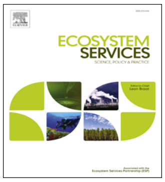
Ecosystem Services 18 (2016) 68–77

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser



A review of seagrass economic valuations: Gaps and progress in valuation approaches

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ARTICLE INFO

Article history:
Received 25 January 2015
Received in revised form
11 February 2016
Accepted 12 February 2016

Keywords:
Seagrass
TEV
Ecological services
Ecosystem
Valuation

ABSTRACT

Multiple studies have documented the ecologically important role that seagrasses play in estuarine and marine ecosystems. Unfortunately, economic valuations of these systems have not been as widespread. To date, most techniques rely on mechanisms that do not incorporate the actual ecological drivers behind the economic service, but rather rely on proxy measures to derive value. In this manuscript we review the many values that seagrasses have that result in economic services, and the valuation techniques used to estimate their monetary value. We present a conceptual framework linking seagrass ecosystems to the economic services they provide, showing the areas where novel valuation approaches are most lacking. We conclude that indirect methods used to valuate seagrass ecosystems underestimate the economic value of their services, and that more derivative-based models linking ecological structure and function to all associated economic services are essential for accurate estimations of their dollar value.

Contents

1. Introduction

Seagrasses are marine angiosperms that inhabit coastal ecosystems worldwide. While the taxonomic diversity of seagrass is

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http://dx.doi.org/10.1016/j.ecoser.2016.02.010

low, its acreage typically extends to hundreds of thousands of kilometers of the coastline (Short et al., 2007; Orth et al., 2006). Seagrasses provide many ecosystem services (Fonseca et al., 2002; Emmett Duffy, 2006). These ecosystem services may be permanently tethered to local economies, meaning that quality of life in some coastal communities might depend on the state of the seagrass meadows. (Anderson, 1989; Spurgeon, 1999; Unsworth et al., 2010). Unlike other primary producers in the marine environment, seagrasses have a broad latitudinal range, inhabiting all but polar ecosystems (Orth et al., 2006). This means that the economic services provided by seagrass ecosystems occur at multiple spatial scales. The nature of some of these services and the proximity of seagrass ecosystems to densely populated areas however, exposes them to a wide variety of activities that negatively impact it (Orth et al., 2006; Duarte, 2002).

Recent studies have reported a perpetual worldwide decline in seagrass abundance (Orth et al., 2006). The causes of these declines vary spatially and temporally. Heavy dredging from marine construction is a well-documented negative impact activity on seagrass beds (reviewed in (Erftemeijer and Robin Lewis, 2006)). Shallow seagrass beds are especially prone to scouring from vessel grounding and scarring from the propellers of motorized boats (Zieman, 1976). These injuries not only remove the aboveground biomass, but excavate the rhizomes and sediment sometimes creating blowholes. Marine fauna can then create further damage by excoriating the adjacent rhizome thus causing neighboring beds to collapse (Patriquin, 1975). Near shore seagrass beds are also vulnerable to allocthonous nutrient inputs as effluent from human activities (Harlin and Thorne-Miller, 1981) or from groundwater (Reide Corbett et al., 1999). These nutrient increases can result in an ecological shift to faster growing micro and macroalgae both of which outcompete seagrasses for light, and are physiologically better equipped to proliferate in a high nutrient environment (den Hartog, 1994; Harlin, 1975; Silberstein et al., 1986). Overfishing can also spur cascading effects that have negative effects on seagrasses in a couple of ways. Firstly, the removal of large predators releases the consumer pressure on smaller predators who feed on epibenthic fauna in seagrass ecosystems. Epibenthic fauna feed on epiphytic algae that accumulate on the blades of seagrasses. When epibenthic fauna is removed from the system, the accumulation of epiphytes on seagrass leaves can prevent seagrasses from accessing much needed light for photosynthetic activity (Heck and Valentine, 2006). Secondly, the removal of large predators allows herbivores to feed unimpeded on seagrass beds (Myers et al., 2007).

Most of the negative impacts on seagrass beds reflect the reality that coastal ecosystems are by-and-large common use areas. High volumes of commercial, recreational and tourist activities ensure a large amount of boat and human traffic within a few miles from the shoreline resulting in direct impact on seagrass beds. In addition, 40% of the world's population live within 60 km of the coastline (Organization, 2005), meaning that coastal communities are more likely to suffer from negative externalities associated with population increase.

There have been many calls for stricter management policies to aid in the preservation and restoration of existing seagrass beds (Fonseca et al., 1998). While many of these requests cite the economic value of seagrass ecosystems, there have been only a few studies that provide dollar estimates of the value of these systems. A main reason for this is that seagrass itself does not have much direct market value. Therefore, economic assessments of their worth rely on indirect values derived from the services these systems provide. Since some of these services result in social benefit, traditional market methods may be insufficient for deducing actual economic value. Additionally, the specific ecological relationship between seagrasses and some of its benefits have only been relatively recently documented, and therefore efforts to translate certain ecosystem functions into economic terms are still in its infancy.

