Ecosystem Services Valuation for Estuarine and Coastal Restoration in Florida[1]

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Introduction

In Florida, human alteration of coastlines has led to large-scale degradation of coastal ecosystems, including oyster reefs, beach dunes, mangrove forests, seagrass beds, and salt marshes. Alteration of those habitats leads to the loss of associated ecosystem services, which are defined as "the benefits that people obtain from ecosystems" (MEA 2005) and include both products such as food and timber products and processes like coastal protection and disease control. Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed while repairing critical ecosystem structure and function in degraded systems and re-establishing the valuable services provided by these ecosystems (Montoya, Rogers, and Memmot 2012; Normile 2010). While ongoing restoration efforts aim to enhance degraded ecosystems, restoration has not always been a priority for coastal management. Indeed, Florida's history consists of widespread coastal development at the expense of the natural environment (Lewis et al 1999; Santschi et al. 2001).

An important component for the success of restoration is to define specific goals (Ehrenfeld 2000). Commonly, success is measured solely as increasing the amount of habitat in a given area (Miller and Hobbs 2007), in which case the appropriate action is straightforward: increase the area restored. Others have recognized that restoration goals should focus on ecosystem function (e.g., sequestration of carbon, nutrient uptake) and products of those functions which include the provision of valuable ecosystem services (Montoya, Rogers, and Memmot 2012). If we acknowledge that restoration will contribute to the well-being of the human population (by providing ecosystem services), goals focused on ecosystem services can be specified (Coen and Luckenbach 2000; Hallett et al. 2013).

Thus, to evaluate restoration success we must measure not only attributes related to ecosystem structure but attributes relevant to ecosystem functions as well. These measurements then can be compared to data from reference (i.e., undisturbed) ecosystems to gauge restoration success (Ruiz-Jaen and Aide 2005). For example, goals for restoration of shellfish habitat may be defined as increasing structural ecosystem services, such as increasing the numbers of shellfish or maintaining water quality, or functional ecosystem services, such as preserving biodiversity.

The need to define ecosystem services for the support of long-term conservation efforts was addressed by a team of social and natural scientists in 2005 and culminated with the Millennium Ecosystem Assessment. This seminal work concludes that examining the environment through the framework of ecosystem services allows us to more easily identify how changes in ecosystems influence human well-being. The report provides information in a form that can guide decision-making in conjunction with other social and economic information.

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The critical role of ecosystem services has been further recognized in light of climate change (Nelson et al. 2013). Climate change projections suggest that impacts to coastal ecosystems will be severe, and include alteration by more frequent storm surges (Emanuel, Sundararajan, and Williams 2008), as well as alterations due to changes in salinity and restricted migration of seagrasses, mangroves, salt marsh, and coastal forest caused by rising sea levels (Geselbracht et al. 2011). Impacts to the human populations that reside along the coasts, therefore, will be correspondingly disproportionate compared to those on their inland counterparts. Coastal habitats, including oyster reefs, salt marshes, mangrove forests, and coastal dunes, are widely acknowledged (Coastal Resilience Network 2013) to protect coastal areas from wind, wave, and storm surges from hurricanes and other storms, which are projected to increase in frequency and intensity in Florida (Knutson et al. 2010). As consideration of these losses is increasingly incorporated into projections of economic consequences of climate change (e.g., tourism-related revenue, land use planning), there is a need to quantify the associated ecosystem service loss, as well as the ecosystem service gain associated with restoration.

Quantifying ecosystem services includes measuring both consumptive uses, such as increased fish catch, and non-consumptive uses, such as improved water quality (Coen and Luckenbach 2000). Non-consumptive uses and impacts include direct and indirect benefits. In general, the more accurately services are quantified, the better the prospect for the long-term sustainability of both the habitats and the services they provide (Grabowski et al. 2007).

Additionally, the social benefits that accrue from restoration efforts (e.g., increased volunteerism [Miles, Sullivan, and Kuo 1998], health benefits to volunteers [Pillemer et al. 2010], and increased education programs [Berkes and Folke 1998]) may be quantified. However, assigning a dollar value to these benefits can be difficult.

