AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **23**: 506–514 (2013)

Published online 5 May 2013 in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2365

Linking human activity and ecosystem condition to inform marine ecosystem based management

SUSANNE MENZEL[a], CARRIE V. KAPPEL[b], BERNARDO R. BROITMAN[c], FIORENZA MICHELI[d,*] and ANDREW A. ROSENBERG[e]

[a]*Swiss Federal Research Institute WSL, Birmensdorf, Switzerland*

[b]*National Center for Ecological Analysis and Synthesis, Santa Barbara, CA, USA*

[c]*Centro de Estudios Avanzados en Zonas Aridas, Universidad Católica del Norte, Coquimbo, Chile*

[d]*Stanford University, Hopkins Marine Station, Pacific Grove, CA, USA*

[e]*Union of Concerned Scientists, Cambridge, MA, USA*

ABSTRACT

1. There is growing consensus that integrated marine management is needed. However, implementation of ecosystem-based management (EBM) faces major operational challenges, including accurately delineating the links between ecosystem components and benefits to humans, and quantifying trade-offs associated with different management decisions.

2. It is suggested using human activity level as an indicator of the benefit provided by marine ecosystems at a certain location in comparison with other locations and establishing links between human activity levels and ecological conditions.

3. This approach allows for the determination of what ecological conditions may provide the greatest human benefits and thus may be targets for management action.

4. This approach is used to investigate the link between scuba diving in the Monterey Bay area, California, USA, and different ecological characteristics of kelp forests. Diving intensity levels correlate with kelp persistence, suggesting that kelp persistence may be used as an indicator of benefits from diving and for evaluating the impact of potentially competing activities through their effects on kelp.

5. Overall, an operational definition of marine ecosystem services is provided and it is suggested that this method could be extended to a suite of different activities and systems and thus may become useful in considering trade-offs among different activities that depend upon the same ecosystem.

Received 8 February 2012; Revised 20 March 2013; Accepted 21 March 2013

KEY WORDS: ecosystem services; natural resource management; ecological indicators; Monterey Bay; California; kelp forest ecosystem; scuba diving; ecological production function; human benefits from ecosystems

*Correspondence to: F. Micheli, Stanford University, Hopkins Marine Station, Pacific Grove, CA 93950, USA. E-mail: micheli@stanford.edu

INTRODUCTION

The profound dependency of human well-being upon 'functioning' or 'healthy' ecosystems has gained increasing recognition (Millennium Ecosystem Assessment (MA), 2003, 2005; Fisher *et al*., 2009). The concept of ecosystem services, defined as the benefits that humans derive from ecosystems (Daily, 1997; de Groot *et al*., 2002; Millennium Ecosystem Assessment (MA), 2005), is now central to ecosystem-based management (EBM) approaches. A central goal of EBM is to sustain the flow of ecosystem services from a given place or ecosystem for future generations. This place-based approach to natural resource management focuses on entire ecosystems, acknowledges ecosystem linkages, and seeks to balance the needs of multiple species and multiple human sectors.

Although there is broad and increasing consensus that integrated multisectoral management is needed (Pew Oceans Commission (POC), 2003; US Commission on Ocean Policy (USCOP), 2004; Maritime Strategy Framework Directive (MSFD), 2008; Executive Order 13547—Stewardship of the oceans, our coasts, and the Great Lakes, 2010), attempts to implement EBM have encountered major challenges, and few comprehensive examples of EBM in the marine environment exist (Ruckelshaus *et al*., 2008). A major challenge is that the concept of ecosystem services is difficult to operationalize for management (Arkema *et al*., 2006; Daily *et al*., 2009). A critical stumbling block has been our ability to establish links between ecosystem condition and human well-being and to characterize quantitatively the relationship between the two. When human well-being is linked to natural resources bought and sold in markets, delineating these links and establishing value is a relatively straightforward economic exercise. But understanding and valuing non-extractive, and especially non-market ecosystem services, remains challenging. In the marine environment, basic gaps in our knowledge of ecosystem dynamics and patterns of human use have compounded this problem (Koch *et al*., 2009).

