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Economic valuation of the ecosystem services provided by the mangroves of the Gulf of Nicoya using a hybrid methodology

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ABSTRACT

Due to the public good nature of many of mangrove's ecosystem services, markets for them do not exist and there is limited potential to manage them with conventional markets. Moreover, because of the difficulties in estimating the value of these non-marketed services, mangroves are often undervalued in benefit cost analysis of conservation versus commercial land uses causing their degradation and loss. With the goal of supporting the current efforts of the government of Costa Rica to develop a new PES scheme that include these ecosystems, as well as other policy initiatives on wetlands conservation and restoration, we applied a hybrid approach to estimate the value of ecosystem services from mangrove forests in the Gulf of Nicoya. Our method consists of traditional benefit transfer and expert modified benefit transfer for 11 ecosystem services, and the application of more specific methods to estimate three of those ecosystem services (i.e. climate regulation, fisheries and coastal protection). Using traditional benefit transfer, we estimated the total economic value of ecosystem services of mangroves in the Gulf of Nicoya in $812 million per year (median=$88 million/year), and the total mean value of the ecosystem services provided by all the mangroves in Costa Rica as $1.5 billion per year (median=$160 million/year). By applying the expert modified benefit transfer we estimated that the mean total value of the mangrove forests of the Gulf of Nicoya is $470 million per year, and a median value of $75 million per year. Combining the three different valuation technics, we calculated the mean total value of the ecosystem services from mangrove forests in the Gulf of Nicoya in $408 million per year, and a median total value of $86 million. Considering the median total value of ecosystem services from mangroves, it represents 0.16% of the GDP in Costa Rica in 2015.

1. Introduction

Mangroves are known for providing many ecosystem services such as food, raw materials, climate regulation, pollution control, coastal protection, recreational opportunities and spiritual experiences among many others (Millennium Ecosystem Assessment, 2005; Russi et al., 2013). We summarize in Appendix A the list of ecosystem services that mangrove forests provide according to different authors. Many of these ecosystem services have the characteristics of "public goods" (Brander et al., 2012). A public good exists when goods (or services) are non-rival (one individual may benefit from the existence of an environmental attribute and this does not reduce the benefit another individual can receive for that same attribute) and non-excludable (it is difficult or impossible to exclude individuals from benefiting). This is in contrast to private goods, which are both rival and excludable (Barbier et al., 1997; Costanza, 2008).

Himes-Cornell et al. (2018) provides the most recent review on mangroves valuation, which was made for 2007–2016. The authors found that most valuation studies are from Asia (53%) and Africa (14%), while Central and South America account only for 6%. Furthermore, the authors state that valuation studies often value only a small number of services, ranging from 1.8 services per study in North America to 4.9 in Africa. The services that are more commonly valued are food, raw materials, climate regulation, coastal protection, waste treatment, maintenance of life cycle of migratory species and opportunities for recreation and tourism (Himes-Cornell et al., 2018). Other authors agree with Himes-Cornell in that fisheries and coastal protection are among the most frequently valued ecosystem services (Mehvar et al., 2018), while studies on biodiversity are very scarce (Vegh et al., 2014).

In Costa Rica there is only one valuation study that we know about

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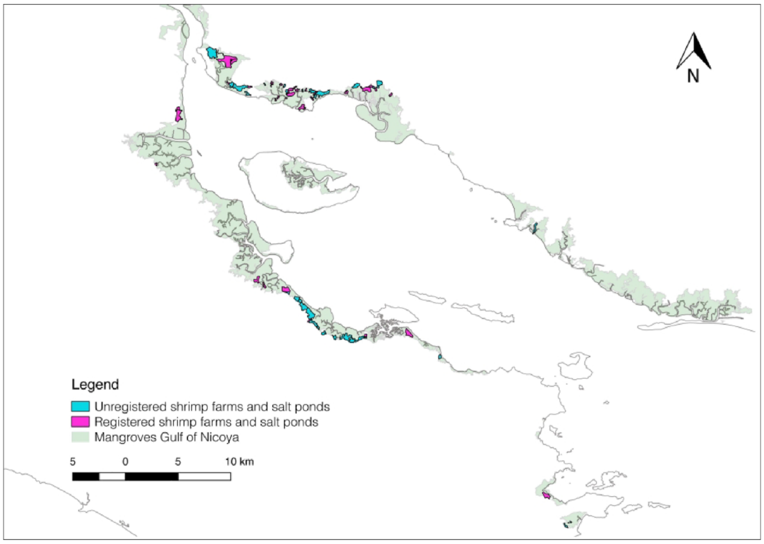

