Economic Valuation of Climate Regulation in the Mediterranean

Abstract

As the scope of the ecosystem services approach expands, research on marine ecosystem services remains limited, mainly due to the lack of sufficient data and poor understanding of the processes that underlie such ecosystems. This study presents a spatiotemporal economic valuation of the climate regulation ecosystem service in the Meditterenean, which accounts for permanent and temporary carbon sequestration. Based on different carbon prices, the estimated value of climate regulation within the Israeli EEZ ranges between 265.1 and 1270.9 € km^{-2} $year^{-1}$, which is ~2.5 to 12 fold higher than estimates by (Melaku Canu et al., 2015), for this area. Comparison with other valuations of climate regulation, which equated oceanic primary productivity (an ecosystem function) with climate regulation (an ecosystem service), points to a recurring economic overestimation of this ecosystem service.

Keywords: ecosystem services valuation, climate regulation, ecosystem services modelling

JEL codes: Q250, Q540

1. Introduction

During the past decade, the ecosystem services approach has gained increased popularity among ecologists and economists as an ecosystem management framework, linking between the physical state of ecosystems and socio-economic welfare (Daily et al., 2009; Jordan et al., 2010). However, applying the ecosystem services framework and Ecosystem-Based Management (EBM) to marine ecosystems has been poorly addressed in the scientific literature (Böhnke-Henrichs et al., 2013), mainly due to difficulties in data gathering and the existence of considerable knowledge gaps. This is evident in the case of the eastern basin of the Mediterranean Sea, which is characterized as an ultraoligotrophic (nutrient-poor) environment (Herut et al., 2016; Siokou-Frangou et al., 2010), prone to high anthropogenic pressures and constant environmental changes (Coll et al., 2010; Kress et al., 2016; Lejeusne et al., 2010; UNEP/MAP, 2012), especially those related to climate change (Gertman et al., 2013; Ozer et al., 2016). Coupled with the limited information on its biogeochemical processes, ecosystem composition and functionality, compiling accurate and reliable valuations for the ecosystem services' flows of the Eastern Mediterranean basin is particularly challenging.

Among the various marine ecosystem services, climate regulation is considered a valuable asset to human welfare. The benefit of this ecosystem service is the moderation of adverse climate change phenomena, such as extreme weather events, health risks or property damage, which are associated with high concentrations of climate-influencing substances in the atmosphere. In the context of the oceanic environment, climate regulation can be addressed as an ecosystem service rendered by marine ecosystems through the absorption and deposition of atmospheric carbon dioxide (CO_2) within deep oceanic layers by marine organisms, a process often referred to as the "biological pump" (Chisholm, 2000). After its formation by primary producers (such as algae or cyanobacteria) during photosynthesis, organic carbon is exported below the euphotic layer (depths corresponding to 0.1-1% of sunlight reaching the surface layer), where it is subjected to remineralization and solubilization at various depths (Raven and Falkowski, 1999). The fraction of organic carbon that remains within the ocean is dependent on various biogeochemical processes and its residence time within deep oceanic layers dictates the duration of temporary reduction of atmospheric CO_2 concentrations.

The aim of this paper is to assess the climate regulation ecosystem service through quantification of carbon sequestered by marine autotrophic organisms, and to estimate its economic value within Israel's Exclusive Economic Zone (EEZ) in the eastern Mediterranean Sea. The assessment is based on the fate of absorbed atmospheric CO_2 as an indicator of climate regulation and provides a quantitative estimation for the current and future supply of this ecosystem service.

1.1. Climate regulation assessments and valuation

Few attempts have been made to evaluate marine climate regulation as an ecosystem service. Mangos et al., (2010) performed an assessment of various marine ecosystem services, including climate regulation, for Mediterranean countries. Their evaluation of this ecosystem service, which was based on the work of (Huertas et al., 2009), relied on carbon sequestration originating in the solubilization of atmospheric CO_2, a process which is not related to ecosystems *per se*, and therefore does not fall into the common definition of ecosystem services (de Groot et al., 2010). A recent estimation of climate regulation in the Mediterranean, which employed a model of both non-biological and biological components associated with this ecosystem service, resulted in a total value of €281.4 and €2.7 million per year, for the entire Mediterranean and Israel's EEZ, respectively (Melaku Canu et al., 2015). This estimation also revealed that, as a whole, the Israeli EEZ acts as a source rather than sink to atmospheric CO_2, but in the context of ecosystem services, the biological component within the oceanic carbon cycle acts as a sink, which hypothetical absence would cause higher levels of CO_2 outgassing back to the atmosphere. Other estimations, relying on the methodology set forth by Beaumont et al., (2008), equated climate regulation with primary productivity, i.e., fixed CO_2 by phytoplankton was considered as sequestered carbon and served as the primary metric for the economic valuation of this ecosystem service (Costanza et al., 2014; de Groot et al., 2012; Mangi et al., 2011; Murillas-Maza et al., 2011), which may ultimately led to overestimated values for this ecosystem service. Yet, in most cases, the majority of the organic carbon generated through primary productivity is being remineralized during respiration by marine organisms and outgassed as CO_2 back to the atmosphere in a relatively short span of time, thus inhibiting long-term sequestration, defined here as periods above 100 years (Murray and Kasibhatla, 2013). This study asserts that in order to properly assess climate regulation, the fate of absorbed CO_2 must be taken into account, i.e. lowered concentrations of atmospheric CO_2 due to its deposition for extended periods. In other words, when assessing an ecosystem service, it is important to relate the benefit flow to human context. Without accounting for the entire processes involved in the biological pump, an overestimation of roughly two orders of magnitude of this ecosystem services, both physically and economically, might occur.