A practical approach is presented to relating human benefits derived from a particular non-extractive ocean use, i.e. recreational scuba diving, to the condition of the marine ecosystem upon which that activity depends. The method, which builds on recent research aimed at producing ecological production functions that define how ecosystem structure and function relate to levels of ecosystem services (Nelson *et al*., 2009; Tallis and Polasky, 2009), is simple and transferrable. An ecological production function is developed by directly linking marine ecosystem conditions with the human benefits from a non-extractive activity. Essentially, it is assumed that people vote with their feet, thus the intensity level of a given activity is assumed to be a reasonable indicator of the benefit of this activity: the higher the activity level at a given place, the higher the benefits or services provided at this location. One can then establish whether ecological conditions influence the activity level by comparing across different locations with varying ecological characteristics.

In this framework, ecosystem services are derived or latent features of the ecosystem, which emerge from the relationship between ecological components and human activity levels. The practical benefit of focusing directly on ecological components and human activities, rather than ecosystem services per se, is that both can be easily delineated and directly measured (e.g. number of fishing or diving trips for activity level, and population abundance or species diversity as measures of ecological components). This approach should ultimately aid managers in identifying target ecosystem conditions that support desired intensity levels and associated benefits for multiple sectors.

Several studies have already suggested links between ecosystem condition and non-extractive benefits in aquatic environments (Freeman, 1995; Guo *et al*., 2000; Wielgus *et al*., 2002; Soderqvist *et al*., 2005; Farber *et al*., 2006; Nunneri *et al*., 2007). For example, Shivlani and Suman (2000) have shown the high dependency of dive operators on designated no-take areas in Florida. Rudd and Tupper (2002) demonstrated for a Caribbean island that divers prefer sites with higher Nassau grouper mean size and abundance compared with reference sites, resulting in a significant increase in market shares for dive trips with more abundant and larger Nassau grouper. Wielgus *et al*. (2003) demonstrated for a region in the Israeli Red Sea how divers' willingness to pay for diving trips depends on coral and fish diversity and water visibility. Finally, in a meta-analysis of 166 coral reef recreation valuation studies, Brander *et al.* (2007) found that reef tourists place higher values on larger reefs with fewer visitors.

Ecosystem components, if any, that influence levels of recreational scuba diving in nearshore rocky reefs of central California (USA) are examined. Statistical modelling is used to link activity levels within the recreational diving sector to variation in characteristics of kelp forests and to develop a production function quantifying benefits to recreational divers provided by kelp forest ecosystems in different states. Two specific questions are addressed: (1) Is variation in ecosystem characteristics and condition associated with different levels of use (i.e. does ecosystem condition influence activity levels)? (2) If so, what are the specific ecosystem characteristics that correlate with activity levels? This case example demonstrates the activity-based approach to assessing links between ecosystem condition and human well-being and illustrates its potential to contribute to ocean planning and ecosystem based management.

METHODS

Study system: kelp forests and scuba diving

Kelp forests are highly productive and diverse marine ecosystems found in temperate shallow rocky bottoms (≤30 m depth). Along the coasts of California and northern Baja California, the giant kelp *Macrocystis pyrifera* forms dense forests that host a diversity of invertebrates, fishes, birds and marine mammals, including sea otters (*Enhydra lutris*), as well as several species targeted by past or current commercial and recreational fisheries such as sea urchins (*Strongylocentrotus* spp.), abalones (*Haliotis* spp.), spiny lobster (*Panulirus interruptus*), and rockfish (*Sebastes* spp.).

Kelp forests also support a large and growing recreational scuba diving industry. In a comprehensive assessment of California's marine economy, the total value of diving and snorkelling was estimated at 900 million US $, approximately nine times greater than the total value of commercial fisheries (Kildow and Cogan, 2005). Diving is, at present, a small but locally important component of the coastal tourism and recreation sector, the fastest growing ocean-related sector of California (Kildow and Cogan, 2005).