Fig. 1. Map of mangrove cover (green) in the Gulf of Nicoya, showing registered and unregistered shrimp farms and salt ponds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the mangroves of the Gulf of Nicoya (Arguedas-Marín, 2015), which estimated the value of the extraction of mollusks ($175–280/ha/year) and carbon sequestration ($15–38/ha/year). Other similar studies include those on wetlands, specifically from Ramsar Sites (Hernández-Blanco et al., 2017), and the Terraba-Sierpe wetland in the south Pacific (Barton, 1995; Earth Economics, 2010; Sánchez et al., 2013).

Markets work best with private, (rival and excludable) goods and services. Because of the public good nature of many of the mangrove's ecosystem services (especially regulating and cultural services) markets for them do not exist and there is limited potential to manage them with conventional markets (Brander et al., 2012). And because of the difficulties in estimating the value of these non-marketed services, mangroves are often undervalued in cost-benefit analysis of conservation versus commercial land uses (Salem and Mercer, 2012; Acharya, 2002), causing their degradation and loss at national and global scales. In Costa Rica, mangrove cover has decreased from 63,400 ha in 1980 (FAO, 2007) to 36,250 ha in 2013 (Programa REDD/CCAD-GIZ - SINAC, 2015), an annual loss rate of 1.3% due to human activities such as the extraction of forest products (e.g. tannic acid, wood and charcoal), land use change to create rice fields, salt ponds, and shrimp ponds (FAO, 2007), among others.

To address this, the government of Costa Rica is in the process of redesigning its Payment for Ecosystem Services (PES) scheme, which is currently focused on privately owned forests, with the goal of finding new ways to provide new funding sources to the program, as well as to incorporate other ecosystems that are threatened with human activities (e.g. agriculture, climate change, urbanization and pollution, among others) and that at the same time provide valuable ecosystem services both to local communities as to the global society. Mangroves have been selected as one of the new ecosystems that could be integrated in the new PES scheme of the country, and therefore it is needed to provide information to decision makers about the main ecosystem services that these ecosystem delivers, including its value, in order to create the financial instruments that can support the conservation and restoration strategies that will ensure the provision of these benefits (Hernández-Blanco, 2019; Mukherjee et al., 2014; Himes-Cornell et al., 2018; Acharya, 2002; Brander et al., 2012).

In this paper, we identify and estimate the value of the main ecosystem services provided by the mangroves of the Gulf of Nicoya, a key economic and ecological area of the country. Furthermore, we expand upon that estimation and provide for the first time an economic value of the ecosystem services for the total cover of mangroves in the country.

2. Methods

2.1. Study area

The Gulf of Nicoya is located in the north-western part of the Pacific coast of Costa Rica. The Tempisque, Barranca and Grande de Tárcoles rivers drain into it creating a highly productive estuary (Kappelle, 2016). It represents one of the largest estuaries in Central America, with a surface area of 1,530 km^2 (Fernández et al., 2006). Mangrove forests in the Gulf of Nicoya are favored by the interaction between the freshwater runoff from the rivers that flow into the gulf and saltwater incoming from the sea. The surge and the high quantity of sediments and nutrients that are deposited in this area by the inflowing rivers and tides support mangrove productivity. The main species of mangroves in the Gulf are *Rhizophora mangle*, *Rhizophora racemosa*, *Avicennia germinans*, *Avicennia bicolor*, and *Laguncularia racemosa* (Proyecto Golfos, 2012). Mangrove forests have been the most studied estuarine ecosystem in the Gulf of Nicoya (Kappelle, 2016). The total mangrove cover in the Gulf is 20,739 ha (Rivera, personal communication, 2018) . We updated the mangrove cover map from Rivera (2018) by extracting salt ponds and shrimp farms that were not taken into account in that map. These activities in total accounted for 814 hectares, which results in a new total mangrove area in the Gulf of Nicoya of 19,924 hectares (Fig. 1).