Despite the fact that no regular market exists for the climate regulation ecosystem service, its economic benefits can be estimated using indirect valuation techniques. One of the most accepted valuation approaches is the Social Cost of Carbon (SCC), which represents the marginal damages associated with additional increase of greenhouse gasses in the atmosphere. It can also be defined as a Pigovian tax applied to CO_2 emissions (Tol, 2008). SCC is often computed using Integrated Assessment Models (IAM), which take into account various socio-economic and climate-related geophysical parameters in order to assess climate change related policies. Among the factors controlling the resulting values of SCC are risk aversion, social discount rate and accompanied uncertainty. These factors are fed into the IAMs' analyses, each employing different methodology, coupled with various assumptions regarding expected changes in production, consumption and welfare. The numerous options associated with these assumptions and parameters result in a wide range of SCC values (van den Bergh and Botzen, 2015). One of the most prominent SCC estimations was performed by the Interagency Working Group on Social Cost of Greenhouse Gases (2016), taking into account the different IAMs and yielding a range of SCC values, depending on the chosen discount rate. Given the fact that SCC valuations are often subjected to general preferences and that no such estimation exist for Israeli context, any such valuation will provide only an approximation of the SCC value suitable for the case study in question. Nonetheless, unlike other valuation methods, SCC deals directly with climate change damages and it can be argued that the values obtained using this methodology represent more accurately the benefits of the climate regulation ecosystem service.

2. Materials and methods

2.1. Model outline

The assessment of the climate regulation ecosystem service, indicated by organic carbon fluxes to deep oceanic layers and their concomitant economic values, was carried out for the Israeli Exclusive Economic Zone (EEZ) (ca. 27,700 km^2). The valuation extended between the years 1998-2015 in order to derive monthly and annual averaged values and to identify interannual trends. In addition, the annual average carbon sequestration was used to project future levels of the ecosystem service until 2050, given future SCC values and physical changes of carbon sequestration.

The focus of the assessment relied on underlying ecosystem functions that take place in surface waters over short periods of time. Therefore, a simplified 1-D deterministic model was used, obviating the need of taking into account spatial processes such as lateral advection below the euphotic layer, which results in a spatial distribution of organic carbon which differs from that of surface waters.

The methodology for evaluating the ecosystem service is detailed in Figure 1. First, primary productivity for the years 1998-2015 was obtained for the Israeli Mediterranean Sea in order to establish long-term average and observe any interannual trends. Next, the flux of carbon exported from the euphotic zone was computed. The spatial analysis was carried out only for bathymetric depths greater than 100 meters in order to exclude coastal areas where vertical mixing may counter long durations of carbon sequestration.

The flux was then partitioned into permanent sequestration (the amount of carbon that remains in oceanic layers over 100 years) and impermanent sequestration (the amount of carbon subjected to remineralization and leakage back to the atmosphere over a period below 100 years). The annualized average of the permanent and impermanent carbon flux served as a baseline for the valuation, using SCC values, of the ecosystem service under current conditions and projected values until 2050. All computations and processing were performed on 3.5 km^2 grid cells using ArcMap 10.3.1.

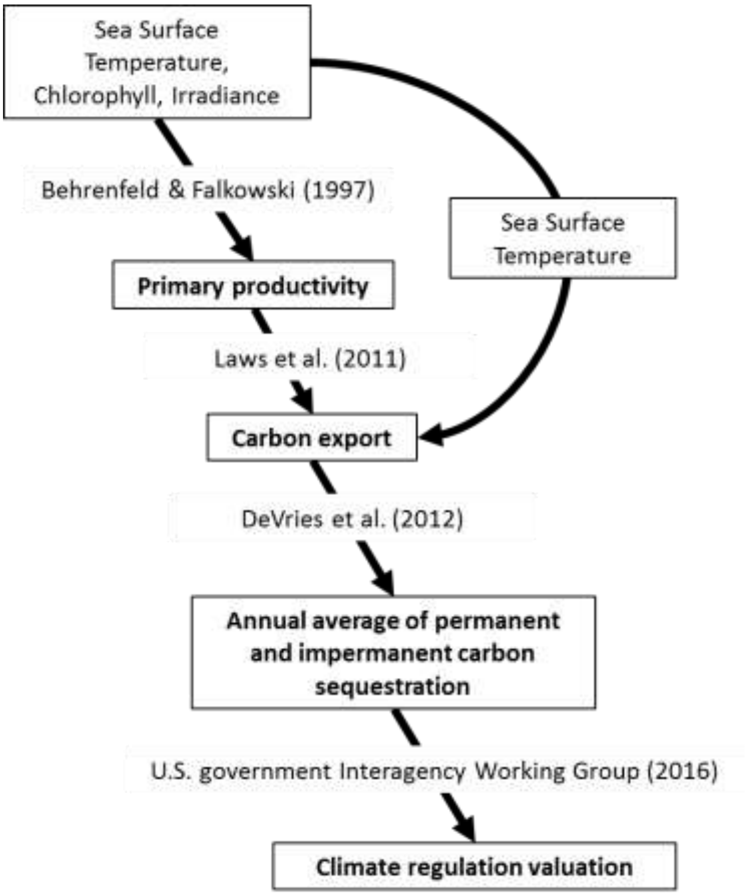

Figure 1. Outline of the methodology used to assess the climate regulation ecosystem service.

