biodiversity and food web dynamics of plant and animal species in kelp forests as compared to a clean soft ocean floor should also be considered. About 90% of fish <15 cm in size may disappear if the kelp is removed (Henriksson and Egeskog, 2015). This ocean forest creates a sheltered biotope for mammals, fish, crabs among a large number of other organisms (Smale et al., 2013). Sea urchins can graze the young kelp plants if attached to the bottom (Norderhaug and Christie, 2009). Cultivation areas are attractive hiding places for fish, thus providing a habitat for an increased availability of younger, smaller and different kinds of species which could allow for larger diversity and food web interactions. In general, sea squirts are not an attractive food source for other species and are therefore not likely to attract predators to feed on them (Loo and Petersen, 2013). However, reports state that marine fauna like sea stars (*Asterias rubens*) (Gulliksen and Skjæveland, 1973), shore crab (*Carcinus maenas*) (Carver et al., 2003) and a number of fish, e.g. the European flounder (*Platichtys flesus*) och the European plaice (*Pleuronectes platessa*) (Nordgaard, 1913) potentially eat sea squirts mainly in its juvenile form. If such predator species will be attracted to cultivation areas of sea squirts for feed, and thus affect the biodiversity around cultivation areas, is not yet documented.

7.3 IMPACT ON CULTURAL SERVICES

Physical and intellectual interaction with biota, ecosystems and landscapes

Increased aquaculture areas means that the area available for recreational and training activities will be reduced, since the biomass production will compete with areas for e.g. boating, wind surfing, diving, and similar activities. On the other hand, areas near the cultivation may become very popular for angling, scuba-diving and snorkeling (Smale et al., 2013). Other recreational activities as e.g. bathing will only be limited affected since cultivation areas normally will be on deeper water a bit off-shore. Fishing should improve in the cultivated, protected habitats carrying increased abundance of fish, though fishing within cultivation areas might not be feasible.

Cultivation sites may attract sea birds leading to positive impact on bird populations and bird watching. Harvesting boats will create noise that may disturb fishing, bird watching and other recreational activities. Decreasing areas for recreational activities as well as negative influence on aesthetics might from large scale cultivation have negative impacts on tourism. The fishing tourism might however be impacted positively with more interested visitors.

Noise and emissions from harvest boats may impact mental and physical health locally. However, during the summer season the peak in recreational boating will clearly supply larger amounts of noise and emissions than harvesting boats will. Most of the noise and air emissions from harvesting boats will occur at the cultivation site, which means that the negative effect on mental and physical health is limited due to the location of the cultivations sites in relative far distance from the coast.

Cultivations sites might be visible from the coast. From an aesthetic point of view this might be negative mainly due to visible buoys on the water surface. However, due to the relatively large distance of the cultivation sites from the shore this effect might not be pronounced. Handling of the macroalgae and sea squirts during harvest in harbors may attract both positive and negative attention. In order to not disturb more than necessary this work should rather be done in industrial harbors than in the marinas.

The development of macroalgae- and sea squirts-based industries occurs in cooperation with different research and educational activities. There is a large potential for further new emerging research and development, e.g. on invention of novel materials and marine-based pharmaceuticals.

Spiritual, symbolic and other interactions with biota, ecosystems and seascapes

Cultivations may provide ways to preserve the culture of the local population in remote areas due to the creation of job.

8 DISCUSSION AND CONCLUSION

We present a synthesis of current knowledge on the potential impacts of an intensification of marine biomass production for biofuel production on ecosystem services from a Swedish perspective. The purpose is to provide research-based knowledge and decision support for policymakers, industrial actors and other stakeholders, with the aim to support qualified and sustainable choices linked to future marine based biomass production for biofuels. Even though marine biomass production seems promising as a future feedstock for biofuels, there is a potential risk that a large intensification of production of marine biofuels will affect the ecosystem negatively through changes of habitat and species abundance, but also positive impacts might occur. A screening of possible impacts of marine-based biofuel production needs to be examined.

In our work, we looked at which ecosystem services may be affected by production of marine feedstock for biofuels in Sweden. We identified and described ecosystem services and their appropriate indicators in general (Chapter 5, Table 2) using the CICES classification and the Ecosystem Service Cascade Model (Chapter 4). In the case of an intensified marine biofuel production in Sweden, the potential influence on each of these ecosystem services was discussed. (Chapter 7, Table 3). This part of the study was performed for two promising marine feedstocks for biofuels production, namely the macroalgae sugar kelp and the sea squirt (Chapter 6). Our study focuses on ecosystem services associated with the biomass production phase of these feedstock species.

The marine environment serves a variety of purposes and provides a multitude of ecosystem services and the ways in which ecosystem services are interacting are complex (Meyerson et al., 2005; Bennett et al., 2009). Interaction between the different ecosystem services may lead to both positive and negative feedback (Bennett et al., 2009). There is evidence that biofuel production through cultivation of macroalgae and sea squirts offer ecosystem services but also compromise other services (e.g. SCOPE, 2009; Fischer et al., 2009).