This study reviews the available ecosystem-service valuation literature for a number of Florida's coastal natural communities including oyster reefs, beach dunes, mangrove forests, seagrass beds, and salt marshes. We summarize the services provided by these five commonly restored natural communities in Florida and provide an analysis intended to support two main objectives: 1) to enumerate the range of ecosystem services provided by coastal natural communities as a way to educate stakeholders and support prioritization of habitat restoration; and 2) to inventory ecosystem measurements from the literature for each of the five natural communities and provide specific metrics for their measurement. This document is a reference to facilitate the quantification of ecosystem services to provide a better measure of the full impact of restoration efforts.

Ecosystem Services Provided by Coastal Habitats of Florida

This study provides ecosystem service assessment for commonly restored natural communities. Florida Sea Grant is a partnership between Florida Board of Education, the National Oceanic and Atmospheric Administration, and Florida's citizens and governments that supports research, education, and Extension to conserve coastal resources and enhance economic opportunities. The program currently reports restoration efforts solely as a measurement of the area (e.g., acres) restored, which does not reflect gain in ecosystem service provided by restoration (see Table 1) or provide economic incentives to support restoration based on the value of the services provided to stakeholders. Focusing our work on the natural communities of coastal Florida (oyster reefs, beach dunes, mangrove forests, seagrass beds, and salt marshes) serves as a case study to illustrate how ecosystem service valuation can better inform restoration efforts by an organization.

The most commonly referenced definition for ecosystem services is that of Costanza and Folke (1997): "ecosystem goods and services represent the benefits human populations derive, directly or indirectly, from ecosystem functions." The 2005 Millennium Ecosystem Assessment defines ecosystem services more specifically as "provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on earth." Table 1 reproduces the Millennium Ecosystem Assessment ecosystem service categories, illustrating several services provided by coastal ecosystems.

While ecosystems provide a diversity of services, this report is restricted to the ecosystem services listed in Table 2, as these are relevant to Florida's natural communities of the coast. The works cited in this study, and especially the 2005 Millennium Ecosystem Assessment, provide a more detailed list of services, along with a discussion of the interactions between the different ecosystem services categories. We focus on these six services because many are common among natural communities, and the most research has been conducted in efforts to quantify or value these services.

Table 1. Categories of ecosystem services and examples of services provided by coastal ecosystems (modified from Millennium Ecosystem Assessment 2005).

Provisioning	Regulating	Cultural
Products from ecosystems	Benefits from regulation of ecosystem processes	Nonmaterial benefits from ecosystems
• food • raw materials • medicinal resources	• gas regulation • climate regulation • disturbance regulation • biological regulation • water purification • soil/sediment regulation • nutrient regulation	• recreation • aesthetic • education • spiritual and historical
Supporting		
Services necessary for the production of all other ecosystem services		
• soil/substrate formation • nutrient cycling • primary production • habitat • hydrologic cycle		

Table 2. Ecosystem services provided by selected coastal natural communities.

Ecosystem Service	Category*	Natural Community				
		Oyster Reefs	Beach Dunes	Mangrove Forests	Seagrass Beds	Salt Marshes
Fisheries production	Provisioning	x		x	x	x
Carbon sequestration	Regulating	x		x	x	x
Protection against coastal erosion/shoreline stabilization	Supporting, Regulating	x	x	x	x	x
Tourism/Recreation	Cultural	x	x	x	x	x
Improve water quality (e.g., particulate matter, nutrients, dissolved oxygen)	Regulating	x		x	x	x
Increase landscape diversity (flora and fauna)	Supporting, Regulating	x	x	x	x	x

* Categories as defined in the 2005 Millennium Ecosystem Assessment.

Valuing Ecosystem Services

Assessing the value of ecosystem services facilitates the following: measuring the success of a restoration effort; comparing ecosystem status across undisturbed and restored habitats to better understand alteration brought about by policies, climate change, natural disasters, or other variables; expressing the benefits of disparate services provided by ecosystems in standard units (monetary or non-monetary); and making objective comparisons between systems. There are two common ways of evaluating ecosystem services: *quantification* and *valuation* (Yoskowitz et al. 2010). Table 3 illustrates some of the units of measurement for both the quantification and valuation of ecosystem services used in this work.