The levels of visitation of different dive locations may be influenced by several factors, including distance, accessibility and physical exposure of sites, their promotion by diving operators, and ecological attributes such as the likelihood of encountering large, rare fishes or marine mammals or the overall diversity of marine life (Figure 1). Determining the influence and relative importance of these different factors is important in a management context because only some of these features are potentially subject to marine management. For example, if diving activity levels at different sites are driven

Figure 1. Underwater view of kelp forest and kelp canopy at the water surface in Monterey Bay, California, USA. Photo credits: G. Shester and F. Micheli.

solely by site accessibility and physical conditions (e.g. depth and exposure to swells), activities that have the potential to negatively impact kelp forests (e.g. commercial and recreational fishing, construction of tourism infrastructure) are not expected to affect the diving sector. If, in contrast, these activities, through their impacts on kelp forest ecosystems, appear to affect the desirability and level of use of different locations by scuba divers, management may be faced with trade-offs between sectors and a need to balance benefits and impacts to each user group.

Data and statistical analyses

Linear regression analysis was used to relate diving activity intensity levels to ecological features of kelp forests and other possible drivers of diving activity, specifically distance of diving locations from port. Data on diving activity levels in the Monterey Bay area (Figure 2) – the dependent variable in the regression models – were collected in July 2006 through a survey of dive shops and operators. Dive shops and dive charters were identified through Internet and telephone directory searches. A letter was sent to all diving businesses in Monterey informing them of the survey and providing some sample questions; the initial pool contained eight potential respondents. Two weeks after the letters were sent out the companies were called to set up an interview date. Interviews were realized with five dive shops and charters active in the area. Interviewees were asked which were their five most-frequented dive sites and how many customers they took in the previous year (2005) to each of these sites. This resulted in data on diving intensity levels (as number of divers per location and year) for multiple locations in Monterey Bay. Approximately 6060 dives, across 14 different locations (Figure 2), were reported by the dive operators and charters.