2.2. Primary productivity and carbon export

The supply metrics of the climate regulation ecosystem service (i.e. tons of carbon sequestered) are based primarily on the primary production which takes place in the euphotic zone. The Vertically Generalized Production Model (VGPM), a chlorophyll-*a*, temperature and irradiance-based primary production algorithm (Behrenfeld and Falkowski, 1997) was chosen due to its compatibility with local primary productivity estimates. Data layers for this parameter were taken from Ocean Productivity website (www.science.oregonstate.edu/ocean.productivity/index.php). Organic carbon flux from surface waters to depths below the euphotic layer, was determined by a ratio of exported to total primary productivity, denoted ef-ratio (Laws et al., 2000). The ef-ratio (EF) for the Israeli EEZ is dependent both on the seawater temperature and primary productivity rates and was calculated using equation 1 (Laws et al., 2011).

$$EF = 0.04756 \cdot \left(0.78 - \frac{0.43 \cdot SST}{30}\right) \cdot PP^{0.307} \qquad \text{(eq. 1)}$$

Where SST the sea surface temperature in ° C is, interpolated from *in-situ* and remotely sensed data by Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/) and PP is the primary productivity rates (based on VGPM model data) in tons carbon/month. The exported fraction of organic carbon (in tons), denoted E, was calculated on a monthly time scale (l) between the years 1998-

2015, for each coordinate in the context area (x, y) according to equation 2. The annual average for this time period (216 months) was then calculated (equation 3) in order to establish the exported carbon baseline (E_0).

$$E_l = \int_l PP(x, y) \cdot EF(x, y) dl \qquad \text{(eq. 2)}$$

$$E_0 = \frac{\sum_{l=1}^{216} E_l}{18} \qquad \text{(eq. 3)}$$

The Eastern Mediterranean Sea is experiencing rapid environmental changes which are predicted to have profound implications on the future state of its ecosystem. These changes, such as sea temperature and salinity increases, are expected to affect primary productivity through the creation of a shallower mixed layer, thus limiting nutrient supply to the surface (Berman-Frank and Rahav, 2012; Stambler, 2014). In addition, the levels of nutrient fluxes into the basin originating from multiple sources, essential to primary productivity, have also changed over the years (Krom et al., 2014; Suari and Brenner, 2015). In light of the complexity of the ecosystem's biogeochemical dynamics and limited data, prediction of the future levels of climate regulation remains unclear. Historic measurements spanning 30 years have shown consistent long-term increase in both temperature and salinity (Ozer et al., 2016). Our assumption for predicting climate regulation levels in the future is that the ecosystem service exhibits the same linear trend observed in these variables. Therefore, the expected carbon flux in subsequent years (E_t) was established using a linear regression analysis of the monthly exported carbon flux, which revealed a decreasing trend, corresponding to an annual loss of 97 tons of carbon (denoted by L in equation 4).

$$E_t = E_0 - (t \cdot L) \qquad \text{(eq. 4)}$$

2.3. Permanent and impermanent carbon sequestration

Permanent carbon sequestration can be defined as the removal of carbon from the atmosphere for a period over 100 years (Murray and Kasibhatla, 2013). This is achieved in the marine environment via the sinking, deposition and burial of organic carbon over this time period by the biological pump. However, a large fraction of the total exported organic carbon is reemitted back to the atmosphere during the 100-year period through remineralization and respiration of the organic carbon. DeVries et al., (2012) define the biological pump's sequestration efficiency as "…the proportion of nutrients regenerated from organic matter exported out of the euphotic zone… that remain sequestered below the surface…"(page 1) for a specified period or longer. Following this proposition, they demonstrated for different seas and time periods the proportion of exported carbon that remains sequestered. Based on the findings of the model presented in DeVries et al., (2012), equation 5 shows, specifically for the Mediterranean Sea, the proportion of exported carbon stock, D, that remains sequestered beneath the euphotic zone for each year n ($n = 1 \dots 99$), after its initial formation and exportation.

$$D_n = -0.135 \cdot \ln n + 0.94 \qquad \text{(eq. 5)}$$

Equation 6 presents, for each year, t, the amount of sequestered carbon in tons (denoted as S), of both the permanent and impermanent fraction. M represents the fraction of exported carbon that remains beneath the euphotic zone for a period of over 100 years and is set at 0.3 for the Mediterranean Sea (DeVries et al., 2012).

$$S_t = E_t \cdot M + \sum_{n=1}^{n=99} [E_t \cdot (1 - M) \cdot (D_n - D_{n+1})] \qquad \text{(eq. 6)}$$

2.4. Monetary valuation of the climate regulation ecosystem service

In order to assess the present climate regulation value, SCC values provided by the Interagency Working Group on Social Cost of Greenhouse Gases (2016) were used. These are based on the incorporation of the three most used IAMs (PAGE, FUND and DICE), thus representing an adequate valuation that takes into account the possible differences between them. Three SCC values and their future trajectories were chosen, differentiated by their discount rate (5.0%, 3.0% and 2.5%). Under this valuation, SCC values increase over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change.