The consequences of increased aquaculture of algae and sea squirts on <u>provisional services</u> are largely positive, e.g. the amount of wild fish and other species is expected to increase in and around macroalgae cultivation sites, as well as increased production of feed, energy and fertilizers from macroalgae and sea squirts. Primary producers such as macroalgae conduct photosynthesis where solar energy and nutrients are converted to biomass. Thus, they ultimately are the foundation of food production for human consumption. Primary production, biochemical cycling and food web dynamics are ecosystem services necessary for food production (Swedish Environmental Protection Agency, 2008). Additionally, the ability of the marine environment to produce food is strongly dependent on ecosystem services such as habitat availability, diversity and resilience in order to deal with biotic and abiotic changes of the ecosystem. In return, food production provides food for human consumption along with cultural services such as recreational and touristic fishing. Neighboring areas to algae and/or sea squirt aquacultures might experience negative effects as e.g. sea squirts are known to compete with mussel cultivations.

Consequences on <u>regulating and maintenance services</u> are both positive and negative. Large scale cultivation of macroalgae and sea squirts in monocultures might lead to low resilience and the spreading of pests. On the other hand, the risk for sea squirts to become an invasive species is insignificant. Furthermore, cultivation of macroalgae or sea squirt counteracts eutrophication by removing nutrients like N and P from the marine environment when biomass is harvested. Climate change can be mitigated when biofuels from marine biomass replace fossil fuels. Another positive potential effect for both algae and sea squirts is the removal of heavy metals from the marine environment in case the harvested biomass is handled correspondingly. Whether the ability of macroalgae and sea squirts to fixate heavy metals and regulate hazardous substances influences the quality of food produced has not been investigated enough yet. On the other hand, large scale aquacultures may lead to low resilience and the dispersal of pests.

Cultural services, such as recreation, tourism and physical and mental health can to some extent be influenced negatively, mainly due to increased boat activity at harvesting and the aesthetic consequences of the cultivation sites. On the other hand, it creates interest for visitors, jobs are created and research and development activities associated with the marine biomass production systems could have positive impacts on the coastal communities.

The exact location, the amount and the size of marine biomass cultivations will largely influence the extent to which ecosystem services are influenced. As such, there is a need to evaluate the locations of different activities and how they provide synergies and trade-offs. In general, effects become more apparent at larger scale of production. Currently, no large scale production of marine biomass for energy purposes is in operation in Sweden. At current biofuels prices in relation to expected production costs for large scale biofuels production from marine feedstocks and in the absence of supporting policies, only producing biofuels is not economically feasible at present.

Co-cultivation of macroalgae and sea squirts in order to increase biomass output and thereby decrease production costs, as well as the co-production of biofuels with other high value products are ways to overcome these economic trade-offs. Examples of high value products are fish feed from the protein rich body of sea squirts and bioactive compounds from macroalgae. Services that can be provided by macroalgae and/or sea squirt cultivation are uptake of nutrients from fish farms. In this way, marine biomass cultivation can be used to counteract the negative environmental effects of fish cultivation and thereby reducing the risk of eutrophication posed by fish farming, while algae and sea squirt biomass can be used to provide fuel, fish feed and fertilizers for agriculture. Such co-cultivation needs to be further investigated.

The use of the ecosystem services concept in evaluating the overall system effects (environmental, social and economic) of an intensified biofuel production based on biomass from marine ecosystems involves a holistic perspective where the relation between mankind and nature is in focus. We conclude that the use of the ecosystem services concept assists in envisioning more aspects of sustainability linked to biofuels, which are not discussed to a great extent in the biofuel debate of today. We believe that the qualitative and semi-quantitative valuation of ecosystem services presented here (Chapter 7) provides a useful overview and a multifunctional understanding of the possible impacts of an intensified biofuel production from marine feedstocks in Sweden.

We suggest a range of specific indicators for marine ecosystem services (Gross list, Table 2) as reference indicators to assess changes in marine ecosystems. In order to continue and deepen an ecosystem service assessment of an intensified biofuel production based on biomass from marine ecosystems, indicators need to be prioritized. Prioritizing indicators through a selection procedure and further assessing them in order to analyze the development for chosen ecosystem services for longer time periods is an important extension of this study. For some provisioning ecosystem service indicators, historical data is available to quantify and value service indicators on suitable spatial and temporal scales and to follow up impacts. For other indicators, for example the cultural, and the regulating and maintenance services, there is few such data available. More analyses on the willingness to pay for certain services as well as on avoided costs are desirable in order to visualize and value these services from an economic point of view. Nevertheless, the methodology applied in this report, including qualitative and semi-quantitative valuation, is helpful in understanding the implications of biofuel production from marine feedstocks on ecosystem services as an important first step towards assuring sustainable biofuel production and making informed and well-thought-out decisions.

REFERENCES /REFERENSER

Adams J.M., Gallagher J.A., Donnison I.S., 2009. Fermentation study on Saccharina latissima for bioethanol production considering variable pre-treatments, Journal of Applied Phycology 21, 569.

Adevi A., Grahn P., 2011. Attachment to certain natural environments: a basis for choice of recreational settings, activities and restoration from stress? Environment and Natural Resources Research 1, 36-52.

Ahn J.W., Hwangbo K., Lee S.Y., Choi H.-G., Park Y.-I., Liu J.R., Jeong W.-J., 2012. A new Arctic Chlorella species for biodiesel production. Bioresource Technology 125, 340-343.

