CASE STUDY BOOKLET

Valuation of kelp forest ecosystem services in the Falkland Islands (simplified version)

Acronym: MOVE

Title: MAPPING AND ASSESSING THE STATE OF ECOSYSTEMS AND THEIR SERVICES IN THE OUTERMOST REGIONS AND OVERSEAS COUNTRIES AND TERRITORIES: ESTABLISHING LINKS AND POOLING RESOURCES

Grant Agreement n° 07.027735/2018/776517/SUB/ENV.D2

Activity Name: Facilitating MAES in Europe´s Overseas
Task Name: Develop and test mapping tools
Deliverable Name:
Report of the development application and participative validation of mapping tools

This project has received funding from the European Commission Directorate - General Environment, under the grant 07.027735/2018/776517/SUB/ENV.D2

Document Information	
Document Name	CASE STUDY BOOKLET Valuation of kelp forest ecosystem services in the Falkland Islands (simplified version)
Case study coordinators	Tara Pelembe; Daniel T.I. Bayley
Author(s)	Daniel T.I. Bayley, Paul Brickle, Paul E. Brewin, Neil Golding, Tara Pelembe
Contributing authors	Gil, A.; Casas, E.; Baylis, A.; Santos-Martín, F.; Failler, P.

Summary

Kelp forests provide many important ecosystem services to people, including mitigating storm damage, cycling nutrients, and providing commercially-harvestable resources. However, kelp forests' ability to sequester carbon dioxide, and therefore help regulate the climate, has until recently, been overlooked in assessments of the beneficial services they provide. In this study we incorporate updated knowledge on the potential of kelp to sequester 'blue carbon', and use the extensive kelp forests of the Falkland Islands as a case study to assess the value of kelp forest to society through multiple associated ecosystem services. Our analysis shows kelp forests provide a highly valuable range of direct and indirect services, which if managed correctly, will continue to benefit people, both now and in the future. The total estimated value of the Falkland Islands' kelp system is currently equivalent to ~ £2.69 billion per year (or £3.24 million km^{-2} $year^{-1}$). However, the true value of the kelp forest surrounding the Falkland Islands is likely to be higher still, given that our estimate does not account for elements such as associated scientific research, tourism, and cultural services, due to the necessary data currently being unavailable. Similarly, the full value of these highly biodiverse ecosystems in supplying habitat and food to a large range of associated species is crucial, yet extremely difficult to fully quantify. This study illustrates the importance of maintaining kelp ecosystems in a healthy state to ensure they continue to supply valuable ecological processes, functional roles, and ecosystem services, including their overlooked role as significant long-term carbon sinks.

Contents

List of Figures

List of Tables

1. Introduction

1.1 Overview of the study area

The Falkland Islands, situated in the temperate and sub-polar South Atlantic, comprises two main islands (East and West Falkland) and 776 smaller surrounding islands (Fig. 1). This archipelago is relatively sparsely populated (2020 population = 3,480 or ~ 0.28 individuals km^{-1}) and is isolated geographically. The region is consequently relatively un-impacted by global human pressures (Jones et al. 2018).

The Falkland Islands is one of the UK's 14 overseas territories (UKOTs). As such, if they choose to have the UK's ratification of the Paris Agreement extended to them along with other UKOTs, they will be included in the UK's future accounting and reporting on emissions under the UN Framework Convention on Climate Change (UNFCC 2015). The surrounding marine area covers 463,897 km within the Exclusive Economic Zone, and includes both shallow and deep sea regions. The waters and coasts are home to a diverse mix of species (Otley et al. 2008) and extensive globally-significant Macrocystis pyrifera kelp forest habitat (Beaton et al. 2020). There is also a managed multi-species squid and finfish fishery which has been in place since 1987 and contributes to ~ 40% of Gross Domestic Product.