The SCC value of each year t was calculated using equation 7, where r is the annual growth rate of the SCC value, which is determined by the discount rate i and the corresponding decade. SCC values and annual growth rates (Table 1) were taken from the Interagency Working Group on Social Cost of Greenhouse Gases (2016). Baseline SCC values for the year 2016 ($t = 0$) were set at 34.22€, 121.33€ and 183.55€ per ton of carbon, corresponding to 5.0%, 3.0% and 2.5% discount rates, respectively.

$$SCC_{i,t} = SCC_{i,t-1} \cdot \left(1 + r_{i,t}\right) \qquad \text{(eq. 7)}$$

Table 1. Annual SCC growth rate according to the Interagency Working Group on Social Cost of Greenhouse Gases (2016)

Years	5% $(i = 1)$	3% $(i = 2)$	2.5% $(i = 3)$
2010-2020	1.2%	3.2%	2.4%
2020-2030	3.4%	2.1%	1.7%
2030-2040	3.0%	1.9%	1.5%

2040-2050	2.6%	1.6%	1.3%

Based on equation 6, equation 8 represents the valuation of the permanent and impermanent organic carbon stocks for each year and selected discount rate ($V_{i,t}$), starting with the year 2016 ($t = 0$).

$$V_{i,t} = E_t \cdot M \cdot SCC_{i.t} + \sum_{n=1}^{n=99} \left\{ E_t \cdot (1 - M) \cdot (D_n - D_{n+1}) \cdot \left[SCC_{i.t} - SCC_{i,t} \cdot \left(1 + r_{i,t+n}\right)^{-n} \right] \right\} \qquad \text{(eq. 8)}$$

Figure 2 shows demonstrates the total value of the impermanent organic carbon fraction for the year 2017. For each year (starting in 2018 until 2116), the impermanent carbon fraction decreases while SCC values rise gradually, thus yielding initially a maximum value initially (when the amount of temporary sequestrated carbon is relatively high) followed by a decrease as the residual amount of carbon decreases.

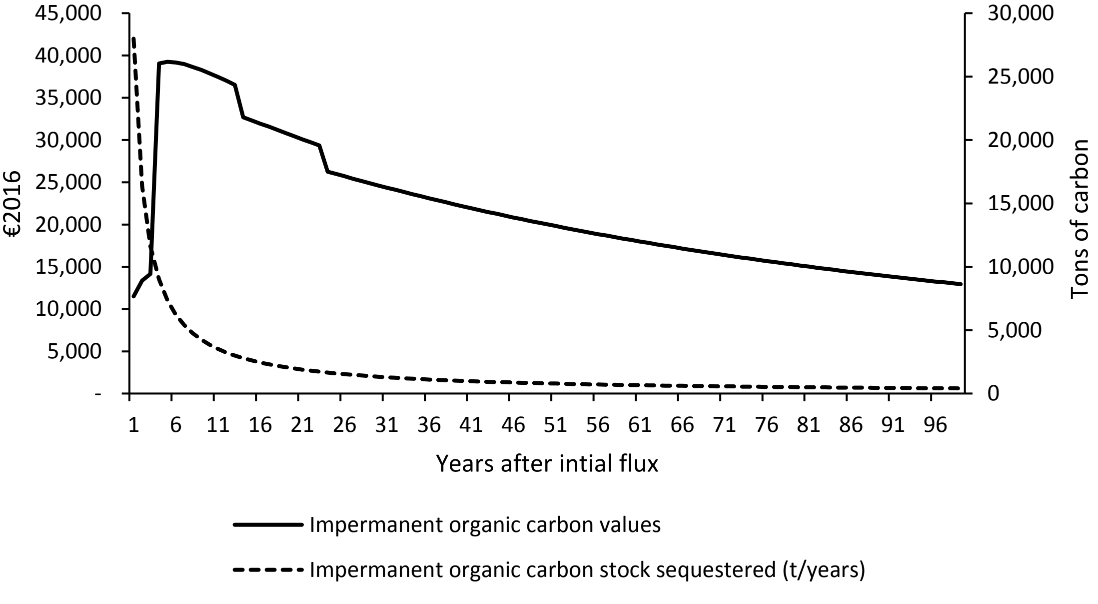

Figure 2. Impermanent carbon sequestration levels and values for exported organic carbon in the year 2017.

3. Results

The results of the climate regulation model, presented in figure Figure 3, demonstrate a clear seasonal trend, with high carbon flux values during the winter and spring and low values during summer and autumn. An interannual decline in the supply of climate regulation was detected for the observed time period and the average annual organic carbon flux out of the euphotic layer in the observed area was estimated at ~427,228 tons of carbon. This amount corresponds to an average of 17.49 g C m^{-2} $year^{-1}$, similar to observed carbon fluxes in the Eastern Mediterranean, e.g. Gogou et al., (2014), which reported a flux of 15.67 g C m^{-2} $year^{-1}$.