Alvarado-Morales M., Boldrin A., Karakashev D.B., Holdt S.L., Angelidaki I., Astrup T., 2013. Life cycle assessment of biofuel production from brown seaweed in Nordic conditions. Bioresource Technology 129, 92-99.

Anastasakis K., Ross A.B., 2011. Hydrothermal liquefaction of the brown macro-alga Laminaria Saccharina: Effect of reaction conditions on product distribution and composition. Bioresource Technology 102, 4876–4883.

Anderson S. 2014. Energianvändningen i gasbussar- Nuläge och prognos. En utredning utförd av 2050 på uppdrag av Västra Götalandsregionen och Region Skåne.

Andersson V, Broberg Viklund S, Hackl R, et al. 2014. Algae-based biofuel production as part of an industrial cluster. Biomass and Bioenergy 71:113–124 . doi: 10.1016/j.biombioe.2014.10.019

Barbot Y.N., Al-Ghaili H., Benz R., 2016. A Review on the Valorization of Macroalgal Wastes for Biomethane Production. Roussis V, ed. Marine Drugs 14(6), 120. doi:10.3390/md14060120.

Bekkby T., Moy F., 2011. Developing spatial models of sugar kelp (Saccharina latissima) potential distribution under natural conditions and areas of its disappearance in Skagerrak. Estuarine, Coastal and Shelf Science 95(4), 477-483.

Bennett E.M., Peterson G.D., Gordon L.J., 2009. Understanding relationships among multiple ecosystem services. Ecology Letters 12, 1394-1404.

Bergström L., 2005. Macroalgae in the Baltic Sea: responses to low salinity and nutrient enrichment in Ceramium and Fucus. PhD thesis, Umeå University, ISBN: 91-7305-816-5.

Bringezu S., Brien M.O., Howarth R.W., Weizsäcker U.V., Hardy Y., Bustamante M., Aksornkoae S., Bella A., McGlade J., 2009. Towards Sustainable Production and Use of Resources: assessing biofuels. United Nations Environmental Programme and International Panel for Sustainable Resource Management, 40 pp.

Broch O., Slagstad D., 2012. Modelling seasonal growth and composition of the kelp Saccharina latissima. Journal of Applied Phycology 24(4), 759-776.

Broch O., Ellingsen I.H., Forbord S., Wang X., Volent Z., Alver M.O., Handå A., Andresen K., Slagstad D., Reitan, K.I., Olsen Y., Skjermo J., 2013. Modelling the cultivation and bioremediation potential of the kelp Saccharina latissima in close proximity to an exposed salmon farm in Norway. Aquacult Environ Interact 4, 187-206.

Brouwer R., Brander L., Kuik O., Papyrakis E., Bateman I., 2013. A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB. TEEB follow-up study for Europe, Final report. University of Amsterdam. Available: http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/EU%20Valuation.pdf

Börjesson P., 2016. Potential för ökad tillförsel och avsättning av inhemsk biomassa i en växande svensk bioekonomi. Lunds Universitet. Rapport nr. 97. ISSN 1102-3651.

Carlsson M, Henningsson G., 2015. Lab scale experiments with Ciona added to a biogas process (Labförsök med tillsats av Ciona i biogasprocess). AnoxKaldnes, Lund, Sweden

Carver C.E., Chisholm A., Mallet A.L., 2003. Strategies to mitigate the impact of *Ciona intestinalis* (L.) biofouling on shellfish production. Journal of Shellfish Research 22, 621–632.

Chader S., Mahmah B., Chetehouna K., Amrouche F., Abdeladim K., 2011. Biohydrogen production using green microalgae as an approach to operate a small proton exchange membrane fuel cell. International Journal of Hydrogen Energy 36(6), 4089-4093.

Christiaen L., Wagner E., Shi W., Levine M., 2009. The sea squirt Ciona Intestinalis. Cold Spring Harb Protoc 2009, http://dx.doi.org/10.1101/pdb.emo138pdb.emo138.

Clarens A.F., Nassau H., Resurreccion E.P., White M.A., Colosi L.M., 2011. Environmental Impacts of Algae-Derived Biodiesel and Bioelectricity for Transportation. Environmental Science & Technology 45, 7554–7560.

Coelho M.S., Barbosa F.G., Souza M.R.A.D., 2014. The scientometric research on macroalgal biomass as a source of biofuel feedstock. Algal Research 6, 132–138.

Costanza R., d'Arge R., de Groot R., Farber S.C., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton P., van den Belt M., 1997. The value of the world's ecosystem services and natural capital. Nature, 387, 253-260.

Daily G., 1997. Introduction: what are ecosystem services? In: Daily, G. (Ed.) Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington DC.

Dale V.H., Efroymson R.A., Kline K.L., Langholtz M.H., Leiby P.N., Oladosu G.A., Davis M.R., Downing M.E., Hilliard M.R., 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 26, 87-102.

Dale V.H., Efroymson R.A., Kline K.L., 2015. A framework for selecting indicators of bioenergy sustainability. Biofuels, Bioproducts and Biorefining 9, 435-446.

Dave A., Huang Y., Rezvani S., McIlveen-Wright D., Novaes M., Hewitt N., 2013. Techno-economic assessment of biofuel development by anaerobic digestion of European marine cold-water seaweeds. Bioresource Technology 135, 120-127.