1.2 Research questions

This work aims to quantify and estimate the total value of the ecosystem services associated with the Falkland Islands' kelp forests, including their value in sequestering carbon dioxide, known as 'blue carbon'. We use a combination of high-resolution satellite-derived kelp habitat extent predictions along with a large dataset of in-situ density measurements to examine the ecosystem service value of these kelp forests. This work builds on previous analyses in this region, showing extensive kelp assemblages (Golding et al. 2019) and significant economic benefits from the Falkland Islands' natural systems (Bayley et al. 2017, Bormpoudakis et al. 2019, Smith 2019). We focus our analysis on quantifying the direct services of kelp-associated harvested goods, as well as the indirect services of nutrient cycling and climate buffering. Our results are presented to aid management of these important ecosystems and to improve the understanding of their value and benefit to society.

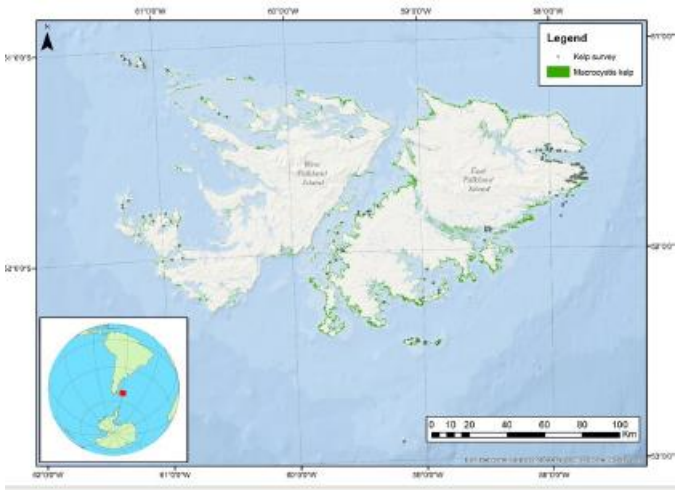

Figure 1 - Mapped distribution of kelp forest (*Macrocystis pyrifera*) across the Falkland Islands, based on habitat modelling undertaken in 2019 (Golding et al. 2019). Site location points of annual benthic surveys of kelp, conducted between 2008 and 2016 are shown (projection: WGS84 UTM zone 21S).

2. Methods and materials

Current kelp distribution was mapped using image classifications based on Sentinel 1 (band 1) and Sentinel 2 (all 10 m bands) satellite imagery; Shuttle Radar Topography Mission (SRTM) data; and Landsat 8, (band 1) inputs within Google Earth Engine (Golding et al. 2019).

Kelp density was calculated based on field survey data collected from across the Falkland Islands between 2008 and 2016 (Shallow Marine Surveys Group, unpublished data), with a total of 315 surveys conducted between 2008 and 2016 (Fig. 1).

Macrocystis pyrifera thalli mean wet weight (excluding bare stipes) was calculated using values from van Tussenbroek (1993) for spring and autumn and multiplied by the mean kelp density observed from surveys conducted during the same season (Table 1). We use the estimated current biomass of kelp to equate stored carbon in standing kelp stock, rather than daily rates of productivity per species (C m day) as used in other studies (Vásquez et al. 2014). This is because turnover of standing biomass is rapid and the total storage value using daily productivity modelled over a multi-year period would likely be an overestimate of total carbon. The mean weight of carbon per metre squared was multiplied by the calculated extent of *Macrocystis pyrifera* within the Falkland Islands to give a total carbon standing stock, then converted to CO using a conversion factor of 3.67 (based on relative atomic weights).

The average net primary productivity (NPP) of *Macrocystis pyrifera* kelp forest (including understorey species), is estimated to be in the range 670 – 1300 g C m yr , with a mean productivity value of 985 g C m yr (Reed and Bzezinski 2009). Following a global analysis by Krause-Jensen and Duarte (2016), sequestration through burial of Particulate Organic Carbon (POC) in deep waters is estimated as ~ 0.92% of annual NPP; sequestration through export of POC to the deep sea is ~ 2.30% of NPP; and sequestration through export of Dissolved Organic Carbon (DOC) is ~ 7.69% of NPP. Sequestration pathway proportions were then multiplied across the current known extent of kelp forest within the Falkland Islands and converted to CO equivalent (CO_2e) weight.