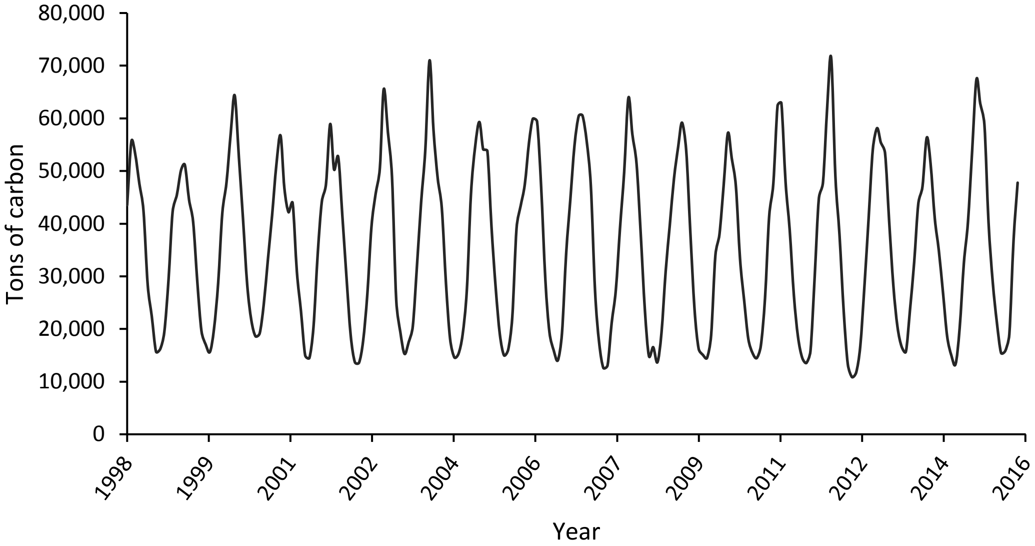

Figure 3. Monthly organic carbon flux from the euphotic layer of the Israeli EEZ (in tons of carbon), for depths below 100 meters, between January 1998 and December 2015.

Figure 4 shows the spatial distribution of average annual carbon sequestration for the years 1998-2015. As expected, the levels of this ecosystem service are high near the continental shelf, due to higher nutrients availability (some from anthropogenic sources) and phytoplankton concentrations. The results of the economic valuation are presented in Table 2.

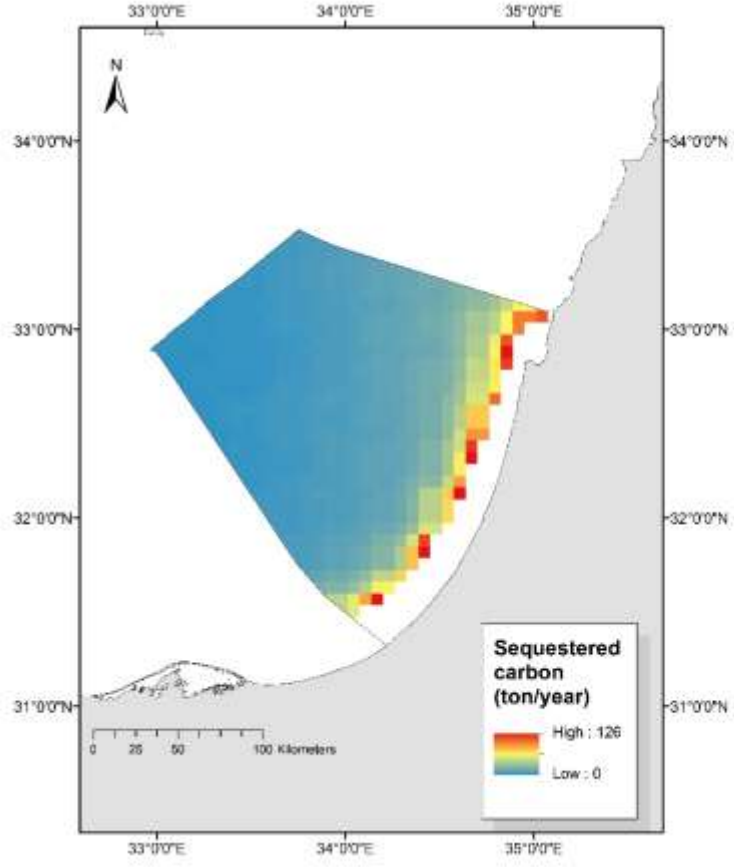

Figure 4. Spatial distribution of sequestered carbon (1998-2015). Each pixel with an area of ~3.5 km2.

Table 2. Annual economic values of the climate regulation ecosystem service.

Discount rate	Value (€/tonC)	Climate regulation value (Mill. €)
5.0%	34	6.48
3.0%	121	21.39
2.5%	184	31.05

Projected climate regulation values are displayed in Figure 5. Although a projected annual loss of 97 tons of sequestered carbon, rising SCC values render this ecosystem service more valuable in the future.