Quantification of Ecosystem Services

Science-based quantification provides common metrics for measuring the provision of services and ecological functions. These metrics typically are expressed in scientific units such as number of species, tons of CO_2 removed, or reductions in nitrogen concentrations. Monitoring for this method of evaluation is variable in its application based on the metric—e.g., number of species, or species diversity, is commonly monitored in restoration projects—while function-based metrics, such as reductions in nitrogen, are less frequently monitored, as they require technical expertise and financial resources beyond simple scientific monitoring (Ruiz-Jaen and Aide 2005). Regardless of the metric, in order to effectively evaluate the impact of restoration efforts on ecosystem service and ecological functions, monitoring of the relevant metric must take place prior to, during, and after restoration to accurately determine changes due to restoration (Coen and Luckenbach 2013), along with some standard to which the restoration can be compared, e.g., a reference site that is monitored in the same fashion (Shindler et al. 1995).

Table 3. Units of measurement for quantification and valuation of ecosystem services used in this work.

Ecosystem Service	Quantification Units	Valuation Units
Fisheries production	• number of species	• commercial • harvest $ per acre • $ per year
Carbon sequestration	• tons of carbon • mg carbon per ha per yr	• $ to sell carbon credits
Protection against coastal erosion / shoreline stabilization	• wave height • wave energy	• value of storm protection • cost of destruction • cost to maintain • $ saved not to rebuild
Tourism / Recreation		• $ generated per trip
Improve water quality (e.g., particulate matter, nutrients, dissolved oxygen)	• mg/L of nutrients or DO • measurements of turbidity	• $ per acre capitalized cost savings over traditional waste treatment
Increase landscape diversity (flora and fauna)	• number of species present • primary production • habitat	• $ generated from increased habitat

Valuation of Ecosystem Services

Numerous studies have assessed the contribution of ecosystems to social and economic well-being (Hartwick 1990; Costanza et al. 1997; Pimentel et al. 1997; Howarth and Farber 2002; Azqueta and Sotelsek 2007). This valuation method looks at the benefits derived from services and their value to humans, as well as their non-utilitarian value. The benefits often are expressed in monetary metrics. The motivation for this method is to assess the contribution of the ecosystem to social and economic well-being. The benefits often are expressed as either direct or indirect use values (MEA 2005). For example, the value of oyster production can be measured by the cost per bushel (direct). However, improved water quality is another outcome of oyster production, but it is not measured on a cost-per-unit basis (indirect). Non-utilitarian values, such as the ethical, religious, or cultural benefit or the intrinsic value of an ecosystem, also should be considered, but they are much more difficult to valuate, particularly in monetary units.

Using salt marshes as an example, many of the ecosystem services provided by this natural community can be quantified by scientific measurements. For instance, how many tons of CO_2 salt marshes sequester each year, how much particulate matter they remove from the water column, or how much biodiversity and habitat protection they provide can all be quantified. Assessment by the valuation method considers these services on a cost basis or by the amount of money that the restoration effort saves. For example, salt marshes provide protection from storm surge, and one method to quantify their value is to calculate the property damage and associated economic losses *not* experienced by property owners every year due to the attenuation of wave height in salt marshes. Salt marshes also improve water quality and thus the cost of marsh restoration could be compared to the cost of implementing conventional water treatment technologies to achieve a similar level of pollutant removal. Finally, the amount of money salt marshes bring to a local community, primarily through tourism and recreation, also can be quantified using economic and social analyses. Consideration of all of these services provides an estimate of the total value of the ecosystem services provided by a habitat and can be used as a benchmark for considering the true cost of replacement relative to the cost of restoration.

Beyond its application to estimating the value of ecosystem restoration, quantification and valuation of ecosystem services is a relatively new endeavor in general, and many researchers note the preliminary status of estimates (Yoskowitz et al. 2010; Coastal Resilience Network 2013). For instance, previous research on ecosystem services is often specific to a local area or region of interest, potentially limiting universal translation. Another caution concerning the application of this relatively new approach to restoration is that the implementation of a single restoration action (e.g., planting seagrasses or building an oyster reef) often results in a surprisingly wide range of outcomes (SER 2004), not all of which ultimately provide the same ecosystem services. Translation of services provided across a wide geographic area also is complicated because different species of plants and animals that naturally occur across environmental gradients provide different services. Monitoring each individual restoration effort will ensure that restoration goals are achieved and that ecosystem services provided are accurately quantified.