There is a clear need for greater progress to be made on seagrass valuation. As humans increasingly populate coastal cities, greater pressure is being applied to coastal ecosystems to satisfy local demands for space, food, and other resources. Chief among the potential impacts to the coastal ecosystem by burgeoning populations is the decrease in water quality due to runoff, dredging and other human activities (Waycott et al., 2009; Grech et al., 2012). The varying ability of seagrass meadows to mitigate these effects, means that local communities bear the negative economic effects of destroyed meadows. Where communities rely heavily on the ecosystem services seagrasses provide, wellbeing suffers much more disproportionately when compared to communities that draw from a variety of ecosystem services (Grech et al., 2012). To create greater awareness among policymakers and the general public of the need to protect seagrasses, and to convince politicians to commit resources to do so, a clearer economic argument for seagrass ecosystem preservation needs to be made. Commercial stakeholders tend to have an easier time demonstrating the economic value of their projects. Income from property taxes, corporate taxes and tourist revenue has visible and tangible benefits for the local economy. These linear economic relationships make it easier for these stakeholders to enlist the support of managers and politicians, even if the enactment of these projects produces long-term harm to coastal ecosystems. Environmental managers however have a more difficult time demonstrating the economic contribution of non-commercial ecosystem uses.

In this paper, we review the different values of seagrass ecosystems and the valuation techniques used to estimate seagrass value around the world. We indicate here the strengths and weaknesses of each approach, and discuss the areas where the field can be advanced. We believe that recent literature on seagrass ecology has uncovered new ecosystem services (Unsworth and Cullen-Unsworth, 2014), and therefore, existing economic valuation studies may be incomplete.

We first discuss the theoretical economic valuation framework that guides the review of this issue. Second, we highlight the list of current attempts at valuation of seagrass ecosystems, pointing out the gaps in their approaches. Finally we present a conceptual model (Seagrass Ecosystem Valuation [SEV] model) that provides a framework to valuate and aggregate the multiple ecosystem services of seagrass ecosystems, discussing ways in which it can be used by managers and future stakeholders in local systems.

2. Methods

We used ISI web of knowledge and searched for valuation papers using the terms ‘SEAGRASS VALUATION’, ‘SEAGRASS ECONOMIC VALUE’ and ‘SEAGRASS VALUATION METHODS’. We culled the papers for all examples where valuation attempts were used to ascribe an economic value to seagrass beds. We also collected papers that originally described the ecological relationship that seagrass beds have with each of its ecosystem services. We then classified the studies into groups based on whether they addressed one or more of direct use values, indirect use values, and non-use values. This classification allowed us to identify any gaps on the seagrass value spectrum.

3. Seagrass value

Total Economic Value (TEV) is an aggregate estimation of the function-based value that an ecosystem provides a local community. This value is a summation of *use* and *non-use* values. The quantification of the different value types often requires different valuation approaches. We use the TEV framework here to discuss both past valuation attempts and areas where new approaches are needed.

3.1. Use value

3.1.1. Direct use

There is some history of direct human use of seagrass biomass. Its high silica content, slowness to rot, and the air pockets formed in dead seagrass mats made it ideal insulation material (Wyllie-Echeverria and Cox, 1999; Harrison, 1989). This was used for things ranging from thatching roofs to making sound proof recording studios. The dead material has also been historically used for the formation of dykes to help prevent beach erosion (Wyllie-Echeverria and Cox, 1999). Since current conservation policies in most parts of the world prevent direct harvesting of live seagrass material, direct use of seagrasses currently is mostly restricted to dead or decaying material. These activities are somewhat localized to specific regions since some of the historical benefits of seagrass (like insulation) are now satisfied with more practical, efficient and cheaper alternatives. Different species of seagrass species have different fates after death. Species that are negatively buoyant remain submerged after death locking decaying organic matter within the local system (Mateo et al., 2006). Positively buoyant species can float over long distances and may be washed up on beaches in large quantities. In these situations, the dead material can have a number of uses including embroidery, erosion prevention, and mulch-use for home gardening. Some companies have been able to use seagrass material to develop a specific nutrient mix for horticultural use, but there have been only a few reported examples of this (Orquin et al., 2001).