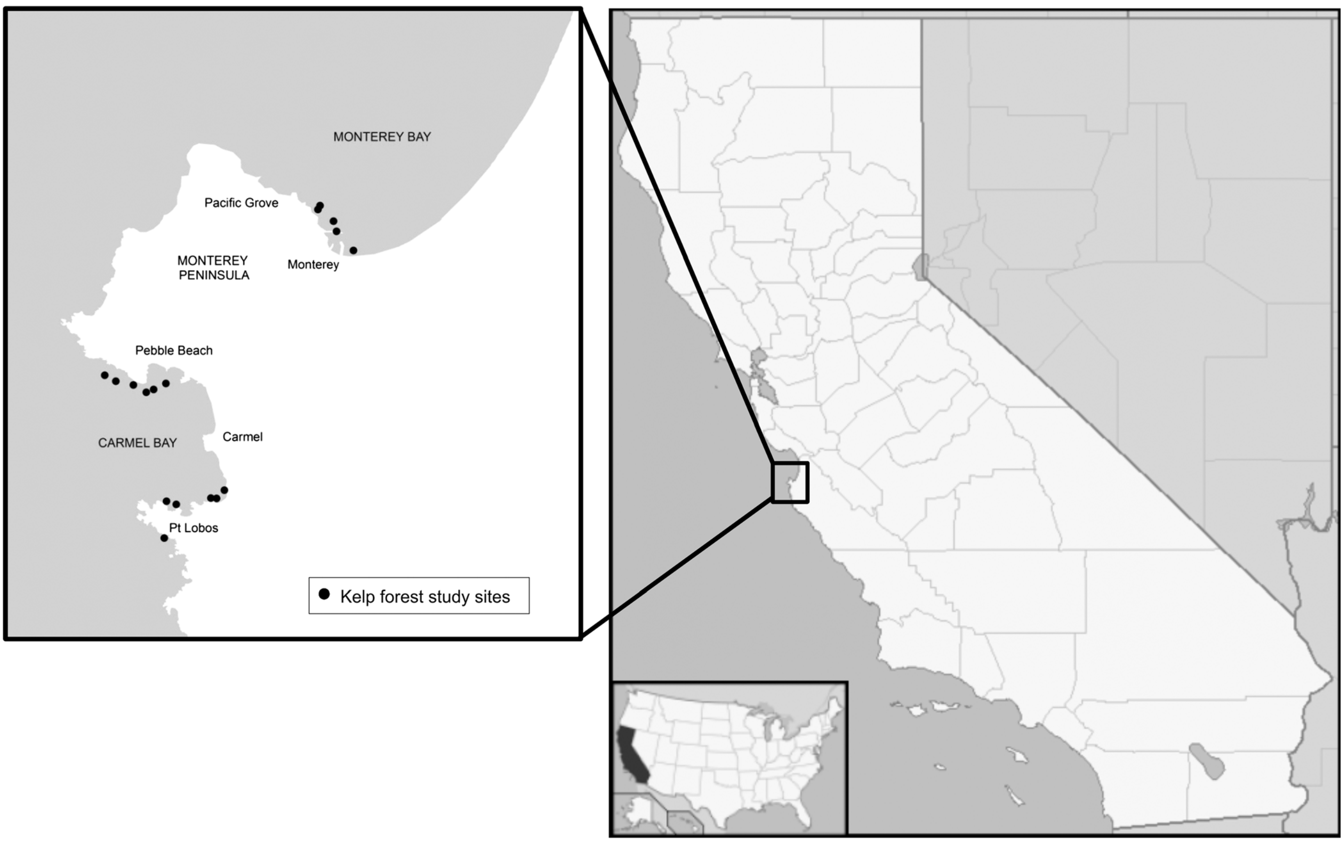

Figure 2. Map of the Monterey Peninsula, Monterey Bay, California, USA, showing the location of sites where diving activity levels were quantified (black points).

Independent ecological data describing kelp forest assemblages in eight of these 14 locations were obtained from the PISCO kelp forest monitoring programme (PISCO, 2010). Field surveys had been conducted at these sites from 1999 to 2005 using consistent methods (see Richards and Kushner (1994), for a detailed description of field survey methods). Briefly, divers surveyed replicate belt transects at each site recording kelp, fish, and mobile invertebrate species identities, sizes and densities, and estimating cover of major benthic organisms (i.e. macroalgae and sessile invertebrates). The abundance of different organisms was included in the statistical analysis outlined below using long-term mean abundances of each species (i.e. *Macrocystis pyrifera*) or the summed abundances of individuals from broader trophic groups (i.e. large piscivorous fishes or understorey kelp), pooled across transects. Field methods and measured variables are based on extensive research and monitoring of kelp forest ecosystems, through which a set of suitable variables describing the structure and dynamics of these assemblages have been identified (CRANE (Cooperative Research Assessment of Nearshore Ecosystems Program), 2004; Hamilton *et al*., 2010). Based on these previous evaluations, the following variables were included in different regression models: species richness, percentage cover of different macroalgal groups (algal turf, coralline algae, crustose algae), abundance of giant kelp and of understorey kelp, and abundance of different animal functional groups (herbivorous, omnivorous, and predatory mobile macroinvertebrates; sessile filter-feeding macroinvertebrates; planktivorous, invertebrate-eating, and piscivorous fishes). A dataset of temporal persistence of kelp canopy cover for these same eight sites was also used. Information was derived from 36 aerial surveys of the region conducted monthly from 1985 to 1989 (Donnellan, 2004). Compared with the PISCO yearly surveys of kelp densities, this dataset tracked kelp forest dynamics with greater frequency, thereby providing higher-resolution measurements of temporal variation in kelp densities and cover. Kelp canopy persistence was calculated by summing the number of surveys in which kelp canopy was present for each grid cell in the composite image. The kelp persistence dataset has a resolution of 3×3 m and when aggregated to match the spatial scale of field surveys (~250 m^2) showed a remarkable match with long-term kelp abundance measured in the PISCO field surveys despite the temporal mismatch in data collection ($r = 0.78$, $P < 0.001$). Following this result, kelp persistence measures at the scale of a diving location were used as an indicator of long-term kelp forest ecosystem functioning. Finally, the distance from port and from shore was calculated in ArcGIS for each location. Ecological information from the eight locations where both field community data and diving intensity were available was used to consider several possible drivers of diving activity levels (e.g. distance from port, abundance and species diversity of fishes and invertebrates, and either kelp density or kelp persistence) as independent variables in multiple linear regression models. All possible combinations of drivers were examined, and the best multilinear model was selected using Akaike Information Criteria (AIC). Partial coefficients of determination for each driver, sr^2, were calculated using a type II sum of squares, and correspond to the decrease in unexplained variance observed when incorporating either predictor in a linear regression model involving only the other variable.