3. Results and main achievements

Modelling outputs using remote sensing data gave an estimated total coverage of kelp forest surrounding the Falkland Islands of 830.1 km^2 in 2019 (Fig. 1)

3.1 Carbon storage

The combined total peak estimate of CO_2 equivalent carbon stored in standing giant and understorey kelp species within the satellite-derived mapped extent of kelp forest in the Falkland Islands is 0.58 million tonnes. Averaged (central estimate) total sequestration to the deep sea is 0.299 million tonnes of CO_2 annually. Based on non-traded high-series carbon dioxide equivalent (CO_2e) values (BEIS 2019), of £103.9 per tonne CO_2e, present-day standing stock of carbon stored in *Macrocystis* and *Lessonia* kelp is equivalent to £60.27 million. The annual value of carbon sequestered to deep sea sediments is estimated to be approximately £31.07 million per year.

3.2 Nutrient cycling

Coastal algae and seagrass beds were collectively estimated by Costanza et al. (2014) to contribute $28,916 USD per hectare per year in terms of nutrient cycling services alone as of 2011 (based on the 2007 USD purchasing power parity). Applying these global values, the Falkland Islands are likely to contribute a total of £2.4 billion per year, based on remote-sensed kelp distribution.

3.3 Associated commercial fisheries

Six of the 15 major fisheries within the Falkland Islands were found to be reliant on kelp for some period of their life-cycle, based on current knowledge. This includes the kingclip (*Genypterus blacodes*), Patagonian scallop (*Zygochlamys patagonica*), Patagonian squid (*Doryteuthis gahi*), Red cod (*Salilota australis*), Rock cod (*Patagonotothen* spp.), and Southern blue whiting (*Micromesistius australis*). Collectively, these fisheries total an annual harvest value of £129,291,813 (~ 24% of the total commercial fishery harvest value), and £7,049,575 in licence fees (equivalent to ~ 36% of the total licence revenue) for the Falkland Islands.

3.4 Alginate extraction

Based on the Shackleton (1982) theoretical estimates of the Falkland Islands' viable annual wet tonnage extraction of 350,000 tonnes (i.e. ~ 5% of the Falkland Islands' kelp area impacted), the total dry weight of kelp for export would be approximately 70,000 tonnes, (assuming *Lessonia* spp. dry weight as 20% of wet weight). Applying the Chilean export value of £917 tonne -1 would lead to a (non-use) revenue value of £64.19 million year^{-1}. In the initial Shackleton (1982) economic assessment, Falkland Islands Government (FIG) would receive licence royalties, which would be equivalent to ~ £147,057 year in present value after inflation.

3.5 Cumulative value of assessed kelp services

Table 1 displays a summary of annual and spatial value estimates for all services investigated during this study. Values for other services including tourism, scientific research, culture, and coastal protection are still currently unknown or data-limited in this region, and are therefore not included within the summary.

The total estimated value of the assessed ecosystem services which are provided by the Falkland Islands' satellite-mapped kelp forests in 2020, was ~ £2.692 billion per year (or £3.24 million GBP km^{-2} year^{-1}). This overall monetary value is constructed using estimated values of both direct and indirect services provided by the kelp system as a whole. Indirect services included atmospheric carbon stored or sequestered to the deep sea by *Macrocystis pyrifera* and *Lessonia* kelps, as well as nutrients which are fixed or recycled within the kelp forests. Direct services included the harvest value of kelp-associated commercial fisheries and the theoretical harvest value of the kelp itself for alginate chemicals used in industry. Despite the differences created by ecosystem service valuations in different locations around the world, our estimates of total value are comparable to other

studies that attempted complete economic valuation of giant kelp forests elsewhere (Blamey and Bolton 2018, Vásquez et al. 2014).

Table 1 - Summary value estimates of services associated with giant kelp forest in the Falkland Islands in 2020. Overall remotely-mapped kelp extent for spatial estimates = 830.1 km². Blue carbon stock value given assuming the standing stock protected over ten years and applying the future projected CO_2e value. Full values for tourism, scientific research, culture, and coastal protection are still currently data-limited or unknown.