3.1.2. Indirect use

Indirectly, seagrasses provide a number of valuable services to human communities. The juveniles of some commercial and recreationally caught fish species make their home in seagrass beds. There is also direct harvest of marine species from seagrass beds. These beds act as a nursery for juveniles, or habitat for various stages of the life cycles of fish species (Jackson et al., 2015), providing protection from larger predators and reduce intra-species competition for resources (reviewed in (Heck et al., 2003)). Seagrasses also reduce the impact of wave action on coastlines thereby reducing erosion. Studies using wave tanks have shown that seagrass beds can cause wave attenuation up to 40%, making their protection effect comparable to those of salt marsh ecosystems (Fonseca and Calahan, 1992). Their extensive rhizome structure also plays a very important role in keeping sediments bound thus reducing sedimentation (Fonseca and Fisher, 1986). The resulting water clarity is very important for the seagrasses themselves who are light dependent, but is also important for sometimes adjacent coral reef ecosystems, that depend on high light incidence to survive. A seagrass die-off in Florida Bay in 1990 resulted in the partial death of coral in the Florida Keys reef tract, exemplifying the importance of this relationship (Porter et al., 1999).

3.2. Non-use value

There have been very few studies done on the non-use value of seagrass ecosystems. Reviews that we have found on ecosystem valuations of coastal ecosystems contain little data on non-use valuation. Some recent studies have used more qualitative approaches to document the impacts of seagrass loss on local communities (Grech et al., 2012). While, these methods may be better at capturing the effect of seagrasses on wellbeing, the documented 'effects' seem largely dependent on the level of dependency the local community has on the seagrass ecosystem service. Otherwise, there is a general lack of public awareness of the presence of seagrass ecosystems (Orth et al., 2006) and their importance to ecosystem goods and services (Vithayaveroj, 2003).

4. Seagrass valuations

Attempts at seagrass ecosystem valuation have used a variety of approaches. These approaches are by and large location specific, and cover only a partial list of values. They typically reflect the nature of the ecosystem service provided in the area. For valuations, seagrass meadows are treated as monolithic entities that provide similar services over the spatial scale of the meadow. While some authors have attempted to capture the variation in service 'quality' within meadows (Kilminster et al., 2015), traditional valuation approaches quantify entire seagrass ecosystems as a unit. One common approach is willingness-to-pay (WTP). This is a choice modeling method where individuals indicate via a survey the amount of money they are willing to pay to ensure the continued existence of a good or service. This willingness however is somewhat correlated to public awareness of the function and value of seagrass ecosystems, which unfortunately is still limited. A recent review of the scientific literature showed that peer-reviewed work on seagrasses still lag behind (in total volume) by orders of magnitude mangrove ecosystems and coral reefs (Orth et al., 2006), a possible explanation for this lack of awareness. Recent studies connecting the decline of seagrasses to reduced carbon sequestration however may help to increase awareness (Fourqurean et al., 2012).

The replacement model is one of the more common valuation methods of seagrass ecosystems. This approach is common in calculating costs incurred by vessels that inadvertently or otherwise run aground or inflict damage onto seagrass beds. The willful or accidental damage of seagrass beds or coral reef habitat is a misdemeanor offense in the state of Florida (Anonymous, 2009). While the replacement model serves as a convenient mechanism to ensure accountability by individuals who value the ecosystem services seagrasses provide, it is in reality an estimate of time and effort of seagrass restoration, and may grossly underestimate the value of the full complement of services seagrasses provide. This approach has also been used to calculate Habitat Equivalency Analyses (HEA), a technique devised to compensate the public for habitat loss by performing restoration work on a habitat of equal ecological value (Dunford et al., 2004).

Some studies simply cite valuations used in similar ecosystems and apply the calculated value to seagrass ecosystems (Engeman et al., 1998). This benefits-transfer approach is convenient since these calculations have sometimes already become part of policy, but it relies on the assumption that the ecosystem services provided by both systems are similar enough allow for the seamless use of the same analysis. Using valuations from mangrove ecosystems (King, 1998) for example ignores the vast differences between the two systems in terms of their nursery function and their respective roles in water quality improvement.

The productivity method is the only method which actually links seagrass ecosystem structure and function to an ecosystem service that has market value. Some studies report location-specific values of seagrass beds based on catch-per-unit-efforts (CPUE), by extrapolating yearly estimates multiplied by the market price of the fish species in question (McArthur and Boland, 2006). MacArthur and Boland (2006) used this approach to estimate the overall contribution of seagrass habitats to the economy in Australia to be US103.74 million dollars per year. While this method might be the strongest approach linking primary productivity to the free market, the approach comes with a few noted assumptions. Firstly, the relationship between a commercial fish species and its seagrass habitat may not be necessarily linear. Complicated food web structures in some areas mean that the presence (or absence) of other non-commercial marine fauna can affect the abundance of commercial fish species. This reality is not always captured by the productivity approach. Productivity models will therefore have to be refined to incorporate more of the factors that affect both primary productivity (as a proxy for habitat quality) and secondary productivity (the market species of interest).