Davidsson Å., 2007. Tång och alger som en naturresurs och förnyelsebar energikälla - Rapport Steg 1, Trelleborg.

Demirbas A., 2010. Use of algae as biofuel sources. Energy Conversion and Management 51, 2738-2749.

Demirbas A., Fatih Demirbas M., 2011. Importance of algae oil as a source of biodiesel. Energy Conversion and Management 52, 163-170.

Dick, J.M., Smith, R.I., Scott, E.M., 2011. Ecosystem services and associated concepts. Environmetrics 22, 598-607.

Dupont S., Dorey N., Thorndyke M., 2010. What meta-analysis can tell us about vulnerability of marine biodiversity to ocean acidification? Estuarine, Coastal and Shelf Science 89, 182-185.

Dybern, Bernt. I. "The Life Cycle of Ciona Intestinalis (L.) F. Typica in Relation to the Environmental Temperature." Oikos 16, no. 1 (1965): 109–31.

Efroymson R.A., Dale V.H., Kline K.L., McBride A.C., Bielicki J.M., Smith R.L., Parish E.S., Schweizer P.E., Shaw D.M., 2013. Environmental Indicators of Biofuel Sustainability: What About Context? Environmental Management 51, 291-306.

Ehrlich, P.R., Mooney, H.A., 1983. Extinction, substitution, and ecosystem services. BioScience 33(4), 248-254.

Elmberg, J., 2009. Jaktbara svenska fågelarters utveckling under 50 år. Vilt och Fisk. Nr 3 2009.

Energigas Sverige, 2016. Production and use of biogas and residues from digestion in 2015 (In Swedish). Swedish Energy Agency, Stockholm, Sweden, No. ES 2016: 04.

European Union, 2008. Directive 2008/56/ec of the european parliament and of the council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

European Union, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Directive 2009/28/EC (ed. E. Union). European Union, Brussels, Belgium.

European Union, 2011. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM (2011) 244 final. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, Belgium.

Eurofins Environment Sweden AB (2010) Lab report - Ciona composition. Eurofins Environment Sweden AB, Lidköping.

Fargione J.E., Plevin R.J., Hill J.D., 2010. The Ecological Impact of Biofuels. Annual Review of Ecology, Evolution and Systematics 41, 351-377.

Fisher B., Turner R.K., Morling P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68, 643-653.

Fonseca M.S., 1989. Sediment stabilisation by *Halophila decipiens* in comparison to other seagrasses. Estuarine Coastal and Shelf Science 29, 501-507.

Forum Skagerrak (2004) Musslor för miljön – musselodlingens positiva och negativa miljöeffekter. Kristinebergs Marina Forskningsstation, ISBN: 91-89507-09-6.

Frank E.D., Elgowainy A., Han J., Wang Z., 2013. Life cycle comparison of hydrothermal liquefaction and lipid extraction pathways to renewable diesel from algae. Mitigation and Adaptation Strategies for Global Change 18(1), 137-158.

Fredman P., Karlsson S.-E., Romild U., Sandell K., 2008a. Vara i naturen – varför eller varför inte? (In Swedish). Rapport 2, Friluftsliv i förändring, http://www.diva-portal.org/smash/get/diva2:128283/FULLTEXT01.pdf.

Fredman P., Karlsson S.-E., Romild U., Sandell K., 2008b. Vilka är ute i naturen? Delresultat från en nationell enkät om friluftsliv och naturturism i Sverige (In Swedish). Rapport nr 1. ISBN 978-91-86073-06-0. 25 pp.

Fredman P., Stenseke M., Sandell K., Mossing A., 2013. Friluftsliv i förändring. Resultat från ett forskningsprogram (In Swedish). Slutrapport. Naturvårdsverket Rapport 6547. ISBN 978-91-620-6547-8. 333 pp.

Fredman P., Hedblom M., 2015. Friluftsliv 2014. Delrapportering av en nationell enkät om svenska folkets friluftsvanor. Mittuniversitetet och SLU, 84 pp.

Gasparatos A., Lee L.Y., von Maltit G.P., Mathai M.V., de Oliveira J.a.P., Willis K.J., 2012. Biofuels in Africa: Impacts on ecosystem services, biodiversity, and human wellbeing. pp. 116-116. Yokohama, Japan.

Gasparatos A., Stromberg P., Takeuchi K., 2011. Biofuels, ecosystem services and human well-being: Putting biofuels in the ecosystem services narrative. Agriculture, Ecosystems & Environment 142, 111-128.

Grabowski R.C., Droppo I.G., Wharton G., 2011. Erodibility of cohesive sediment: The importance of sediment properties. Earth-Science Reviews 105, 101–120.

Gulliksen B., 1972. Spawning, larval settlement, growth, biomass, and distribution of Ciona intestinalis L. (Tunicata) in Borgenfjorden, North-Tröndelag, Norway. Sarsia 51:83–96. doi: 10.1080/00364827.1972.10411225.

Gulliksen B., Skjæveland S.H., 1973. The sea-star, Asterias rubens L., as predator on the ascidian, *Ciona intestinalis* (L.), in Borgenfjorden, North-Tröndelag, Norway. Sarsia 52, 15–20.