RESULTS

A linear model including only distance from port and kelp canopy persistence as explanatory variables accounted for large and significant amounts of variation in diving activity levels among sites ($r^2 = 0.7514$, $P = 0.0004$) (Table 1). Diving intensity was negatively related to distance to port and positively related to kelp persistence (Table 1). Although both predictor variables explain statistically significant amounts of variation, including kelp persistence in a model already containing only distance from harbour decreases unexplained variation by 71%. In contrast, distance from harbour decreases unexplained variation by 39% when added to a model already including kelp persistence (Table 1). Thus, the greatest intensity of diving activity occurred at locations where kelp cover tended to be more stable through time.

Table 1. Partial coefficients of determination (sr^2) of distance to harbour (in km) and kelp persistence (the number of months during which kelp canopy is observed in aerial photographs from each location) on the numbers of divers at different locations around the Monterey Peninsula. The slope of each relationship (β), its standard error (SE), T statistic and associated significance level (p) are also reported

Predictors	β	SE	$T(H_0:\beta = 0)$	P	sr^2
Distance to harbour	–0.0180	0.00678	–2.6593	0.02221	0.39132
Kelp persistence	67.2670	12.8360	0.6600	0.0002	0.71401

DISCUSSION

The analysis shows that kelp persistence is a significant correlate of diving activity levels in coastal marine ecosystems of central California. Ecological production functions linking the condition of ecosystems to the benefits they can provide, such as the one identified here for recreational scuba diving, are scarce for marine ecosystems because of the general lack of data simultaneously quantifying human benefits and ecosystem condition at the same locations. Adopting an activity-based approach allows one to: (1) establish a link between ecosystem components and human benefits by clearly defining how the latter are quantified (i.e. in terms of activity level); (2) link ecological components to benefits even when the observed activity is non-extractive (and thus cannot be quantified through catch or yield); and (3) select from among the many possible variables describing ecosystem condition, those that most strongly correlate with activity levels and thus may serve as a focus for management. Thus integration of existing ecological and human activity data and future coordinated collection of such data have great potential for informing and enabling marine EBM.

Management implications

Kelp persistence is influenced by physical conditions, sea urchin grazing, human kelp harvesting, and water quality, including eutrophication, increased sedimentation, and oil spills (Steneck *et al*., 2002; Graham *et al*., 2007). The significant correlation between diving activity and kelp persistence allows for the identification of other human activities that may influence the diving sector through their direct and indirect impacts on kelp persistence, namely kelp harvesting, fishing, and coastal development (Steneck *et al*., 2002; Lafferty, 2004). The results highlight an important ecosystem linkage between these sectors and the recreational diving sector and suggest that future expansion of these sectors might negatively impact recreational diving. Moreover, the regression approach provides a quantitative assessment of diving activity losses that might be associated with different scenarios for development and harvest intensity. Results of this study highlight that useful insights can be generated with limited data and an incomplete understanding of the causal links and dynamic feedbacks between ecological conditions and human activities in an ecosystem.