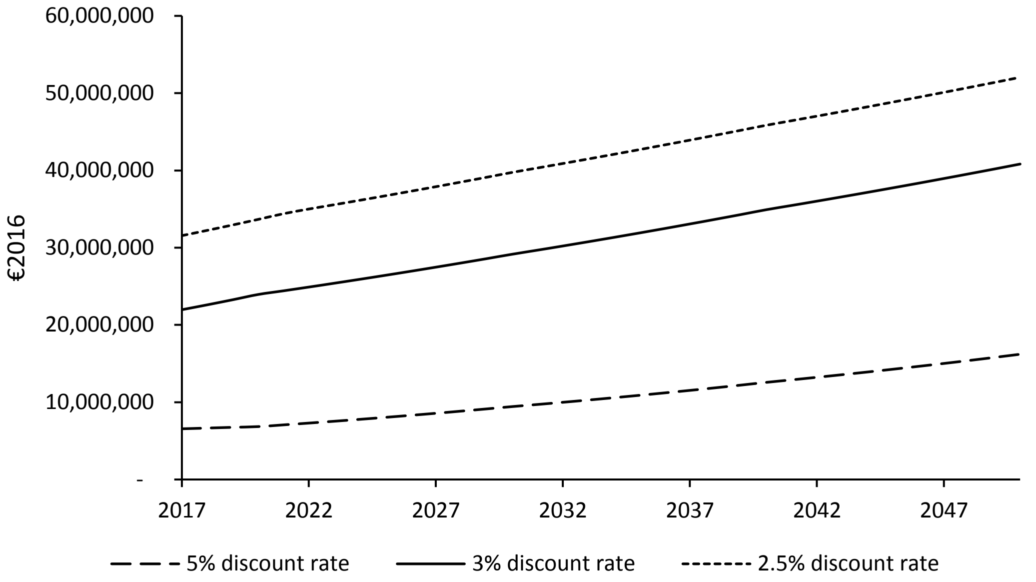

Figure 5. Projected climate regulation values until 2050 using different social discount rates.

4. Discussion

This study estimated the physical levels of the climate regulation ecosystem service and its economic value for the Israeli EEZ by spatially modelling organic carbon sequestration below the euphotic layer. The results hint to a relatively limited supply of this service, mainly due to the oligotrophic nature of the eastern basin of the Mediterranean (Kress et al., 2014; Rahav et al., 2013). This valuation is lower than that of Mangos et al., (2010), which estimated the annual value of this ecosystem service for Israel at €72 million (based on emissions trading schemes with an average price of €20.5 per ton of carbon, at 2005 prices). This is mainly due to the fact that their valuation was largely based on the solubility of atmospheric CO_2. However, our results are higher than a recent study by Melaku Canu et al., (2015), which estimated this ecosystem service at €2.7 million (using SCC of €19/t CO_2), translated to 38,720 tons of sequestered carbon. When comparing this analysis with previous estimations of the climate regulation ecosystem service (Section 1.1), a clear difference arises. Indeed, primary productivity removes CO_2 from the atmosphere, but in the temporal context of societal benefits, much of the carbon is rapidly released back into the atmosphere. We argue that in the case of climate regulation, the cumulative ecological processes involved in generating the social benefit (removal of atmospheric CO_2 for extended periods of time) must be considered while taking into account both permanent and impermanent fractions of sequestered carbon. Assessing climate regulation based on the initial process involved (i.e., primary productivity), eventually leads to erroneous and overestimated valuations. Using these methodologies (with an average value of €6,521/tonC km^{-2} $year^{-1}$ compared with €265-1271/tonC km^{-2} $year^{-1}$ in this study) would have given an overestimated value ranging between €129-630 million, annually. Indeed, the Israeli EEZ acts as a source of atmospheric CO_2 when accounting for the solubility pump but its biological sequestration component, although limited by the oligotrophic nature of the ecosystem, has a valuable contribution to mitigating climate change implications.

Given these results, some remarks are in order:

1. The economic value of this ecosystem service is dependent on the chosen SCC value, discount rate and the physical model used to estimate primary productivity, and therefore exhibits a wide range of values accordingly. Although the former is subject to further enhancement and validation, social and economic preferences, determined by policy makers, have a considerable effect on resulting ecosystem values. In the context of the Israeli Mediterranean, the Israeli Ministry of Environmental Protection recommends using a 3.0% discount rate, yielding an annual value of €21.39 million for climate protection.

2. The marine ecosystem is comprised of multiple components featuring intricate bonds and mechanisms. Assessing the economic implications of management policies or external environmental pressures in the form of marginal values becomes much more complex under uncertain conditions and lack of data. Without clear knowledge on the mechanisms of the Israeli Mediterranean ecosystem, attempting to force marginal changes in order to derive economic insights might lead to unsubstantiated results. Future data on the inner workings of this marine ecosystem will help better evaluate hypothetical scenarios and their implications for ecosystem services' values.

3. The partition of exported carbon between permanent and impermanent as well as the rate of outgassing of the impermanent fraction of organic carbon back to the atmosphere are based on a general model, presented by DeVries et al., (2012). Future *in-situ* data acquisition for Levantine waters will undoubtedly contribute to honing the valuation results.

4. The trends that were calculated based on observed data are linear in nature. However, the response of the biological functions and organisms involved in the future supply of the climate regulation ecosystem service, under varying conditions, will not likely follow the same path, as a new equilibrium will be established over time. The future levels of the climate regulation will inevitably be associated with the biological components of the ecosystem, such as phytoplankton functional types (Stambler, 2014). Any future investigation of this ecosystem service will have to take into account such aspects.