5. Missing values and valuation methods

The most glaring gap in the seagrass valuation literature is the need to better link indirect use values to market goods and services. Clifton et al. (2014) documents the limitations in current valuation approaches for all marine ecosystems. Part of these limitations include the difficulty that contemporary valuation approaches face recognizing the complexity inherent within ecosystems. A productivity approach would be more mindful of this complexity and will greater emphasize the relative contribution that a seagrass bed makes to the delivery of a particular ecosystem good or service. For example, Jackson et al. (2015) used the residency index technique to measure the contributions of seagrass to commercial and recreational fisheries based on the length of the resident time that the individual fish species spend on seagrass beds. (Fonseca et al., 2002; Fonseca and Calahan 1992; Fonseca and Fisher, 1986) determined the relative effects that various seagrass species had on the relative velocity of waves. This reduction in velocity has implications for the amount of erosion that may take place in the presence or absence of these seagrass species. Currently, some studies use hedonic pricing (a valuation technique that estimates a good based on its contributing characteristics) to estimate the value of coastal properties with or without erosion (Pompe and Rinehart, 1995). The effect of seagrasses on reducing erosion of the coastline can be a contributing estimator toward the total value of the coastline area.

The water clarity *is* important for seagrasses as they require a high incidence of light to carry out its photosynthetic activities (Abal et al., 1994; Duarte, 1991). High turbidity in the water column or changes in depth can impede the ability of seagrasses to capture enough light for photosynthesis, and thus may become limiting factors for seagrass productivity (Abal et al., 1994). In this model, seagrasses improve water quality but are also themselves limited by this factor. Any estimation of the value of seagrass with respect to water quality will have to consider the contribution water quality makes to economic activities that depend on water clarity. Other estimators of water quality focus on its nutrient composition and its subsequent capability to support different types of primary producer communities (Tomasko, 1991; McGlathery, 2001; Burkholder et al., 1992; Duarte, 1995). High values of nitrogen and phosphorus can result in stable state changes that favor faster growing macro and micro algae (Duarte, 1995). The presence of seagrass beds can result in the incorporation of macronutrients from the water column into biomass, thus making it unavailable for microalgae (Ziegler and Benner, 1999). A primary producer community that comprises mostly algae is structurally very different to larger macrophytes and has broad implications for the types of secondary consumers they support (Edgar, 1990). Higher microalgae concentrations can also severely reduce the attenuation of light to the benthos causing a collapse of the seagrass community (Duarte, 1995). The rhizomes of seagrasses hold the sediment in place and thus reduce the flux of nutrients from the benthos into the water column. This lessens the probability of algal blooms taking place that can cause permanent seagrass loss.

Seagrasses act as a nursery habitat for various species of fish. This nursery hypothesis has been used as a primary reason to enact conservation policies of seagrass systems worldwide. Some of these species have commercial importance when they become adults. Other species are the prey for species that are commercially important (crustaceans are eaten by red snapper for example). There is a spatial component to seagrass' function as a nursery. A meta-analysis of 'nursery' studies indicates that this is more true for seagrass beds in the northern hemisphere versus the southern hemisphere (Heck et al., 2003). Ultimately, the quality of seagrass beds as a nursery depends largely on the structure of the blades of the seagrass species as opposed to its overall abundance (Heck et al., 2003). Clear relationships between seagrass beds and commercially caught species however have been established for different locations in the world, and this allows for better economic estimates to be made as far as seagrass' actual value. The seagrass nursery also provides habitat (and sometimes feeding grounds) for marine species that inhabit coral reefs in their adult stages, or make diurnal treks between reefs and surrounding seagrass beds (Robblee and Zieman, 1984). Current studies linking seagrass bed structure to secondary productivity are still mostly limited to comparative estimates of consumer biomass within and outside of seagrass beds. Our knowledge of morphology affecting nursery function in seagrass beds has improved such that new models should incorporate both this reality, and the contribution that primary productivity plays in creating this structure. Consumer biomass can then be calculated as a derivative of primary productivity *and* morphology.

The contributions of coral reef systems to local economies have been well documented across multiple spatial scales (Moberg and Folke, 1999). Recreational SCUBA diving and snorkeling, concession boats and private boating all proliferate in regions where there are vibrant, intact coral reefs. The relationship between seagrass beds and coral reefs has also been fairly well studied. Seagrasses service coral reef ecosystems in a number of ways. Seagrass root structure keep water column transparent allowing corals to benefit from high light incidence, necessary for its survival (Rogers, 1990). Seagrasses also house meiofauna that are a food source for some diurnal reef fish species that leave the reef tract to feed in the seagrass beds at night (Robblee and Zieman, 1984). The relative contribution that seagrasses make to the overall survivability of a coral reef is not well quantified, and as a result, an economic valuation using this model might be a challenge. Until there is an empirical determination of the level of ecosystem function of coral reefs with and without a symbiotic relationship with seagrass beds, economic valuations using this relationship will have to rely on extrapolated estimates based on secondary productivity.