Hansen P.K., Ervik A., Schaanning M., Johannessen P., Aure J., Jahnsen T., Stigebrandt A., Gustafson A., 2007. Leaching Losses of Nitrogen from Agricultural Soils in the Baltic Sea Area. Chapter 8 in Reducing Nutrient Losses from Agriculture, Swedish University of Agricultural Sciences, pp 65-81.

Haamer J., Holm A.S., Edebo L., Lindahl O., Norén F., Hernroth B., 1999. Strategic mussel farming to create sustainability and balance in the ecosystem (In Swedish). Swedish National Board of Fisheries, Gothenburg, Sweden, 1999.

Hackl R, Hansson J, Norén F, et al., 2017. Cultivating Ciona intestinalis to counteract marine eutrophication: Environmental assessment of a marine biomass based bioenergy and biofertilizer production system. Renewable Energy. doi: 10.1016/j.renene.2017.07.053

Haines-Young R., Potschin M., 2010. Common International Classification of Ecosystem Services (CICES): 2011 Update. Paper prepared for discussion at the expert meeting on ecosystem accounts organised by the UNSD, the EEA and the World Bank. London, UK, European Environmental Agency: 19.

Haines-Young R., Potschin M., 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. Report to the European Environmental Agency. EEA Framework Contract No. EEA/IEA/09/003. European Environmental Agency, Nottingham, UK, p. 19.

Handå A., Forbord S., Wang X., Broch O.J., Dahle S.W., Størseth T.R., Reitan K.I., Olsen Y., Skjermo J., 2013. Seasonal- and depth-dependent growth of cultivated kelp (Saccharina latissima) in close proximity to salmon (Salmo salar) aquaculture in Norway. Aquaculture 414–415, 191-201.

Hanning A., 2013. Den svenska maritima näringen 2007–2011. Vinnova Analys rapport VA 2013: 09. Fritzes, Stockholm, 68 s.

Hansen K., Malmaeus M., Lindblad M., 2014. Ekosystemtjänster i svenska skogar. IVL Rapport B2190, 85 pp.

Hansen K., Malmaeus M., 2016a. Ecosystem services in Swedish forests. Scandinavian Journal of Forest Research 31(6), 626-640. DOI:10.1080/02827581.2016.1164888.

Hansen K., Hansson J., Maia de Souza D., Russo Lopes G., 2016b. Biofuels and ecosystem services. Report No 2018:01, f3 The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden. Available at www.f3centre.se.

Hansen R., Pauleit S., 2014. From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. Ambio 43(4), 516-529.

HELCOM, 2017. First version of the 'State of the Baltic Sea' report – June 2017 – to be updated in 2018. Available at: http://stateofthebalticsea.helcom.fi

Hellmann F., Verburg P.H., 2010. Impact assessment of the European biofuel directive on land use and biodiversity. Journal of Environmental Management 91, 1389-1396.

Henriksson P., Egeskog J., 2015. Ecosystem services deriving from sugar kelp cultivation in Skagerrak. Bachelor of Science Thesis, KTH School of Industrial Ecology, Stockholm.

Holling C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4,1-23.

Holmgren A., 2012. Summary of measurements within the voluntary measures on decreased methane emissions from biogas production 2007 - 2012 (Sammanställning av mätningar inom frivilligt åtagande 2007 - 2012). Avfall Sverige, Malmö, Sweden.

Howarth R.W., Marino R., 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades, Limnol. Oceanogr. 51, 364e376.

Huesemann M.H., Kuo L-J., Urquhart L., Gill G.A., Roesijadi G., 2012. Acetone-butanol fermentation of marine macroalgae. Bioresource Technology 108, 305-309.

Hughes A.D., Kelly M.S., Black K.D., Stanley M.S., 2012. Biogas from Macroalgae: is it time to revisit the idea? Biotechnology for Biofuels 5, 86.

Härkönen T., 1983. Vattensystemen i området: Råssö till havstenssund med sannäsfjorden. Länsstyrelsen Västra Götaland.

Håkanson L., Ragnarsson Stabo H., Bryhn A.C., 2010. The fish production potential of the Baltic Sea. Springer, Berlin/Heidelberg, 396 pp.

ICES, 2014. ICES Advice 2014. ICES, Copenhagen.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, 1535 pp.

Jard G., Jackowiak, D., Carrére, H., Delgenes, J.P., Torrijos, M., Steyer, J.P., Dumas, C., 2012. Batch and semi-continuous anaerobic digestion of Palmaria palmata: Comparison with Saccharina latissima and inhibition studies. Chemical Engineering Journal 209, 513-519.

Jard G., Marfaing H., Carrère H., Delgenes J.P., Steyer J.P., Dumas C., 2013. French Brittany Macroalgae Screening: Composition and Methane Potential for Potential Alternative Sources of Energy and Products. Bioresour. Technol. 144, 492-498.

Jarvis Å., Schnürer A., 2009. Microbiological handbook for biogas plants (Mikrobiologisk handbok för biogasanläggningar). Swedish Center for Gas Technology, Sweden.

John R.P., Anisha G.S., Nampoothiri K.M., Pandey A., 2011. Micro and macroalgal biomass: A renewable source for bioethanol. Bioresource Technology 102, 186-193.