The analysis provides two key results. First, that ecosystem condition (i.e. the stability of the kelp forest canopy through time) is significantly correlated with diving activity levels (Shivlani and Suman, 2000; Rudd and Tupper, 2002; Wielgus *et al*., 2003). To our knowledge this is the first study to show this for kelp forest ecosystems. Second, with simple statistical methods and without a complete mechanistic understanding of all the processes influencing kelp forest dynamics and their responses to natural variability and human use, kelp persistence has been identified as an easily monitored indicator of kelp forest ecosystem condition. The quality of kelp forests for supporting diving activities might be monitored and managed on the basis of this single variable. Because the analysis is correlational, it is not possible to establish a causal link between diving activity levels and kelp forest condition. While this relationship needs to be further investigated with additional observational and experimental studies, the results support the hypothesis that changes in ecosystem condition influence human use and provide a means of expressing this relationship quantitatively.

Adopting an approach that focuses on observable activities and observable ecological components, while explicitly treating ecosystem services as unobservable or latent variables, may facilitate the operationalization and implementation of EBM. The approach is relatively simple and easy to implement, replicate and demonstrate to broad and diverse groups, and it involves elements that can be subject to management actions. By using the intensity level of an activity we can quantify human benefits without attempting monetary valuation of non-market ecosystem services, although monetary valuation could also be performed as an additional step in the analysis. Further, this method allows for identification of the ecological indicators that best explain observable differences in activity level or intensity of use of different locations of ecosystems. Thus, this approach might enhance the communication between scientists, managers and users. Despite these contributions, there were some obstacles and limitations of these analytical approaches in general and the activity-based approach in particular.

Limitations

A key limitation of this approach is that it does not capture dynamic feedbacks or non-linearities between changing ecosystem conditions and levels of use. Such non-linearities might be particularly important for extractive activities, where ‘perverse’ reactions to scarcity have been observed. For example, in fisheries, a commonly observed reaction to lower catches is an increase in effort (Murawski *et al*., 2000; Rosenberg, 2003) and not a decrease as assumed by the linear regression model used here.

The activity-based approach also cannot account for the possibility of sudden unanticipated shifts in ecosystem condition or human behaviour; these thresholds, if not previously observed, will not be captured by a statistical modelling approach to generating production functions. Over longer time frames and for both extractive and non-extractive activities, the relationship between ecosystem condition and human activity levels might be influenced by the human capacity to adapt to changing environmental conditions captured by the ‘shifting baseline syndrome’ idea wherein historical depletion of marine resources establishes new and temporally shifting aesthetic, productivity or biodiversity reference points influencing human preferences and levels of use (Pauly, 1995). However, all other approaches to ecosystem services modelling encounter this limitation as well, as it follows from the assumption of clear and static functional relationships between nature and human well-being.

Another key limitation of an activity-based approach is that some important benefits do not translate directly into activities. Some cultural, regulating and supporting services might not directly result in observable activities. Thus, this approach does not solve the major challenge of comprehensively quantifying the benefits ecosystems provide to humans, though it does contribute to quantifying human benefits that can be expressed as activity levels. Finally, both extractive and non-extractive uses can result in negative impacts on ecosystems, with complex feedbacks to human benefits when these are linked to ecosystem condition. A quantification of such feedbacks and their inclusion in an activity-based approach is needed before this approach can be broadly applied to informing marine EBM.

Data scarcity even in data rich regions

Despite the fact that the case study dealt with a particularly data rich region, the analysis highlighted the gaps and spatio-temporal mismatches in the data needed for developing quantitative tools for EBM. Comprehensive datasets describing variation in both ecological components and human uses at similar and overlapping spatial and temporal scales are still limited. Despite every effort being made, the data that were available for the analyses covered a few locations and a short time frame. Thus, the generality of the results needs to be tested with a more extensive dataset describing ecosystem condition and diving activity at more sites across multiple regions. Human activity data are particularly scarce. Applying this approach to other sectors or activities would probably encounter similar data limitations.