Until very recently, the role of seagrass ecosystems in carbon sequestration was not documented on a global scale. In the wake of concerns over the climate change effects resulting from increased carbon dioxide emissions, multiple stakeholders are seeking ways to reduce the global carbon footprint. These reductions can occur by reducing emissions, as well as increasing the number of sinks available. A compilation of the carbon sequestration potential of the global seagrass stock has documented exactly this effect (Fourqurean et al., 2012; Mcleod et al., 2011; Greiner et al., 2013; Pendleton et al., 2012; Lavery et al., 2013). These estimates purport that globally, seagrasses can possibly store up to 19.9 Pg of organic carbon in their meadows. The economic implications of these calculations are made more apparent by the reality that many of these meadows are disappearing at a substantial rate. The loss of these meadows means that the resulting carbon release increases the atmospheric carbon pool. The

Table 1
Ecological contributions of seagrasses to local ecosystems. Papers indicate various models used to quantify the ecological functions of seagrass beds. Vector labels correspond to arrows in the SEV conceptual model.

System	Vector	Model	Reference
Ecological	a	Nutrient cycling Root uptake$=$[(mineralization–diff.flux)/incorporation] $\times$ 100% Leaf uptake$=$[(diff.flux$+$(flushing $\times$ conc.))/incorporation] $\times$ 100%	Erftemeijer and Middelburg (1995)
	b	Water quality Principle Components Analysis (PCA) of location-specific relevant water quality parameters	Fourqurean et al. (2003)
	c	*Water quality effects on seagrass* Discriminant Function Analysis (DFA) using PCA values and seagrass Cluster AnalysisK_d (PAR)$=(1/z_r)$ X ln(PAR_z/PAR_0) where PAR$=$photosynthetically active radiation	Fourqurean et al. (2003), Gallegos and Kenworthy (1996)
	d	*Seagrass loss from herbivory* Location-specific biomass loss rates from the northern Florida Keys	Kirsch et al. (2002)
	e	Seagrass bed morphology PCA of seagrass morphometrics with abiotic factors	Hackney (2003)
	f	Carbon sequestration	Fourqurean et al. (2012)
	g	Wave energy reduction $F=\rho C_d U^2$ where F is force per volume, ρ is density, C_d is the bulk drag coefficient for waves and steady currents, and U is the steady current speed at a particular height	Fonseca and Calahan (1992)
	h	Sediment stabilization $Ft=a^{*}e^{-b^{*}H}$ *where FT=downward sediment flux in g DWm*$^{-2}$ *day*	Gacia et al. (1999)
	i	*Sediment stabilization and water quality* Shields diagram $u_{*}^{2}=\tau/\rho$ where u is friction velocity, τ is shear stress on particles and ρ=water density	Madsen et al. (2001)
	j,k	Direct herbivory Mixed-effects model for manatee feeding Feeding Cycle Length$=B_0+B_1$ *X ln(body length–231.5 cm)*	Marshall et al. (2000)
	l,m	Nursery function Seagrass Residency Index (SRI)–$S_i=ax_i+by_i+cz_i$	Scott et al. (2000)
	n	Wave energy and coastline integrity $dX/dT \equiv F$ where dX/dT is the erosion rate and F is the force of the waves	Sunamara (1977)
	o	Water quality and coral reef health Conceptual model	Haynes et al. (2007)

economic loss caused by the amount of carbon lost to the atmosphere by seagrass meadow destruction can thus be used as an estimator of seagrass value. (Table 1)

6. Seagrass ecosystem valuation model

Current valuation models typically address only partial functions of seagrass ecosystems (Unsworth and Cullen-Unsworth, 2014). Most of the valuation estimates in the literature (Table 2) report seagrass value with respect to commercial fish production. Fisheries as an economic good have a clear, tangible, market-related mechanism by which its value is measured. A few studies have also valued the economic contribution of seagrasses due to its nutrient cycling capability. Sorely lacking from the literature are studies that valuate seagrasses for their economic contribution to non-consumptive activities. These activities (snorkeling, SCUBA diving, boating etc.) are varied, and the ability to engage in them often relies on multiple attributes of the ecosystem above and beyond seagrasses. Valuation studies often calculate economic value (Scientists HaSEEa, 2005) based on total ecosystem capacity and often fail to isolate the seagrass contribution to this figure. Carbon sequestration (another non-consumptive value) also does not appear in many valuations because seagrasses as a major carbon sink (with global warming and economic ramifications) is a relatively recent discovery. (table 3)

Table 2
Economic contributions of seagrass ecosystems. Papers indicate current publications that describe methods used to quantify these values. Vector labels correspond to the arrow labels in the SEV model (Fig. 1).