Koh L.P., 2007. Potential habitat and biodiversity losses from intensified biodiesel feedstock production. Conservation Biology 21, 1373-1375.

Landers D.H., Nahlik A.M., 2013. Final ecosystem goods and services classification system (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Lassus P., Fremy J.-M.. Ledoux M., Bardouil M., Bohec M., 1989. Patterns of experimental contamination by Protogonyaulax tamarensis in some French commercial shellfish. Toxicon 27, 1313-1321.

Liu H., Wang G. 2014. Fermentative hydrogen production from macroalgae Laminaria japonica using anaerobic mixed bacteria. International Journal of Hydrogen Energy 39(17), 9012-9017.

Loo L.-O., Petersen J.K., 2013. Environmental consequences of cultivating sea squirts Ciona intestinalis (Miljökonsekvenser av odling av tarmsjöpungen Ciona intestinalis). Institute for biology and environmental sciences at Gothenburg University, Strömstad, Sweden

Länsstyrelsen Västra Götalands Län, 2008. Marint områdesskydd Västra Götalands Län. Hav i balans samt levande kust och skärgård. http://www.tillvaxtbohuslan.se.

Länsstyrelsen Västra Götalands Län, 2014a. Miljögifter och miljögiftseffekter i blåmussla. Miljöövervakning i Västra Götalands län 2014. Rapport 2015:18, ISSN: 1403-168X, 44 pp.

Länsstyrelsen Västra Götalands Län, 2014b. Vattenbruksplan för Västra Götaland – Marina områden. Av Per Bergström, pp 1-51.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC. www.millenniumassessment.org/en/index.html

Maes J., Teller A., Erhard M., Liquete C., Braat L., Berry P., Egoh B.N., Puydarrieux P., Fiorina C., Santos-Martín F., Paracchini M.L., Keune H., Wittmer H., Hauck J., Fiala I., Verburg P.H., Condé S., Schägner J.P., San Miguel-Ayanz J., Estreguil C., Ostermann O.P., Barredo Cano J.I., Pereira H.M., Stott A., Laporte V., Meiner A., Olah B., Royo Gelabert E., Spyropoulou R., Petersen J.-E., Maguire C., Zal N., Achilleos E., Rubin A., Ledoux L., Murphy P., Fritz M., Brown C., Raes C., Jacobs S., Raquez P., Vandewalle M., Connor D., Bidoglio G., 2013. Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Publications Office of the European Union, Luxembourg. http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

Marin Biogas AB. 2015. Biogas production from *Ciona intestinalis*. Company presentation.

Marinho G., Holdt S.L., Jacobsen C., Angelidaki I., 2015. Lipids and Composition of Fatty Acids of Saccharina latissima Cultivated Year-Round in Integrated Multi-Trophic Aquaculture. Mar. Drugs 13(7), 4357-4374.

Meyerson L.A., Baron J., Melillo J.M., Naiman R.J., O'Malley R.I., Orians G., Palmer M.A., Pfaff A.S.P., Running S.W., Sala O.E., 2005. Aggregate measures of ecosystem services: can we take the pulse of nature? Frontiers in Ecology and the Environment 3, 56-59.

Milledge J.J., Smith B., Dyer P.W., Harvey P., 2014. Macroalgae-Derived Biofuel: A Review of Methods of Energy Extraction from Seaweed Biomass. Energies 7(11), 7194-7222.

Nahlik A.M., Kentula M.E., Fennessy M.S., Landers D.H., 2012. Where is the consensus? A proposed foundation for moving ecosystem services into practice. Ecological Economics 77, 27-35.

Nelson E., Mendoza G., Regetz J., Polasky S., Tallis H., Cameron D., Chan K.M.A., Daily G.C., Goldstein J., Kareiva P.M., Lonsdorf E., Naidoo R., Ricketts T.H., Shaw M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7, 4-11.

Nielsen M.M., Manns D., D'Este M., Krause-Jense D., Rasmussen M.B., Larsen M.M., Alvarado-Morales M., Angelidaki I., Bruhn A., 2016. Variation in biochemical composition of Saccharina latissima and Laminaria digitata along an estuarine salinity gradient in inner Danish waters Algal Research 13, 235-245.

Norderhaug K.M., Hartvig C., Christie H.C., 2009. Sea urchin grazing and kelp re-vegetation in the NE Atlantic. Marine Biology Research 5, 515-528.

Nordgaard O., 1913. Utklækning av guldflyndare. Det Kongelige Norske Videnskabers Selskabs Skrifter 6, 1-104.

Norén, F., 2017. pers. comm.

Norén F, Norén K, Magnusson K, et al., 2012. Ekologiska effekter av ascidieodling. Lysekil Municipality, Lysekil, Sweden

Odhner P.B., Grontmij A.B., Thelin H., et al., 2013. Marin biogas-cultivation of ascidians for biogas production (Marin biogas-odling av ascidier för biogasproduktion).

Ohlsson L., Karlsson D., Gustafsson L.-G., 2011. Tätorters inverkan på recipienters bakteriella status. Rapport 2011-08. Svenskt Vatten Utveckling, Stockholm, 92 pp.

Olrog L., Christensson E., 2003. Musselodling och jordbruk i samverkan. Hushållningssällskapet, Dingle, 20 s.