Service	Value estimate (£GBP year^{-1})	Spatial value estimate (£GBP km^{-2} year^{-1})
Blue carbon stock	0.703 million	84,721
Blue carbon sequestration	31.07 million	37,436
Nutrient cycling	2,400.29 million	2.89 million
Associated commercial fisheries value	126.3 million	152,177
Alginate industry (non-use)	64.19 million	77,337
TOTAL	**2,692.17 million**	**3.24 million**

The present study provides the first quantified basis for development of contemporary kelp management strategies on the Patagonian Shelf, as well as a value to form a basis from which future estimates can be made under various climate change scenarios.

In terms of the climate buffering benefit from carbon capture, the study showed that the Falkland Islands likely sequesters 0.299 million tonnes of CO_2 annually (at a conservative minimum estimate). This amount represents an additional annual contribution of approximately 0.1% of current UK net emissions (364.1 million tonnes CO_2e/year in 2018) towards their Nationally Determined Contribution (NDC) legally committed to through the Paris Agreement. While the contribution from Falkland Islands kelp is relatively small, this is a year-on-year national-scale positive benefit from simply maintaining the natural habitat at its current extent and condition, even applying our conservative estimates.

This study illustrates that the Falkland Islands' kelp forests supply a range of valuable services to people, which are important both locally and globally. Thanks to the area's geographical isolation and low population, the kelp system currently appears healthy and stable. If future detrimental environmental changes, such as increased local pollution, introduction of unsustainable fisheries, or rapid temperature rise were to occur, we would expect to see declines in terms of habitat distribution and condition. If the system were to decline on a large scale, the loss of direct ecosystem service benefits to the Falkland Islands and the loss of wider benefits to the

world through its indirect services, would be substantial and costly. Close monitoring of habitat extent and active management of local stressors will be key to the long term stability of the system, and ensure continued flow of multiple ecosystems services to society.

References

Arafeh-Dalmau N, Montaño-Moctezuma G, Martinez J, Beas-Luna R, Schoeman D, Torres-Moye G (2019) Extreme marine heatwaves alter kelp forest community near its equatorward distribution limit. Frontiers in Marine Science 6 (JUL): 1-18. https://doi.org/10.3389/fmars.2019.00499

Barbier EB, Hacker SD, Kennedy C, Koch E, Stier AC, Silliman BR (2011) The value of estuarine and coastal ecosystem services. Ecological Monographs 81 (2): 169-193. https://doi.org/10.1890/10-1510.1

Bax N, Sands C, Gogarty B, Downey R, Moreau CE, Moreno B, Held C, Paulsen M, McGee J, Haward M, Barnes DA (2020) Perspective: Increasing blue carbon around Antarctica is an ecosystem service of considerable societal and economic value worth protecting. Global Change Biology (April)1-8. https://doi.org/10.1111/gcb.15392

Bayley DTI, Marengo I, Baker H, Pelembe T (2017) Giant kelp 'Blue carbon' storage and sequestration value in the Falkland Islands. South Atlantic Environment Institute, Falkland Islands. https://doi.org/10.13140/RG.2.2.31988.24966

Beaton EC, Küpper FC, van West P, Brewin PE, Brickle P (2020) The influence of depth and season on the benthic communities of a Macrocystis pyrifera forest in the Falkland Islands. Polar Biology (0123456789). https://doi.org/10.1007/s00300-020-02662-x

Beaumont NJ, Austen MC, Atkins JP, Burdon D, Degraer S, Dentinho TP, Derous S, Holm P, Horton T, van Ierland E, Marboe AH, Starkey DJ, Townsend M, Zarzycki T (2007) Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. Marine Pollution Bulletin 54 (3): 253-265. https://doi.org/10.1016/j.marpolbul.2006.12.003

BEIS (2019) Valuation of energy use and greenhouse gas: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government. Department for Business, Energy and Industrial Strategy.