2.2. Hybrid approach for the economic valuation of ecosystem services provided by mangroves

We applied a hybrid approach to estimate the value of ecosystem services from mangrove forests in the Gulf of Nicoya, using both secondary and primary data.

Because of the limited biophysical-economical information available in Costa Rica required for natural capital studies in mangroves, and the limited time and resources available for this study, we used the benefit transfer method as one of our main approaches (Plummer 2009). Following this approach, we extracted 67 estimates in per hectare per year units from the Ecosystem Services Valuation Database (ESVD) from The Economics of Ecosystems and Biodiversity (TEEB) (Van der Ploeg and de Groot, 2010) (see References section in this paper for the list of studies from which these values where extracted) for the following 11 ecosystem services from mangroves: 1) food; 2) medical/bioprospecting; 3) fibers; 4) fodder; 5) sand, rock, gravel; 6) timber and fuel wood; 7) other raw materials; 8) climate regulation; 9) coastal protection; 10) recreation/tourism and 11) biodiversity protection). We chose studies that share similar characteristics to Costa Rica, especially location (i.e. tropical countries) and studies that provide values of flows instead of capital.

Because we used estimates from different countries (hence different currencies) and from different years, we converted all estimates into 2015 international dollars per hectare per year, first by applying the Consumer Price Index to express all values in 2015 values and then the Purchasing Power Parity index to convert values into international dollars in order to consider the different levels of income of the countries from where we extracted the data. We finally calculated the minimum, maximum, mean and median values of each ecosystem service.

We also used these values to make a first approximation of the value of the ecosystem services provided by the total cover of mangroves in Costa Rica. In this case, we used the spatial data from the most recent national forest inventory developed by the government of Costa Rica, which estimated the national area of mangroves as 36,250 ha (Programa REDD/CCAD-GIZ - SINAC, 2015). These values were then multiplied by the per ha per year values of mangroves to obtain total value estimates.

To overcome some of the limitations of the benefit transfer method, such as providing values only from the demand side and differences in population characteristics (Bergstrom and Taylor, 2006), in July 2018 we conducted a workshop with experts from the government, the academic sector and NGO's to determine which ecosystem services from our list of 11 are in reality provided by mangroves in the Gulf of Nicoya, as well as to define where these services are benefiting people. Having calculated the area of provision of ecosystem services through a participatory mapping process with the experts, we multiplied it by its respective per ha per year value.

Once we estimated the value of ecosystem services using expert modified benefit transfer, we conducted a more in-depth analysis for specific services (using primary data when possible). We selected the ecosystem services of 1) climate regulation, 2) fisheries, and 3) coastal protection through a dual process of literature review and expert opinions from the workshops conducted before. We recognize this is a first approximation of the most important services in the area. However, we consider these three services to be the most relevant for the scope of this study since they encompass a broad range of services most commonly evident in the Gulf of Nicoya and relevant for the local populations.

In April 2018, we interviewed governmental officials from the National System of Conservation Areas (SINAC by its acronym in Spanish) that were working around the Gulf to validate our list of ecosystem services and to rank their importance (i.e. low, medium, high) in each conservation area. The experts selected for this survey are currently working on mangrove projects in the Gulf of Nicoya. Although the governmental officials do not represent all experts in the field, they work in this ecosystem and have relevant local experience and first-hand information. Appendix 2 provides the list of experts interviewed.

Table 1
Specific methods for the economic valuation of three ecosystem services from the Gulf of Nicoya.

Ecosystem service	Method
Climate regulation	Social cost of carbon, marginal abatement cost
Food (fisheries)	Production/ha and market price
Coastal protection	Spatial modelling and benefit transfer

Each of these ecosystem services were valued according to the most appropriate methods for each one (Millennium Ecosystem Assessment, 2005; Lal, 2003; Mehvar et al., 2018; Salem and Mercer, 2012; Himes-Cornell et al., 2018; Brander et al., 2012) (Table 1).

2.2.1. Climate regulation – Carbon stocks

We estimated the economic value of the total organic carbon storage in the mangrove forests of the Gulf of Nicoya using the Marginal Abatement Cost of Carbon (MAC) as the value of carbon stock per hectare. MAC represents the costs of eliminating an additional unit of carbon emissions, and "these costs are the benefits forgone when scarce resources are used to avoid the chances of negative impacts of emissions instead of being used in alternative activities" (Jerath, 2012, p35), in other words, MAC represents the opportunity costs. Specifically, we used the estimate that Fisher et al. (2007) produced for the IPCC 4th Assessment Report, with a mean MAC of $125/tC (calculated for the year 2010). This value was then converted to 2015 international dollars.