Oirshot R., Thomas J.-B.E., Gröndahl F., Fortuin K.P.J., Brandenburg W., Potting J., 2017. Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. Algal Research 27, 43-54.

Onwudili J.A., Lea-Langton A.R., Ross A.B., Williams P.T., 2013. Catalytic hydrothermal gasification of algae for hydrogen production: Composition of reaction products and potential for nutrient recycling. Bioresource Technology 127, 72–80.

Park J.-I., Lee J.L., Sim S.J., Lee J.-H., 2009. Production of hydrogen from marine macro-algae biomass using anaerobic sewage sludge microflora. Biotechnology and Bioprocess Engineering 14, 307.

Pechsiri J., Thomas J.-B.E., Risén E., Ribeiro M.S., Malmström M.E., Nylund G.M., Jansson A., Welander U., Pavis H., Gröndahl F., 2016. Energy performance and greenhouse gas emissions of kelp cultivation for biogas and fertilizer recovery in Sweden. Science of the Total Environment 573, 347–355.

Peteiro C., Sanchez N., Duenas-Liano C., Martinez B., 2014. Open-sea cultivation by transplanting young fronds of the kelp Saccharina latissima. J Appl Phycol 26(1), 519-528.

Petersen J.K., Svane I., 1995. Larval dispersal in the ascidian Ciona intestinalis (L.). Evidence for a closed population. Journal of Experimental Marine Biology and Ecology 186(1), 89-102.

Power A.G., 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society of London B: Biological Sciences 365, 2959-2971.

Radakovits R., Jinkerson R.E., Darzins A., Posewitz M.C., 2010. Genetic Engineering of Algae for Enhanced Biofuel Production. Eukaryotic Cell 9(4), 486-501.

Rosqvist K., 2010. Distribution and role of macrophytes in coastal lagoons: Implications of critical shifts. Doktorsavhandling, Åbo Akademi. Åbo Akademi, Åbo, 39 pp.

SCB, 2014. Saltsjöfiskets fångster under december 2013 och hela år 2013. Preliminära uppgifter. Sveriges officiella statistik, statistiska meddelanden JO 50 SM 1402. SCB, Stockholm, 12 s.

SCB, 2017. Aquaculture in Sweden in 2016 (In Swedish). Sveriges Centrala Statistiska Byrå. Statistiska Meddelanden, JO 60 SM 1701.

Scharlemann J.P.W., Laurance W.F., 2008. Environmental science. How green are biofuels? Science 319, 43-44.

SCOPE (Scientifc Committee on Problems of the Environment), 2009. Biofuels: environmental consequences and interactions with changing land use. Proceedings of the SCOPE International Biofuels Project Rapid Assessment. http://cip.cornell.edu/DPubS?service=UI&version=1.0&verb=Display&handle=scope

Shumway S.E., Van Egmond H.P., Hurst J.W., Bean L.L., 1995. Management of shellfish resources. In: Haellegraeff, G. M., Anderson, D. M., Cembella, A. D. (Editors) Manual on Harmful Marine Microalgae. IOC Manuals and Guides 33, UNESCO: 433-461.

Smale D.A., Burrows M.T., Moore P., O´Connor P., Hawkings S.J., 2013. Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3(11), 4016-4038.

Soratana K., Harper Jr. W.F., Landis A.E. Microalgal biodiesel and the Renewable Fuel Standard's greenhouse gas requirement. Energy Policy 46, 498-510.

SOU, 2013:68 Synliggöra värdet av ekosystemtjänster - Åtgärder för välfärd genom biologisk mångfald och ekosystemtjänster. http://www.riksdagen.se/sv/Dokument-Lagar/Utredningar/Statens-offentliga-utredningar/Synliggora-vardet-av-ekosystem_H1B368/

Stadmark J., Conley D. J., 2011. Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles. Marine Pollution Bulletin 62, 1385-1388.

Swedish Environmental Protection Agency, 2008. Ecosystem services provided by the Baltic Sea and Skagerrak. Report 5873. ISBN 978-91-620-5873-9.pdf. 193 pp.

Swedish Environmental Protection Agency, 2009. Vad kan havet ge oss? Östersjöns och Västerhavets ekosystemtjänster. Rapport 5937, ISBN 978-91-620-5937-8.

Swedish Environmental Protection Agency, 2014. National Inventory Report 2014. Greenhouse gas emissions inventories 1990-2014. Stockholm: Naturvårdsverket.

Swedish Environmental Protection Agency, 2015. Guide för värdering av ekosystemtjänster. Rapport 6690, August 2015 (In Swedish).

Swedish Energy Agency, 2015a. Transportsektorns energianvändning 2014 (Energy use in the Swedish transport sector in 2014). ES 2015:01. Available (in Swedish): https://www.energimyndigheten.se/globalassets/nyheter/2015/transportsektorns-energianvandning-2014.pdf

Swedish Agency for Marine and Water Management, 2015. Ekosystemtjänster från svenska hav - Status och påverkansfaktorer. Havs- och vattenmyndighetens rapport 2015:12, ISBN 978-91-87025-83-9.

Söderqvist T., Soutokorva Å., Moreno-Arancibia P. et al., 2012. Marine tourism and recreation in Sweden. Rapport 2012:2. Havs- och vattenmyndigheten, Göteborg, 111 pp.