Bertocci I, Araújo R, Oliveira P, Sousa-Pinto I (2015) REVIEW: Potential effects of kelp species on local fisheries. Journal of Applied Ecology 52 (5): 1216-1226. https://doi.org/10.1111/1365-2664.12483

Bixler H, Porse H (2011) A decade of change in the seaweed hydrocolloids industry. Journal of Applied Phycology 23 (3): 321-335. https://doi.org/10.1007/s10811-010-9529-3

Blake D, Augé A, Sherren K (2017) Participatory mapping to elicit cultural coastal values for Marine Spatial Planning in a remote archipelago. Ocean and Coastal Management 148: 195-203. https://doi.org/10.1016/j.ocecoaman.2017.08.010

Blamey L, Bolton J (2018) The economic value of South African kelp forests and temperate reefs: Past, present and future. Journal of Marine Systems 188: 172-181. https://doi.org/10.1016/j.jmarsys.2017.06.003

Bormpoudakis D, Fish R, Guest A, Smith N (2019) South Atlantic Natural Capital Assessment: Cultural Ecosystem Services in the Falkland Islands.

Costanza R, D'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, van den Belt M (1998) The value of the world's ecosystem services and natural capital. Nature 387 (6630): 253-260. https://doi.org/10.1038/387253a0

Costanza R (1999) The ecological, economic, and social importance of the oceans. Ecological Economics 31: 199-213. https://doi.org/10.1016/S0921-8009(99)00079-8

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson S, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. Global Environmental Change 26 (1): 152-158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

DECC (2009) Carbon Valuation in UK Policy Appraisal: A Revised Approach. Department of Energy and Climate Change.

Duarte C, Agusti S, Barbier E, Britten G, Castilla JC, Gattuso J, Fulweiler R, Hughes T, Knowlton N, Lovelock C, Lotze H, Predragovic M, Poloczanska E, Roberts C, Worm B (2020) Rebuilding marine life. Nature 580 (7801): 39-51. https://doi.org/10.1038/s41586-020-2146-7

Elith J, Leathwick J (2009) Species distribution models: Ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40 (1): 677-697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

European Commission (2020) Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions: EU Biodiversity Strategy for 2030 - Bringing nature back into our lives. Publications Office of the European Union, Luxembourg. [ISBN 9279207628]

Falkland Islands Government (2018) Fisheries Statistics. FIG Fisheries Department 22: -100.

FIG Environmental Planning Department (2016) Falkland Islands Biodiversity Framework.

Filbee-Dexter K (2020) Ocean forests hold unique solutions to our current environmental crisis. One Earth 2 (5): 398-401. https://doi.org/10.1016/j.oneear.2020.05.004

Filbee-Dexter K, Wernberg T (2020) Substantial blue carbon in overlooked Australian kelp forests. Scientific Reports 10 (1). https://doi.org/10.1038/s41598-020-69258-7

Gaylord B, Rosman J, Reed D, Koseff J, Fram J, MacIntyre S, Arkema K, McDonald C, Brzezinski M, Largier J, Monismith S, Raimondi P, Mardian B (2007) Spatial patterns of flow and their modification within and around a giant kelp forest. Limnology and Oceanography 52 (5): 1838-1852. https://doi.org/10.4319/lo.2007.52.5.1838

Golding N, Black B, Blake D, Brewin P, Harte M, Havercroft H, James R, Jones G (2019) Long-term coastal habitat mapping & monitoring handbook. Examples based on work undertaken in the Falkland Islands & South Georgia. DPLUS065 Coastal Habitat Mapping project.

González S, Holtmann-Ahumada G (2017) Quality of tourist beaches of northern Chile: A first approach for ecosystem-based management. Ocean & Coastal Management 137: 154-164. https://doi.org/10.1016/j.ocecoaman.2016.12.022

Graham MH, Vásquez JA, Buschmann AH (2007) Global ecology of the giant kelp macrocystis: From ecotypes to ecosystems. Oceanography and Marine Biology 45: 39-88.