We applied the following equation to estimate the value of the carbon storage service:

$$V_{cs} = TC * MAC * A_m \quad (1)$$

where V_{cs} is the value of the carbon storage service, TC is the total carbon stored per hectare, MAC is the marginal abatement cost of one tonne of carbon and A_m is the area of mangrove in hectares.

We obtained the total carbon stored at the ecosystem level (i.e. sum of carbon in all epigeous components plus carbon in the soil) per hectare from Cifuentes-Jara et al. (2014), who estimated that TC in mangroves in the Gulf of Nicoya ranges between 413 and 1334 MgC/ha at 3 meters of depth.

The simplest way of calculating the V_{cs} is using a mean TC for the entire area of analysis, but this can produce an imprecise result because of local variations in mangrove characteristics due to forest structure and stature. Therefore, we took the values of each research plot that Cifuentes-Jara et al. (2014) assessed in different locations through the Gulf and grouped them statistically and geographically to have a more precise estimate.

2.2.2. Climate regulation – Carbon sequestration

The methodology to estimate the value of carbon sequestration is different from the one for carbon stocks (Ramirez et al., 2002), and it requires data that is not available for the study area (e.g. carbon sequestration rate), and therefore this version of the climate regulation service had to be calculated with data from the literature. We incorporated this method here since it is not part of any of the benefit transfer methods explained before. Here, we used the Social Cost of Carbon (SCC) also referred as the Marginal Damage Cost. The SCC is defined as the net present value of the incremental damage on the environment and society due to the increase in carbon dioxide emissions. In other words, the SCC is the damage avoided by reducing emissions by one tonne (Tol, 2011).

For policy purposes, SCC is equal to the Pigouvian tax (i.e. tax on market activities that generates negative externalities) that could be placed on carbon (Tol, 2011), because SCC reflects, in theory, what a society should be willing to pay now to avoid the future damage caused by the increase of carbon emissions (Jerath, 2012).

We valued the carbon sequestration service applying the following equation:

$$V_{cseq} = SR * SCC * 3.67 * A_m \quad (2)$$

where V_{cseq} is the value of the carbon sequestration service, SR is the sequestration rate in tonnes of CO_{2eq} per hectare per year, 3.67 is the conversion factor to obtain CO_{2eq} from C, A_m is the area of mangrove in hectares and SCC is the Social Cost of Carbon as estimated in the meta-analysis that Tol (2011) conducted with 311 published estimates. In this study, the mean estimate for SCC is $177/tC, and $80/tC (calculated for the year 2010) if only peer review papers are considered. We chose the peer reviewed values since they have a higher quality. This value was then converted to 2015 international dollars.

We applied a sequestration rate of 6 CO_{2eq}/ha/year for mangroves as reported in Murray, et al. (2010) and Maldonado & Zarate-Barrera (2015). This sequestration rate is also very similar to the 6.96 CO_{2eq}/ha/year value from Chmura et al. (2003) as cited in Sifleet et al. (2011) and is well within the conservative values for annual tropical forest growth rates (Cifuentes-Jara et al., 2014).

2.2.3. Fisheries

In Costa Rica, between 75–80% of the total fish landings are made by the artisanal fleet, and approximately 95% of these landings come from the Pacific and, more specifically, the Gulf of Nicoya (Ocean Outcomes, 2018). To value fisheries, we selected the species with the highest commercial importance that are caught by the artisanal fleet. According to a sampling made by Araya and Vasques (2005), 40% of fish catches comes from four species of the family Sciaenidae: *Cynoscion albus* (Queen corvina), *Cynoscion squamipinnis* (Scalyfin corvina), *Cynoscion phoxocephalus* (Sharpnose corvina) and *Cynoscion stolzmanni* (Yellowfin corvina). This study also found that white shrimp (*Litopenaeus sp*.) was one of the most important species from the commercial perspective (Araya and Vasques, 2005).