System	Previous valuation approaches	Example reference
Economic	Travel cost method, WTP	Spurgeon (1992), Pendleton (1995)
	Productivity method	McArthur and Boland (2006)
	Cost-benefit analysis	Nordhaus (1991)
	Hedonic pricing method	Feenberg and Mills (1980), Joan Poor et al. (2007)
	WTP	Vithayaveroj (2003)
	Benefits transfer	Engeman et al. (2008)

The bias in the type of valuations currently done on seagrass ecosystems is likely due to the paucity of research that significantly quantifies the relationship between seagrasses and economic goods and services. Economists have an easier time therefore valuing goods that have a clear market-based system in their analyses. Some of these relationships are only just being figured out.

The conceptual seagrass ecosystem valuation model (Fig. 1) we propose links an ecological model of a seagrass ecosystem with economic models that valuate its goods and services. The model in essence teases apart the different services that are derived from this system so that they can be delineated individually. This approach is important both for ecological and economic reasons. Ecologically speaking, it recognizes the fact that seagrass beds occupy a complex niche in estuarine and marine environments, and the dimensions of this niche are shaped by biotic and abiotic factors. By quantifying these factors for a given system, one can conceivably predictively model how a seagrass patch might function under a variety of scenarios. These scenarios will vary spatially and temporally. For instance, patch growth rate of a monospecific bed of *Thalassia testudinum* in Biscayne Bay, Florida will be very different to the patch growth rate of *Zostera marina* in Tomales Bay, California. The morphology of these beds (as well as patch diversity) will determine its relative ability to affect wave velocity, to act as suitable habitat, and to prevent sediment from being stirred into the water column. The rate of conversion of atmospheric carbon dioxide into organic matter will also vary with the rate of primary productivity of the species, and the fauna that inhabit these seagrass beds will vary widely spatially in terms of their economic importance (Beck et al., 2001).

Table 3
Published seagrass ecosystem economic valuations.

Value	MEA service	Ecology studies	Economic valuation studies	Valuation method	Value
Use (direct)					
Mulch	Fiber	Orquin et al. 1999, Orquin et al. (2001)			
Insulation	Fiber	Wyllie-Echeverria and Cox (1999)			
Embroidery	Ornamental resources	Huong et al. (2003)			
Provisioning			Dirhamsyah (2007)	Market price; Travel cost	US2,287/ha/yr
			Kuriandewa et al. (2003)		US80,226/ha/yr
Use (indirect)					
Nursery	Food/Recreation	Heck et al. (2003)	Anderson (1989)	Productivity method (commercial fisheries)	US1.8million/yr
			Watson et al. 1993, Kirsch et al. (2002)	Productivity method (prawn commercial value)	US1150/ha/yr
			NOAA 1997, Gacia et al. (1999)	Replacement	US28,000–684,000/ha
			Vithayaveroj (2003), Madsen et al. (2001)	Productivity method	US203,200/yr
			McArthur and Boland (2006)	Productivity method (fish commercial value)	US103.74 million/yr
			Paulsen (2007)	CVM	US960,000/yr
			Samonte-Tan et al. 2007, Sunamara (1977)	Productivity	US 204/ha/yr
			Unsworth et al. (2010)	Market price	US78/ha/yr
			Guerrey et al. 2012, Spurgeon (1992)	Productivity method (multiple services)	US4585/ha
			Vassallo et al. (2013)	Market cost	US2.3 M/ha/yr
Tourism	Recreation	Daby (2003)			
Carbon sequestration	Primary Production	McLeod et al. 2012, Mcleod et al. (2011), Fourqurean et al. (2012), Greiner et al. (2013)	Pendleton et al. (2012), Lavery et al. (2013)	Carbon storage calculation	US394/ha/yr
Wave attenuation	Erosion regulation	Fonseca and Calahan (1992)			
Sediment stabilization	Erosion regulation	Terrados and Duarte (2000)	Guerrey et al. 2012, Spurgeon (1992)	Productivity method (multiple services)	US4585/ha
Nutrient cycling	Nutrient cycling	Short (1987)	Costanza et al. (1997)	WTP	US19,004/ha/yr
			Brenner et al. 2004, Marshall et al. (2000)	Meta-analysis	US24,228/ha/yr
			Engeman et al. (2008), Fourqurean et al. (2012)	Transfer method (original WTP, King, 1998)	US140,752.23/ha
			Han et al. 2008, Haynes et al., (2007)	CVM, Benefits-transfer, WTP	US100,640/ha
			Guerrey et al. 2012, Spurgeon (1992)	Productivity method (multiple services)	US4585/ha
Non-Use					
Existence			Vithayaveroj, (2003)	WTP	US10.43million/yr
Wellbeing			Cullen-Unsworth et al., (2014)	Case study analysis	Location-specific range of positive externalities