Haines-Young R, Potschin M (2013) Common International Classification of Ecosystem Services (CICES): Consultation on Version 4. https://doi.org/10.1038/nature10650

Himes-Cornell A, Pendleton L, Atiyah P (2018) Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. Ecosystem Services 30: 36-48. https://doi.org/10.1016/j.ecoser.2018.01.006

Isbell F, Tilman D, Polasky S, Loreau M (2015) The biodiversity-dependent ecosystem service debt. Ecology Letters 18 (2): 119-134. https://doi.org/10.1111/ele.12393

Jiang Z, Liu J, Li S, Chen Y, Du P, Zhu Y, Liao Y, Chen Q, Shou L, Yan X, Zeng J, Chen J (2020) Kelp cultivation effectively improves water quality and regulates phytoplankton community in a turbid, highly eutrophic bay. Science of the Total Environment 707 https://doi.org/10.1016/j.scitotenv.2019.135561

Jones KR, Klein CJ, Halpern BS, Friedlander AM, Possingham HP, Watson JEM (2018) The location and protection status of Earth's diminishing marine wilderness. Current Biology 28: 1-7. https://doi.org/10.1016/j.cub.2018.06.010

Kenny A, Cato I, Desprez M, Fader G, Schuttenhelm R, Side J (2003) An overview of seabed-mapping technologies in the context of marine habitat classification. ICES Journal of Marine Science 60 (2): 411-418. https://doi.org/10.1016/S1054-3139(03)00006-7

Krause-Jensen D, Duarte C (2016) Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9 (10): 737-742. https://doi.org/10.1038/ngeo2790

Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, Cavanaugh KC, Connell SD, Johnson CR, Konar B, Ling SD, Micheli F, Norderhaug KM, Pérez-Matus A, Sousa-Pinto I, Reed DC, Salomon AK, Shears NT, Wernberg

T, Anderson RJ, Barrett NS, Buschmann AH, Carr MH, Caselle JE, Derrien-Courtel S, Edgar GJ, Edwards M, Estes JA, Goodwin C, Kenner MC, Kushner DJ, Moy FE, Nunn J, Steneck RS, Vásquez J, Watson J, Witman JD, Byrnes JEK (2016) Global patterns of kelp forest change over the past half-century. Proceedings of the National Academy of Sciences of the United States of America 113 (48): 13785-13790. https://doi.org/10.1073/pnas.1606102113

Loomis J (2006) Estimating recreation and existence values of sea otter expansion in California using benefit transfer. Coastal Management 34 (4): 387-404. https://doi.org/10.1080/08920750600860282

Lowman H, Emery K, Kubler-Dudgeon L, Dugan J, Melack J (2019) Contribution of macroalgal wrack consumers to dissolved inorganic nitrogen concentrations in intertidal pore waters of sandy beaches. Estuarine, Coastal and Shelf Science 219 (September 2018): 363-371. https://doi.org/10.1016/j.ecss.2019.02.004

Macreadie P, Jarvis J, Trevathan-Tackett S, Bellgrove A (2017a) Seagrasses and macroalgae: Importance, vulnerability and impacts. In: Philips BF, Pérez - Ramírez M (Eds) Climate Change Impacts on Fisheries and Aquaculture. John Wiley & Sons, Ltd, Chichester, UK, 41 pp. [ISBN 9781119154051]. https://doi.org/10.1002/9781119154051.ch22

Macreadie P, Nielsen D, Kelleway J, Atwood T, Seymour J, Petrou K, Connolly R, Thomson AC, Trevathan-Tackett S, Ralph P (2017b) Can we manage coastal ecosystems to sequester more blue carbon? Frontiers in Ecology and the Environment 15 (4): 206-213. https://doi.org/10.1002/fee.1484

Maes J, Egoh B, Willemen L, Liquete C, Vihervaara P, Schägner JP, Grizzetti B, Drakou E, Notte AL, Zulian G, Bouraoui F, Luisa Paracchini M, Braat L, Bidoglio G (2012) Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services 1 (1): 31-39. https://doi.org/10.1016/j.ecoser.2012.06.004

Martin C, Momtaz S, Gaston T, Moltschaniwskyj N (2016) A systematic quantitative review of coastal and marine cultural ecosystem services: Current status and future research. Marine Policy 74: 25-32. https://doi.org/10.1016/j.marpol.2016.09.004

Martínez ML, Intralawan A, Vázquez G, Pérez-Maqueo O, Sutton P, Landgrave R (2007) The coasts of our world: Ecological, economic and social importance. Ecological Economics 63 (2-3): 254-272. https://doi.org/10.1016/j.ecolecon.2006.10.022

MEA (2005) Millenium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press.