Valuing Ecosystem Services Gained by Restoring Florida's Coastal Habitats

Dependence of the Florida economy and resident quality of life on the ecological integrity of Florida's coastal natural communities demands special attention to the restoration of these environments. This paper demonstrates the quantitative link between the importance of these ecosystems and the incentive for restoration.

The matrix included in this study incorporates both quantification and valuation assessments for five natural communities that are commonly restored in Florida: oyster reefs, beach dunes, mangrove forests, seagrass beds, and salt marshes (Table 4). For example, oyster reefs generate biological diversity and productivity and therefore an increase in fisheries production can be quantified. Over a 5.8km oyster reef in the northern Gulf of Mexico, 3130 kg per year of additional finfish were caught, equating to $38,000–$46,000 per year (Kroeger 2012). In many cases the values reported were not developed specifically for Florida and are therefore not specific for Florida (for citations see Table 5). Much of the research on mangrove forests is conducted in the dense forests on the coasts of Thailand and Fiji, providing valuations that are specific for these regions. Where possible, values were taken from studies that examined the East Coast or the Gulf Coast of the United States; however, in some cases studies are global. It is important to consider the location of each study to provide guidance on generalization across ecosystems or locations, as the values reported are specific to that study area. The measurements reported here should be interpreted as estimates and provide an approximation of potential of ecosystem services provided by restoration projects.

The matrix is designed to help restoration managers, planners, and natural resource agencies link restoration efforts to ecosystem services provided by those projects. The values presented can be used—in conjunction with acreage—to more holistically represent the benefits of coastal ecosystem restoration. However, caution should be used in developing specific cardinal-value estimates using this benefits-transfer approach. Applying ecosystem values per unit from a region where the specific study was conducted (see citations in Table 5) to restored ecosystem units in a region of interest may not be valid. Rather, such values can be used to make ordinal comparisons across a range of ecosystem services. This material can be used to educate and inform volunteers and restoration practitioners, as well as to aid funding agencies, policy makers, and local stakeholders in appropriately prioritizing their restoration efforts.

Additional Resources

Many of the valuation values were obtained from http://www.gecoserv.org. This website is updated regularly and has many resources, including citations of how values were calculated.

The Millennium Ecosystem Assessment was directed by the United Nations Secretary-General Kofi Annan in 2000, with the objective of assessing the consequences of ecosystem change for human well-being. The findings provide the conditions and trends of the world's ecosystems and the services they provide. http://www.millenniumassessment.org/en/index.html

The Coastal Resilience Network is a community of practitioners who apply nature-based solutions to coastal hazards and adaptation issues. The organization has an extensive website that allows users to map coastal characteristics including oyster restoration habitat potential along the Gulf Coast. It has the future goal of mapping quantified oyster ecosystem services. http://maps.coastalresilience.org/network/