Correct and accurate understanding of the magnitudes and trends of different ecosystem services is crucial for the application of Ecosystem Based Management (EBM) policies. Therefore, the need to review the different components and processes involved in the creation of ecosystem services' values must be stressed in order to avoid inaccurate future valuations. Although performed at a local level, the insights from this study apply to other magnitudes and ecosystem services.

Acknowledgments

We wish to thank the following colleagues for their advices and comments: Paulo A.L.D. Nunes (UNEP, Calouste Gulbenkian Foundation), Andrea Ghermandi (The Department of Natural Resources and Environmental Management, University of Haifa) and Jack Silverman (Israel Oceanographic and Limnological Research). This study was financially supported by a philanthropic fund, Israel Oceanographic and Limnological Research fellowship and the Mediterranean Sea Research Center of Israel fund as part of Yoav Peled's PhD. dissertation.

References

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M., 2008. Economic valuation for the conservation of marine biodiversity. Mar. Pollut. Bull. 56, 386–396. doi:10.1016/j.marpolbul.2007.11.013

Behrenfeld, M.J., Falkowski, P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr. 42, 1–20.

Berman-Frank, I., Rahav, E., 2012. Nitrogen fixation as a source for new production in the Mediterranean Sea: a review, in: Life in the Mediterranean Sea: A Look at Habitat Changes. Nova Science Publishers, New York, pp. 199–226.

Böhnke-Henrichs, A., Baulcomb, C., Koss, R., Hussain, S.S., de Groot, R.S., 2013. Typology and indicators of ecosystem services for marine spatial planning and management. J. Environ. Manage. 130, 135–145. doi:10.1016/j.jenvman.2013.08.027

Chisholm, S., W., 2000. Stirring times in the Southern Ocean. Nature 407, 685–687. doi:10.1038/35037696

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F., Aguzzi, J., Ballesteros, E., Bianchi, C.N., Corbera, J., Dailianis, T., Danovaro, R., Estrada, M., Froglia, C., Galil, B.S., Gasol, J.M., Gertwagen, R., Gil, J., Guilhaumon, F., Kesner-Reyes, K., Kitsos, M.-S., Koukouras, A., Lampadariou, N., Laxamana, E., López-Fé de la Cuadra, C.M., Lotze, H.K., Martin, D., Mouillot, D., Oro, D., Raicevich, S., Rius-Barile, J., Saiz-Salinas, J.I., San Vicente, C., Somot, S., Templado, J., Turon, X., Vafidis, D., Villanueva, R., Voultsiadou, E., 2010. The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. PLoS ONE 5, e11842. doi:10.1371/journal.pone.0011842

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Change 26, 152–158. doi:10.1016/j.gloenvcha.2014.04.002

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7, 21–28. doi:10.1890/080025 de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1, 50–61. doi:10.1016/j.ecoser.2012.07.005

de Groot, R., Fisher, B., Christie, M., Aronson, J., Braat, L., Gowdy, J., Haines-Young, R., Maltby, E., Neuville, A., 2010. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation, in: Kumar, P. (Ed.), The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations. Earthscan, London and Washington, pp. 1–40.

DeVries, T., Primeau, F., Deutsch, C., 2012. The sequestration efficiency of the biological pump: BIOLOGICAL PUMP SEQUESTRATION EFFICIENCY. Geophys. Res. Lett. 39, n/a-n/a. doi:10.1029/2012GL051963

Gertman, I., Goldman, R., Ozer, T., Zodiatis, G., 2013. Interannual changes in the thermohaline structure of the South Eastern Mediterranean. Presented at the CIESM congress 2013.

Gogou, A., Sanchez-Vidal, A., Durrieu de Madron, X., Stavrakakis, S., Calafat, A.M., Stabholz, M., Psarra, S., Canals, M., Heussner, S., Stavrakaki, I., Papathanassiou, E., 2014. Carbon flux to the deep in three open sites of the Southern European Seas (SES). J. Mar. Syst. 129, 224–233. doi:10.1016/j.jmarsys.2013.05.013

Herut, B., Rahav, E., Tsagaraki, T.M., Giannakourou, A., Tsiola, A., Psarra, S., Lagaria, A., Papageorgiou, N., Mihalopoulos, N., Theodosi, C.N., Violaki, K., Stathopoulou, E., Scoullos, M., Krom, M.D., Stockdale, A., Shi, Z., Berman-Frank, I., Meador, T.B., Tanaka, T., Paraskevi, P., 2016. The Potential Impact of Saharan Dust and Polluted Aerosols on Microbial Populations in the East Mediterranean Sea, an Overview of a Mesocosm Experimental Approach. Front. Mar. Sci. 3. doi:10.3389/fmars.2016.00226

Huertas, I.E., Ríos, A.F., García-Lafuente, J., Makaoui, A., Rodríguez-Gálvez, S., Sánchez-Román, A., Orbi, A., Ruíz, J., Pérez, F.F., 2009. Anthropogenic and natural CO 2 exchange through the Strait of Gibraltar. Biogeosciences 6, 647–662.

Interagency Working Group on Social Cost of Greenhouse Gases, 2016. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.