Narayan S, Beck M, Reguero B, Losada I, Van Wesenbeeck B, Pontee N, Sanchirico J, Ingram JC, Lange GM, Burks-Copes K (2016) The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PLoS ONE 11 (5): 1-17. https://doi.org/10.1371/journal.pone.0154735

Nash K, Cvitanovic C, Fulton E, Halpern B, Milner-Gulland EJ, Watson R, Blanchard J (2017) Planetary boundaries for a blue planet. Nature Ecology & Evolution 1 (11):1625-1634. https://doi.org/10.1038/s41559-017-0319-z

Nikula R, Fraser CI, Spencer HG, Waters JM (2010) Circumpolar dispersal by rafting in two subantarctic kelp-dwelling crustaceans. Marine Ecology Progress Series 405: 221-230. https://doi.org/10.3354/meps08523

Otley H, Munro G, Clausen A, Ingham B (2008) Falkland Islands State of the Environment Report, Falkland Islands Government and Falklands Conservation.

Pecl G, Araújo M, Bell J, Blanchard J, Bonebrake T, Chen I, Clark T, Colwell R, Danielsen F, Evengård B, Falconi L, Ferrier S, Frusher S, Garcia R, Griffis R, Hobday A, Janion-Scheepers C, Jarzyna M, Jennings S, Lenoir J, Linnetved H, Martin V, McCormack P, McDonald J, Mitchell N, Mustonen T, Pandolfi J, Pettorelli N, Popova E, Robinson S, Scheffers B, Shaw J, Sorte CB, Strugnell J, Sunday J, Tuanmu M, Vergés A, Villanueva C, Wernberg T, Wapstra E, Williams S (2017) Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. Science 355 (6332). https://doi.org/10.1126/science.aai9214

Peters J, Reed D, Burkepile D (2019) Climate and fishing drive regime shifts in consumer-mediated nutrient cycling in kelp forests. Global Change Biology 25 (9): 3179-3192. https://doi.org/10.1111/gcb.14706

Pfister C, Altabet M, Weigel B (2019) Kelp beds and their local effects on seawater chemistry, productivity, and microbial communities. Ecology 100 (10): 1-15. https://doi.org/10.1002/ecy.2798

Queirós AM, Stephens N, Widdicombe S, Tait K, McCoy S, Ingels J, Rühl S, Airs R, Beesley A, Carnovale G, Cazenave P, Dashfield S, Hua E, Jones M, Lindeque P, McNeill C, Nunes J, Parry H, Pascoe C, Widdicombe C, Smyth T, Atkinson A, Krause-Jensen D, Somerfield P (2019) Connected macroalgal-sediment systems: blue carbon and food webs in the deep coastal ocean. Ecological Monographs 89 (3): 1-21. https://doi.org/10.1002/ecm.1366

Reed D, Washburn L, Rassweiler A, Miller R, Bell T, Harrer S (2016) Extreme warming challenges sentinel status of kelp forests as indicators of climate change. Nature Communications 7 (1). https://doi.org/10.1038/ncomms13757

Reed DC, Bzezinski MA (2009) Kelp Forests. In: Laffoley Dd, Grimsditch G (Eds) The management of natural coastal carbon sinks. IUCN, Gland, Switzerland. [ISBN 0160-8347]. https://doi.org/10.1007/s00114-001-0283-x