The Board of Agriculture, 2014. Marknadsöversikt – fiskeri- och vattenbruksprodukter. Jordbruks-verkets rapport 2014: 23. Jordbruksverket, Jönköping, 77 pp.

The Economics of Ecosystems and Biodiversity (TEEB), 2009. Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. Progress Press, Malta.

The Public Health Agency of Sweden, 2011. Giardia och Cryptosporidium i svenska ytvattentäkter. Smittskyddsinstitutet, Solna, 30 pp.

Therriault T.W., Herborg L.-M., 2008. A qualitative biological risk assessment for vase tunicate Ciona intestinalis in Canadian waters: using expert knowledge. ICES Journal of Marine Science 65, 781-787.

Tjensvoll I., 2014. Sediment resuspension: Impacts and extent of human disturbances. Doktors-avhandling, Stockholms universitet, 42 pp.

Tolstoy A., Willén T., 1997. Preliminär checklista över Makroalger i Sverige. - ArtDatabanken.

Tonderski K.S., 2016. Biorefineries and biogas solutions in a blue bio-economy. IFM Biology, Linköping University, Sweden.

Tuvendal M., 2012. Ecosystem services - a tool in sustainable landscape management. Doctoral Thesis in Natural Resources Management at Stockholm University, Sweden, 168 pp.

Wargacki A.J., Leonard, E., Win, M.N., Regitsky, D.D., Santos, C.N.S, Kim, P.B., Cooper, S.R., Raisner, R.M., Herman, A., Sivitz, A.B.,Lakshmanaswamy, A., Kashiyama, Y., Baker, D. & Yoshikuni, Y. 2012. An Engineered Microbial Platform for Direct Biofuel Production from Brown Macroalgae. Science 335:6066, 308-31.

Wiens J.J., Pyron R.A., Moen D.C., 2011. Phylogenetic origins of local-scale diversity patterns and causes of Amazonian megadiversity. Ecology Letters 14, 643-652.

Vihervaara, P., Kumpula, T., Tanskanen, A., Burkhard, B., 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Eco-logical Complexity, 7, 410-420.

Worm B., Barbier E.B., Beaumont N., Duffy J.E., Folke C., Halpern B.S., Jackson J.B.C., Lotze H.K., Micheli F., Palumbi S.R., Sala E., Selkoe K., Stachowicz J.J., Watson R., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314, 787-790.

Zhao Y., Li, J., 2016. Ascidian bioresources: common and variant chemical compositions and exploitation strategy – examples of Halocynthia roretzi, Styela plicata, Ascidia sp. and Ciona intestinalis. Zeitschrift für Naturforschung C - A Journal of Biosciences, ISSN 0939-5075, E-ISSN 1865-7125, 71(5-6), 165-180.

Yamaguchi M., 1975. Growth and reproductive cycles of the marine fouling ascidians Ciona intestinalis, Styela plicata, Botrylloides violaceus, and Leptoclinum mitsukurii at Aburatsubo-Moroiso Inlet (Central Japan). Marine Biology 29, 253–259.

Yanfen L., Zehao H., Xiaoqian M., 2012. Energy analysis and environmental impacts of microalgal biodiesel in China. Energy Policy 45, 142-151.

Yang W., Dietz T., Kramer D.B., Chen X., Liu J., 2013. Going Beyond the Millennium Ecosystem Assessment: An Index System of Human Well-Being. PLoS ONE 8, e64582.

APPENDIX: OUTREACH OF THE PROJECT

WEB PAGES AND SOCIAL MEDIA

Information about the project has been published at IVL's web site at the following link:

http://www.ivl.se/toppmeny/pressrum/nyheter/nyheter---arkiv/2017-02-23-okad-produktion-av-biodrivmedel-fran-havet---hur-paverkar-det-ekosystemet.html

INTERNAL PROJECT MEETINGS

Through the project time the consortium had in total four physical project meetings to advance the project.

REFERENCE GROUP

The reference group consisted of persons representing N-Research, the Maritime Cluster of West Sweden, Region Västra Götaland, and the CEO Swedish Algae Factory. The contact persons are:

Stakeholder	Person	E-mail
N-Research	Fredrik Norén	fredrik.noren@n-research.se
Maritime Cluster of West Sweden, Region Västra Götaland	Jessica Hjerpe Olausson	jessica.hjerpe.olausson@vgregion.se
CEO Swedish Algae Factory	Sofie Allert	sofie@swedishalgaefactory.com

The stakeholders assisted us in reviewing project progress and deliverables through one physical meeting held October 18th, 2017 at IVL in Gothenburg. Furthermore, the stakeholders reviewed and commented the final report.

PRESENTATIONS

- The project was presented orally at the annual general assembly of f3 in Umeå on February 6th-7th, 2017 by Karin Hansen.
- The project was presented to and discussed with the reference group in a half-day meeting at IVL in Gothenburg on October 18th, 2017.
- The project was presented orally at the program conference for the Swedish Energy Agency and f3 collaborative research program Renewable transportation fuels and systems in Uppsala on October 26th, 2017 by Karin Hansen.

The project was presented orally at the annual conference at the Maritime Cluster of West Sweden in Gothenburg on November 7th, 2017 by Julia Hansson.

www.f3centre.se

www.energimyndigheten.se