Jordan, S.J., Hayes, S.E., Yoskowitz, D., Smith, L.M., Summers, J.K., Russell, M., Benson, W.H., 2010. Accounting for Natural Resources and Environmental Sustainability: Linking Ecosystem Services to Human Well-Being. Environ. Sci. Technol. 44, 1530–1536. doi:10.1021/es902597u

Kress, N., Gertman, I., Herut, B., 2014. Temporal evolution of physical and chemical characteristics of the water column in the Easternmost Levantine basin (Eastern Mediterranean Sea) from 2002 to 2010. J. Mar. Syst. 135, 6–13. doi:10.1016/j.jmarsys.2013.11.016

Kress, N., Shoham-Frider, E., Galil, B.S., 2016. Twenty two years of sewage sludge marine disposal monitoring in the Eastern Mediterranean Sea: Impact on sediment quality and infauna and the response to load reduction. Mar. Pollut. Bull. 110, 99–111. doi:10.1016/j.marpolbul.2016.06.076

Krom, M.D., Kress, N., Berman-Frank, I., Rahav, E., 2014. Past, Present and Future Patterns in the Nutrient Chemistry of the Eastern Mediterranean, in: The Mediterranean Sea: Its History and Present Challenges. Springer Netherlands, Netherlands, pp. 49–68.

Laws, E.A., D’Sa, E., Naik, P., 2011. Simple equations to estimate ratios of new or export production to total production from satellite-derived estimates of sea surface temperature and primary production: Equations for ef ratios. Limnol. Oceanogr. Methods 9, 593–601. doi:10.4319/lom.2011.9.593

Laws, E.A., Falkowski, P.G., Walker, S.O.J., Ducklow, H., McCarthy, J.J., 2000. Temperature effects on export production in the open ocean. Glob. Biogeochem. Cycles 14, 1231–1246.

Lejeusne, C., Chevaldonné, P., Pergent-Martini, C., Boudouresque, C.F., Pérez, T., 2010. Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. Trends Ecol. Evol. 25, 250–260. doi:10.1016/j.tree.2009.10.009

Mangi, S.C., Davis, C.E., Payne, L.A., Austen, M.C., Simmonds, D., Beaumont, N.J., Smyth, T., 2011. Valuing the regulatory services provided by marine ecosystems. Environmetrics 22, 686–698. doi:10.1002/env.1095

Mangos, A., Bassino, J.-P., Sauzade, D., 2010. The economic value of sustainable benefits rendered by the Mediterranean marine ecosystems. Plan bleu, Valbonne.

Melaku Canu, D., Ghermandi, A., Nunes, P.A.L.D., Lazzari, P., Cossarini, G., Solidoro, C., 2015. Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: An ecological economics approach. Glob. Environ. Change 32, 87–95. doi:10.1016/j.gloenvcha.2015.02.008

Murillas-Maza, A., Virto, J., Gallastegui, M.C., González, P., Fernández-Macho, J., 2011. The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone, in: Natural Resources Forum. Wiley Online Library, pp. 122–133.

Murray, B.C., Kasibhatla, P.S., 2013. Equating Permanence of Emission Reductions and Carbon Sequestration: Scientific and Economic Foundations for Policy Options. Duke Environmental and Energy Economics Working Paper EE 13-08.

Ozer, T., Gertman, I., Kress, N., Silverman, J., Herut, B., 2016. Interannual thermohaline (1979–2014) and nutrient (2002–2014) dynamics in the Levantine surface and intermediate water masses, SE Mediterranean Sea. Glob. Planet. Change. doi:10.1016/j.gloplacha.2016.04.001

Rahav, E., Herut, B., Stambler, N., Bar-Zeev, E., Mulholland, M.R., Berman-Frank, I., 2013. Uncoupling between dinitrogen fixation and primary productivity in the eastern Mediterranean Sea: N_2 FIXATION AND PRIMARY PRODUCTIVITY IN THE

EASTERN MEDITERRANEAN SEA. J. Geophys. Res. Biogeosciences 118, 195–202. doi:10.1002/jgrg.20023

Raven, J.A., Falkowski, P.G., 1999. Oceanic sinks for atmospheric CO2. Plant Cell Environ. 22, 741–755.

Siokou-Frangou, I., Christaki, U., Mazzocchi, M.G., Montresor, M., Ribera d'Alcalá, M., Vaqué, D., Zingone, A., 2010. Plankton in the open Mediterranean Sea: a review. Biogeosciences 7, 1543–1586. doi:10.5194/bg-7-1543-2010

Stambler, N., 2014. The Mediterranean Sea–Primary Productivity, in: The Mediterranean Sea: Its History and Present Challenges. Springer Netherlands, Netherlands, pp. 113–121.

Suari, Y., Brenner, S., 2015. Decadal biogeochemical history of the south east Levantine basin: Simulations of the river Nile regimes. J. Mar. Syst. 148, 112–121. doi:10.1016/j.jmarsys.2015.02.004

Tol, R.S., 2008. The social cost of carbon: trends, outliers and catastrophes. Econ. Open-Access Open-Assess. E-J. 2, 1–22. doi:10.2139/ssrn.1716668

UNEP/MAP, 2012. State of the Mediterranean Marine and Coastal Environment. UNEP/MAP – Barcelona Convention, Athens.

van den Bergh, J.C.J.M., Botzen, W.J.W., 2015. Monetary valuation of the social cost of CO2 emissions: A critical survey. Ecol. Econ. 114, 33–46. doi:10.1016/j.ecolecon.2015.03.015