Rodrigues Garcia J, Conides A, Rodriguez Rivero S, Raicevich S, Pita P, Kleisner K, Pita C, Lopes PM, Roldán Alonso V, Ramos S, Klaoudatos D, Outeiro L, Armstrong C, Teneva L, Stefanski S, Böhnke-Henrichs A, Kruse M, Lillebø A, Bennett E, Belgrano A, Murillas A, Pinto Sousa I, Burkhard B, Villasante S (2017) Marine and coastal cultural ecosystem services: Knowledge gaps and research priorities. One Ecosystem 2 https://doi.org/10.3897/oneeco.2.e12290

Roleda M, Hurd C (2019) Seaweed nutrient physiology: application of concepts to aquaculture and bioremediation. Phycologia 58 (5): 552-562. https://doi.org/10.1080/00318884.2019.1622920

Sanchirico J, Mumby P (2009) Mapping ecosystem functions to the valuation of ecosystem services: Implications of species-habitat associations for coastal land-use decisions. Theoretical Ecology 2: 67-77. https://doi.org/10.1007/s12080-008-0034-0

Shackleton E (1976) Economic Survey of the Falkland Islands: Resources and Development Potential. Foreign and Commonwealth Affairs Report.

Shackleton E (1982) Falkland Islands Economic study. Foreign and Commonwealth Affairs Report.

Smale D, Burrows M, Moore P, O'Connor N, Hawkins S (2013) Threats and knowledge gaps for ecosystem services provided by kelp forests: A northeast Atlantic perspective. Ecology and Evolution 3 (11): 4016-4038. https://doi.org/10.1002/ece3.774

Smale D, Wernberg T, Oliver EJ, Thomsen M, Harvey B, Straub S, Burrows M, Alexander L, Benthuysen J, Donat M, Feng M, Hobday A, Holbrook N, Perkins-Kirkpatrick S, Scannell H, Sen Gupta A, Payne B, Moore P (2019) Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nature Climate Change 9 (4): 306-312. https://doi.org/10.1038/s41558-019-0412-1

Smith N (2019) Understanding the value of land based tourists in the Falkland Islands. South Atlantic Overseas Territories Natural Capital Assessment.

Spalding M, Burke L, Wood SA, Ashpole J, Hutchison J, zu Ermgassen P (2017) Mapping the global value and distribution of coral reef tourism. Marine Policy 82 (May): 104-113. https://doi.org/10.1016/j.marpol.2017.05.014

Steneck R, Graham M, Bourque B, Corbett D, Erlandson J, Estes J, Tegner M (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation 29 (4): 436-459. https://doi.org/10.1017/S0376892902000322

Sutherland W, Dias M, Dicks L, Doran H, Entwistle A, Fleishman E, Gibbons D, Hails R, Hughes A, Hughes J, Kelman R, Le Roux X, LeAnstey B, Lickorish F, Maggs L, Pearce-Higgins J, Peck L, Pettorelli N, Pretty J, Spalding M, Tonneijck F, Wentworth J, Thornton A (2020) A Horizon Scan of Emerging Global Biological Conservation Issues for 2020. Trends in Ecology & Evolution 35 (1): 81-90. https://doi.org/10.1016/j.tree.2019.10.010

UNFCC (2015) The Paris Agreement to the United Nations Framework Convention on Climate Change.

van Tussenbroek BL (1993) Plant and frond dynamics of the giant kelp, *Macrocystis pyrifera*, forming a fringing zone in the Falkland Islands. European Journal of Phycology 28 (March): 161-165. https://doi.org/10.1080/09670269300650251

Vásquez J, Zuñiga S, Tala F, Piaget N, Rodríguez D, Vega JM (2014) Economic valuation of kelp forests in northern Chile: values of goods and services of the ecosystem. Journal of Applied Phycology 26 (2): 1081-1088. https://doi.org/10.1007/s10811-013-0173-6

Viana D, Gornik K, Lin CC, McDonald G, Ng NR, Quigley C, Potoski M (2017) Recreational boaters value biodiversity: The case of the California Channel Islands National Marine Sanctuary. Marine Policy 81 (March): 91-97. https://doi.org/10.1016/j.marpol.2017.03.017