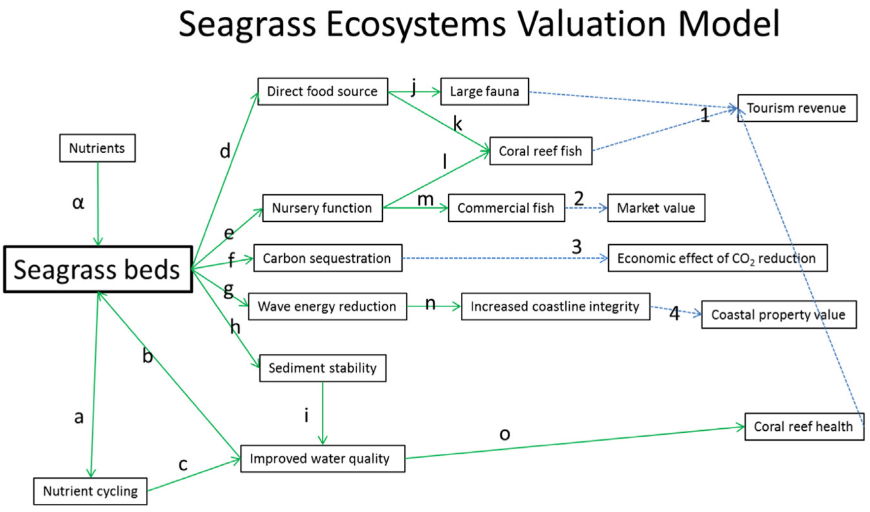

Fig. 1. SEV model. Green arrows represent ecological function, blue arrows represent economic contribution. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Economically, the model allows for the application of different valuation methods to quantify overall value. This differential use of valuation methods is based on the fact that goods and services provided by seagrass beds are qualitatively different, and should therefore be assessed using different approaches. For instance, an ecological understanding of the relationship between seagrass beds as habitat for commercial fish, can allow for the use of a ‘productivity method’ model to make a valuation estimate. However, estimating the economic contribution of tourism to the local economy will probably involve analyzing expenditure that tourists are willing to cover to experience the pleasure of coral reefs and other seagrass-related pleasures. Coastal properties are also affected by hedonic pricing schemes, and a valuation model in this case would have to incorporate the role that an intact seagrass bed might play in the quality and ultimately the pricing of the adjacent real estate.

The total economic value of a seagrass ecosystem for a particular location will therefore be the sum of the value of the goods and services provided by the seagrass beds as determined by the multiple valuation metrics. Each connector (both ecological and economic) is a vector that represents one or more ecological or economic processes that contribute to its subsequent product. In many seagrass systems, tourism services from coral reefs would not be a secondary service provided by seagrasses. The dynamic properties of this model allow it to have multiple applications for managers and local stakeholders.

7. Management applications of the sev Model

7.1. Costs-benefit analysis (CBA)

By providing location-specific economic estimates of seagrass value, managers can implement CBAs while weighing alternative development options each of which could leave a given seagrass ecosystem at different ecological states. This is important because in local situations where human development needs and ecosystem service provision clash, developers generally have an easier time demonstrating the economic benefit of brick and mortar structures through the property taxes generated and jobs created. The SEV model recognizes the ecosystem services to the local community, such that if the needs of the local community and the environment clash, there is an available framework within which one can estimate which (and how much of it) service is being affected. The CBA approach can also be used by environmental managers interested in estimating the costs of protecting endangered ecosystems. The costs associated with staffing, concessions, monitoring, and infrastructure can be weighed against the services that these ecosystems provide the local community.

7.2. Regulatory impact analysis (RIA)

RIA is a widely used technique in developed and developing countries to ensure that regulations associated with a certain program or project do not result in a cost increase that negates the benefits of the project. CBAs are typically conducted as part of RIA to assess the relative costs of regulations. Such an analysis can be built specifically to the services that the local ecosystem provides, with quantifiable estimates of each service as well as the regulations that are in place to ensure that the service is appropriately delivered.