In order to implement quantitative approaches to EBM, existing data should be made more readily available through public databases or clearing houses, and new data collection efforts should be coordinated to ensure that data collected are useful for management. Further work is needed that explicitly links social and ecological systems (Folke *et al*., 2002; Chapman *et al*., 2009), in the current analysis this was done by assuming that intensity levels from activities that are performed in interaction with the natural environment reflect contributions to human well-being, but this assumption requires additional tests in a broader suite of systems and case studies.

CONCLUSIONS

Taken together, the approach and results presented here provide an operational definition of some marine ecosystem services, highlight the relationship between ecosystems and specific human activities, and provide a means of developing ecological production functions for marine EBM. This approach could be extended to a suite of different activities and systems and thus may become useful in considering trade-offs among different activities that depend upon the same ecosystem.

ACKNOWLEDGEMENTS

This work is a product of the working group ‘A synthetic approach to the science of ecosystem based management’ supported by the National Center for Ecological Analysis and Synthesis, a center funded by NSF (Grant #DEB-94-21535), the University of California Santa Barbara, the California Resources Agency, and the California Environmental Protection Agency. We thank Irit Altman and Mike Fogarty for their insight, Steve Gaines, Mark Carr and Mark Readdie for access to kelp forest monitoring data, and Ana Spalding for conducting interviews.

REFERENCES

Arkema KK, Abramson SC, Dewsbury BM. 2006. Marine ecosystem-based management: from characterization to implementation. *Frontiers in Ecology and the Environment* **4**: 525–532.

Brander LM, Van Beukering P, Cesar, HSJ. 2007. The recreational value of coral reefs: a meta-analysis. *Ecological Economics* **63**: 209–218.

Chapman DS, Termansen M, Quinn CH, Jin NL, Bonn A, Cornell SJ, Fraser EDG, Hubacek K, Kunin WE, Reed MS. 2009. Modelling the coupled dynamics of moorland management and upland vegetation. *Journal of Applied Ecology* **46**: 278–288.

CRANE [Cooperative Research Assessment of Nearshore Ecosystems Program]. 2004. Compilation and analysis of Coastal Impact Assistance Program (CIAP) nearshore survey data. Available: www.dfg.ca.gov/marine/fir/crane.asp [February 14, 2013]

Daily GC. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press: Washington, DC.

Daily GC, Polasky S, Goldstein J, Kareiva PM, Mooney HA, Pejchar L, Ricketts TH, Salzman J, Shallenberger R. 2009. Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment* **7**: 21–28. (Available from: http://dx.doi.org/10.1890/080025)

de Groot RS, Wilson MA, Boumans RMJ. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* **41**: 393–408.

Donnellan MD. 2004. Spatial and temporal variability of kelp forest canopies in central California. Master of Science Dissertation, Moss Landing Marine Laboratories and the Department of Marine Science, San Jose State University, California, USA.

Executive Order 13547—Stewardship of the oceans, our coasts, and the Great Lakes. 2010. Federal Register **75**, No. 140: 43023 (July 22, 2010); (Available from: http://www.gpo.gov/fdsys/pkg/FR-2010-07-22/pdf/2010-18169.pdf)

Farber S, Costanza R, Childers DL, Erickson J, Gross K, Grove M, Hopkinson CS, Kahn J, Pincetl S, Troy A, *et al*. 2006. Linking ecology and economics for ecosystem management. *Bioscience* **56**: 121–133.

Fisher B, Turner RK, Morling P. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* **68**: 643–653.

Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* **31**: 437–440.

Freeman AM. 1995. The benefits of water quality improvements for marine recreation: a review of the empirical evidence. *Marine Resource Economics* **10**: 385–406.

Graham MH, Vásquez JA, Buschmann AH. 2007. Global ecology of the giant kelp *Macrosystis*: from ecotypes to ecosystems. *Oceanography and Marine Biology: An Annual Review* **45**: 9–88.

Guo ZW, Xiao XM, Li DM. 2000. An assessment of ecosystem services: water flow regulation and hydroelectric power production. *Ecological Applications* **10**: 925–936.