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Table 4

		OYSTER REEFS		SAND DUNES		MANGROVE FORESTS		SEA GRASS BEDS		SALT MARSHES	
Ecosystem Service	Ecosystem Process/ Function	Quantification Value	Valuation Value	Quantification Value	Valuation Value	Quantification Value	Valuation Value	Quantification Value	Valuation Value	Quantification Value	Valuation Value
Fisheries Production	Generates biological productivity and diversity	3130 kg per yr of additional finfish and crab catchover 5.8 km of oyster reef	$38,000-$46,000 per year from additional finfish and crab catch over 5.8 km of oyster reef				$708-987 per ha capitalized value of increased offshore fishery production		loss of 12,700 ha of seagrasses in Australia; associated with lost fishery production of $212,000		$6471 per acre and $981 per acre capitalized value for recreational fishing for the east and west coasts of Florida
		20 oysters per m^2 per yr									
		2600 kg per ha per yr of fish and large crustacean biomass	$4123 per ha per yr (commercial finfish and mobile crustacean value)				$7500 – 16,750 per km^2 per year market value in fisheries supported by mangroves		$3500 per ha per year in commercial landings of species dependent on seagrass		$0.19–1.89 per acre marginal value product in blue crab fishery
Carbon Sequestration	Generates biological productivity, biogeochemical activity					2.1 Mg C per ha per yr by global salt marshes	Price of carbon $5.58 per ton (Aug 2013)	83,000 metric tons C per km^2	Price of carbon $5.58 per ton (Aug 2013)	1150 tons of CO_2 equivalents per hectare in storage pools	low marsh $540 at $20per ton of C
						7,144 Mg C per ha [3]					salt flat -$4 at $20per ton of C
						1,023 Mg C per ha		500 tons of CO_2 equivalents per ha in storage pools		100 g of Carbon per m^2 per yr	high marsh $500 at $20 per ton of C
						1400 – 2400 tons of CO_2 equivalents per hectare in storage pools					price of carbon $5.58 per ton (Aug 2013)
Protection Against Coastal Erosion / Shoreline Stabilization	Attenuates and/or dissipates waves; sediment retention; soil retention in vegetation root structure	51-90% reduction in wave height and 76-99% reduction in wave energy at the shore	$1,074,475 – 1,504,265 value per ha of 5m wide oyster reef (represents the present value of stabilization services over the life of human-made structures)		$254.00 per 30cm (willingness to pay for home prices)	20% reduction in wave energy per 100 m^2	$8966-10,821 per ha capitalized value for storm protection		$67,400 per ha per year for disturbance regulation		$8236 per ha per yr in reduced hurricane damages
					$4.45 per household for an erosion control program to preserve 8 km of beach		$3676 per ha per yr annualized replacement cost				low marsh $5,000 per acre per yr
											salt flat $170 per acre per yr
											high marsh $500 per acre per yr
											$693 in cost of damage avoidance
											$8,980-25,572 per hectare per year in damage costs avoided
Tourism & Recreation	Provides unique landscapes suitable habitat for flora and fauna				$166 per trip or $1574 per visiting household per yr		$498 per hectare per yr		$64 per ha per year for recreation		$49.15 per person for otter habitat creation
											$1.87 per person for protecting birds
					$3.29 – 6.69 per person per visit						$224 per person per yr willingness to pay
					$70.50 per person per day (travel cost estimate)						$11,900 per ha per year (willingness to pay)
Improve Water Quality	Provides biogeochemical activity, sedimentation, biological productivity; stores and filters water; nutrient and pollution uptake; particle deposition and retention	3.45 mg/L of nitrogen per m^2 per hour during the day for oyster reefs	$1385-6716 per hectare per year in nitrogen removal (estimated by quantifying the value of enhanced denitrification rates on oysters reefs)				$5,820 per ha per year of nutrient filtering services by mangrove soils.		$20,900 per ha per year for replacement cost for nutrient cycling		$785–15,000 per acre capitalized cost savings over traditional waste treatment
		0.08-0.8% N in oyster shell	$28.23 price per kilogram of nitrogen removed for estuary sites in North Carolina Nutrient Offset Program								
		8.6% N in oyster tissue (depends on oyster size and gram dry mass)									
		0.75 gram N per gram oyster dry mass per yr	$0-2,584 in submerged aquatic vegetation enhancement per hectare per year (assuming that 1% of the linear length of the reef performs this function)								$17,353 per ha per year in waste regulation
		0.144-2.182 kg N per hectare per day									
		13-44 % of chlorophyll-a from adjacent water column					$608 per ha per year in waste regulation				$2480 per acre per year cost of replacement nitrogen removal (based on trading rate of $13/kg N)
		Reduced summer avg. light attenuation by 8013%; increases summer SAV biomass 21-43%									
Increase Landscape Diversity (flora and fauna)	Provides suitable reproductive habitat and nursery ground, sheltered living space	Provided habitat for 24,585 macrobenthics	$ 4,220 per ha per year for habitat providing (based on estimate for products bought and sold)		$ 2.65 per person per visit (willingness to pay for habitat)		$83.20 per ha per yr for habitat (if sold in commercial markets)		$3760 per ha per year for habitat for products sold (cost in commercial markets)		$1350-2280 per ha per year for net primary productivity willingness to pay
											$1570 per ha per year for habitat (cost in commercial markets)