7.3. Damage assessment

There are a number of damage assessment statutes implemented by the federal government to protect natural resources (Donald Elliott et al., 1985). These statutes provide certain federal institutions the power to pursue claims with respect to damage to natural resources, and mandate these institutions and guilty parties to make the injured areas whole, as well as provide the public compensation for the ecosystem services not received while recovery is taking place. Estimates of claims and compensation (using Habitat Equivalency Analyses (HEA)) are typically based on a combination of replacement costs and sometimes benefits transferred from other systems where valuations have already taken place. While some of the adjudicated damages can total fairly large amounts, damage assessments are still a reflection of proxy estimates of repair costs and are not derivatives of the actual services provided by the seagrass beds. Using the SEV model not only provides greater jurisprudence in determining economic costs of environmental damage, but gives spatial and social relevance to this estimate. For instance, all services provided by seagrass beds may not be occurring in the same magnitude at the site of the injury. By understanding the ecological dynamics of the local seagrass community and their relationship with the services they provide, damage assessments can be better tailored to the specific ecosystem that sustained damage and to the societal communities that suffered economic hardship. HEA uses simple ecosystem metrics as a proxy for function. The presence or absence of certain keystone species protected by a primary producer habitat will be used for example to determine if a particular system is functioning at or away from its ‘baseline’. While this is an ecologically valid approach it does not capture the full breadth of services that the area can provide. These relationships can be extracted from the SEV, and thus provide a more accurate estimate of what the societal compensation should be while the injury recovers.

8. Future directions

Multiple studies have documented the services that seagrass ecosystems provide to local communities. Unfortunately, the economic valuations of these systems have not kept pace with the widening breadth of ecological knowledge. As coastal communities continue to develop disproportionately to their inland counterparts, better models need to be created to quantify both the economic value of coastal ecosystems as well as the monetary loss incurred when they become damaged. Recently, there have been a number of models that have attempted to capture the full range of ecosystem services that seagrass ecosystems (and others) provide, and the spatial variation associated with those provisions (e.g., TESSA [Toolkit for Ecosystem Service Site-Based Assessment], Invest [Integrated Valuation of ecosystem services and tradeoffs], MIMES [Multi-scale Integrated Model of Ecosystem Services]). These models incorporate the different valuation approaches used to quantify the various ecosystem services provided, and are likely the way forward on holistically valuating the entire service scope of seagrass ecosystems. The SEV model provides a framework within which both the ecological and the economic relationships of seagrass ecosystems and the goods and services they provide can be delineated. By having the processes parsed out in this way, the model can be adapted across multiple spatial scales to address local variations and serve as the theoretical framework that informs computer-based valuation models. The robustness and reliability of the model will depend on the empirical determination of the variables that drive both the ecological and economic processes. For example, long-term monitoring can capture the temporal scales of patch growth dynamics within the context of the herbivory and nutrient pressure in a local system. Long-term monitoring can also capture fluxes in water column nutrients that are important both for the seagrass community, as well as the pelagic microalgae. Elucidating each vector that connects seagrass beds to an ecosystem function can provide an indication of how a basic understanding of ecological processes has large ramifications on local economies. As our understanding of these relationships improve, our conceptual framework of the seagrass ecology-economics relationship will simultaneously become more reliable.

Similarly, valuations of seagrass ecosystems should focus on specific relationships, as each relationship may require a different valuation approach. The total ecosystem value of seagrass beds can then be a summation of these different services.

9. Conclusion

The economic valuation frameworks for natural systems is a field still in its developing stages, but a lot of progress has been made especially with respect to terrestrial systems. The Natural Capital project (Anonymous, 2006) for example, offers models that assist stakeholders in determining ecosystem service value of their managed system with a certain amount of spatial resolution. This paper argues that the existing valuation frameworks particularly for the seagrass ecosystem is very limiting and incomplete at best. We propose a more comprehensive Seagrass Ecosystem Valuation framework that takes into account more nuances of seagrass ecosystem functions and services, some of which were unknown to valuation experts until recently. The proposed framework takes recognizes not only the more traditional productivity aspect of seagrass, but also values based on people's WTP for non-consumptive uses and existence values. It is possible that with improved education and outreach, public understanding of seagrass systems will increase resulting in a corresponding increase in WTP.

With yearly declines in acreage, the need to valuate seagrass systems is urgent. Failure to completely grasp the full range of local ecosystem services that these systems provide means that the corresponding local economic loss is not known. As humans continue to populate coastlines, coastal ecosystems will continue to be exposed to increased anthropogenic pressure that may accelerate this loss. The absences of models that appropriately connect the ecological to the economic systems have resulted in valuations that are based on proxy variables that may unintentionally grossly undervalue seagrass beds. The SEV model provides a conceptual framework to use both existing ecological and economic models to address this need.

Acknowledgments

This is contribution number 780 from the Southeast Environmental Research Center at Florida International University.

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