Hamilton SL, Caselle JE, Malone DP, Carr MH. 2010. Incorporating biogeography into evaluations of the Channel Islands marine reserve network. *Proceedings of the National Academy of Sciences* **107**: 18272–18277.

Kildow J, Cogan CS. 2005. California's Ocean Economy. National Ocean Economics Program's Report to the Resources Agency, State of California.

Koch EW, Barbier EB, Silliman BR, Reed DJ, Perillo GME, Hacker SD, Granek EF, Primavera JH, Muthiga N, Polasky S, *et al*. 2009. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment* **7**: 29–37.

Lafferty KD. 2004. Fishing for lobsters indirectly increases epidemics in sea urchins. *Ecological Applications* **14**: 1566–1573.

Maritime Strategy Framework Directive (MSFD). 2008. Directive 2008/56/EC of the European Parliament and of the Council; (Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF)

Millennium Ecosystem Assessment (MA). 2003. *Ecosystems and Human Well-being: a Framework for Assessment*. Island Press: Washington, DC.

Millennium Ecosystem Assessment (MA). 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press: Washington, DC.

Murawski SA, Brown R, Lai HL, Rago PJ, Hendrickson L. 2000. Large-scale closed areas as a fishery management tool in temperate marine systems: the Georges Bank experience. *Bulletin of Marine Science* **66**: 775–798.

Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron R, Chan KM, Daily GC, Goldstein J, Kareiva PM, *et al*. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* **7**: 4–11.

Nunneri C, Windhorst W, Turner KR, Lenhart H. 2007. Nutrient emission reduction scenarios in the North Sea: an abatement cost and ecosystem integrity analysis. *Ecological Indicators* **7**: 776–792.

Pauly D. 1995. Anecdotes and the shifting base-line syndrome of fisheries. *Trends in Ecology & Evolution* **10**: 430–430.

Pew Oceans Commission (POC). 2003. America's living oceans: charting a course for sea change. (Available from: http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Protecting_ocean_life/env_pew_oceans_final_report.pdf) [9 July 2010]

PISCO. 2010. (Available from: http://www.piscoweb.org) [9 July 2010]

Richards DV, Kushner D. 1994. Kelp forest monitoring, 1992 annual report. Technical Report CHIS-94-01. Channel Islands National Park, Ventura, CA.

Rosenberg AA. 2003. Managing to the margins: the overexploitation of fisheries. *Frontiers in Ecology and the Environment* **1**: 102–106.

Ruckelshaus M, Klinger T, Knowlton N, Demaster DR. 2008. Marine ecosystem-based management in practice: Scientific and governance challenges. *Bioscience* **58**: 53–63.

Rudd MA, Tupper MH. 2002. The impact of Nassau grouper size and abundance on scuba diver site selection and MPA economics. *Coastal Management* **30**: 133–151.

Shivlani MP, Suman DO. 2000. Dive operator use patterns in the designated no-take zones of the Florida Keys National Marine Sanctuary (FKNMS). *Environmental Management* **25**: 647–659.

Soderqvist T, Eggert H, Olsson B, Soutukorva A. 2005. Economic valuation for sustainable development in the Swedish coastal zone. *Ambio* **34**: 169–175.

Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner MJ. 2002. Kelp forest ecosystems: biodiversity stability resilience and future. *Environmental Conservation* **29**: 436–459.

Tallis H, Polasky S. 2009. Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences* **1162**: 265–283.

US Commission on Ocean Policy (USCOP). 2004. An ocean blueprint for the 21st century. Final Report of the US Commission on Ocean Policy to the President and Congress. (Available from: http://www.oceancommission.gov) [9 July 2010]

Wielgus J, Chadwick-Furman NE, Dubinsky Z, Shechter M, Zeitouni N. 2002. Dose-response modeling of recreationally important coral reef attributes: a review and potential application to the economic valuation of damage. *Coral Reefs* **21**: 253–259.

Wielgus J, Chadwick-Furman NE, Zeitouni N, Shechter M. 2003. Effects of coral reef attribute damage on recreational welfare. *Marine Resource Economics* **18**: 225–237.