Table 5

		OYSTER REEFS		SAND DUNES		MANGROVE FORESTS		SEA GRASS BEDS		SALT MARSHES	
Ecosystem Service	**Ecosystem Process/ Function**	**Quantification Value**	**Valuation Value**	**Quantification Value**	**Valuation Value**	**Quantification Value**	**Valuation Value**	**Quantification Value**	**Valuation Value**	**Quantification Value**	**Valuation Value**
Fisheries Production	Generates biological productivity and diversity	Kroeger 2012; Northern Gulf of Mexico	Kroeger 2012; Northern Gulf of Mexico				Barbier 2007; Thailand		McArthur and Boland, 1996; Australia		Bell 1997; Florida, USA
		Kroeger 2012; Northern Gulf of Mexico									
		Peterson et al. 2003; Southeastern USA estuaries	Grabowski et al. 2012; USA				Ronnback, 1999; Global		Watson et al. 1993; Australia		Freeman 1991; Gulf Coast, USA
Carbon Sequestration	Generates biological productivity, biogeochemical activity					Chumra et al., 2003; Global	European Union Emissions Trading System	Fourqureen et al., 2012; Global and Wilson et al., 2012; Global	European Union Emissions Trading System	Megonigal et al., 2013; Global	Feagin et al. 2010; San Fransisco Bay, USA
						Jerath 2012; Everglades National Park, USA					Feagin et al. 2010; San Fransisco Bay, USA
						Donato et al., 2011; Tropical Mangrove Forests		Megonigal et al., 2013; Global		Piehler and Smyth, 2011	Feagin et al. 2010; San Fransisco Bay, USA
						Megonigal 2013. Global					European Union Emissions Trading Systems
Protection Against Coastal Erosion / Shoreline Stabilization	Attenuates and/or dissipates waves; sediment retention; soil retention in vegetation root structure	Kroeger 2012; Northern Gulf of Mexico	Grabowski et al. 2012; USA		Pompe and Rinehart 1999; South Carolina, USA	Mazda et al., 1997	Barbier 2008; Thailand		Costanza et al., 1997; California USA		Costanza et al. 2008; FL, USA
					Huang et al. 2007; Maine and New Hampshire beaches, USA		Sathirathai and Barbier, 2001; Thialand				Feagin et al. 2010; San Fransisco Bay, USA
											Feagin et al. 2010; San Fransisco Bay, USA
											Feagin et al. 2010; San Fransisco Bay, USA
			Grabowski et al. 2012; USA								Barbier et al., 1997; Louisiana, USA
											Costanza et al. 2008; FL, USA
Tourism and Recreation	Provides unique landscapes suitable habitat for flora and fauna		NOAA, 2004 and Henderson and O'Neil, 2003: Louisiana, USA		Landry and Liu 2009; North Carolina beaches, USA		Valdez et al., 2013. Mexico		Costanza et al., 1997; California USA		Birol and Cox, 2007; UK
											Birol and Cox, 2007; UK
					Bell 1992; Florida USA and Curtis et al., 1982; Florida USA						Barbier et al., 1997; Louisiana, USA
					Bell and Leeworth 1990; Florida USA						Bell 1997; Florida, USA
Improve Water Quality	Provides biogeochemical activity, sedimentation, biological productivity; stores and filters water; nutrient and pollution uptake; particle deposition and retention	Grabowski et al., 2012; USA	Grabowski et al. 2012; USA				Lal, 1990, Fiji		Costanza et al., 1997; California, USA		Breaux et al., 1995; USA
		Higgins et al., 2011; Chesapeak Bay, USA									
		Carmichael et al., 2012; MA, USA									
		Newell et al., 2005; Chesapeake Bay, USA	Grabowski et al. 2012; USA								Costanza et al. 2006; New Jersey USA
		Kroeger 2012; Northern Gulf of Mexico					Mendoza-Gonzales et al. 2012; Gulf of Mexico				
		Grizzel et al. 2006; Gulf of Mexico	Grabowski et al. 2012; USA								Piehler and Smyth, 2011
		Cerco, 2005; Chesapeake Bay, USA									
Increase Landscape Diversity (flora and fauna)	Provides suitable reproductive habitat and nursery ground, sheltered living space	Kellogg et al. 2013; Maryland, USA	Grabowski and Peterson, 2007; North Carolina, USA		Shivlani et al. 2003; South Florida, USA		Bann, 1997, USA		Johnston et al., 2002; New York, USA		Costanza et al. 2008; USA
											Bell 1997; Florida, USA

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