In another study conducted by Araya et al. (2007), they estimated that, between 2002 and 2005, these same species (except the Yellowfin corvina) represented 31% of fish catch in the Gulf of Nicoya. Furthermore, a more recent study from Marín (2018), in which the author sampled more than sixty fish species caught in the Gulf of Nicoya in 2014, found similar results as Araya and Vasques (2005) and Arayaet al. (2007). Marín argues that five species represented 76% of the total catch sampled (Queen corvina = 43%, Scalyfin corvina = 13%, White shrimp = 9%, Sharpnose corvina = 7%, and Snook = 4%).

From the fish catch database for the Gulf of Nicoya from the Costa Rican Institute of Fishing and Aquaculture (INCOPESCA by its acronym in Spanish) (INCOPESCA, 2018) (Tables A3.1 and A3.2 from Appendix 3), we determined that the commercial categories of "first large" (i.e. individuals of 2 kg or more), "first small" (i.e. individuals of less than 2 kg), and "class" (i.e. individuals between 800 g and 1 kg) represented together 30% of 2015 catches, spotted rose snapper 4%, white shrimp 4%, and bivalves 2%. These six commercial categories accounts for 40% of the total catch. According to Marín (2018), the categories of "first large", "first small" and "class", can be disaggregated by species as shown in A3.3-A3.5 from Appendix C. The species that were fished the most under these three commercial categories are the Queen corvina, the Scalyfin corvina and the Sharpnose corvina, which supports the findings of the studies previously mentioned. The same INCOPESCA database that contains the aggregated information for fish catch in the Gulf of Nicoya, also provides aggregated data for the extraction of bivalves, and therefore this information had to also be disaggregated, which was done by the Statistics Department of that organization as shown in Table A3.6 from Appendix C.

After processing the initial data base and determining the species that conforms each commercial category, we confirmed that all fish species contained in "first large", "first small" and "class" utilise mangroves as habitat during their life cycle (Rönnbäck, 1999). This is also the case for spotted rose snapper and white shrimp (Goti, 1991; Rönnbäck, 1999), as well as for the species of bivalves assessed in this study (Morton, 2013) (Table A3.7 from Appendix C). Once we had identified the species of highest commercial interest, and confirmed that these species depend on mangroves, we were able to select these categories/species to be valued in this study.

To estimate the economic value of fisheries, we assumed that the marginal and average products of mangrove area are equal for all species harvested since there isn't data for the country on fishing effort (Costanza et al., 1989). This could result in an overestimation, because the marginal product is generally lower than average product. However, there is also a compensating underestimation because the market price does not fully capture the value of fishing to society. We obtained the monthly mean prices for all commercial categories from INCOPESCA (2018), which we then multiplied by the total catch of each species under each commercial categories to estimate the value of fisheries through a market approach. In the case of bivalves, we used the values on catch and mean price per species per area of extraction provided by Duran (2018) (Table A3.2 from Appendix C).

2.2.4. Coastal protection

The coastal protection service of mangroves was determined through a combination of economic and biophysical techniques that together constitute a *benefit transfer method modified by modelling*. This technique consisted broadly of three stages: 1) determine an economic value of the ecosystem service of coastal protection per hectare of mangrove through the same process of benefit transfer explained above, 2) model geographically the variables that play a role in the provision of this service in order to identify which areas of the Gulf are more vulnerable and where and with what intensity the mangroves provide this service, and 3) multiply the per hectare value obtained previously by the classified geographic areas according to its service provision.

Using the Coastal Vulnerability model from the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST, version 3.6) tool suite (Natural Capital Project; Sharp et al., 2016), we created a relative index of exposure for each 250 m segment of the coast to erosion and flooding caused by coastal storms and sea level rise. The Coastal Exposure Index ranges from 1 to 5 (5 equals highest exposure) and accounts for the combined influence of shoreline geomorphology, presence of different habitat types, coastal relief, winds, waves, storm surge potential, and trends in sea level rise on relative vulnerability of each shoreline segment to erosion and inundation (Silver et al., 2019). The Coastal Exposure Index can be calculated with and without habitats present. The difference between these two values estimates the relative influence of habitats on protecting the coastline from these threats, and it identifies locations where that protection is highest along the coast.

To create this index, we first created a mangroves polygon using national data from Costa Rica. We then produced a polyline layer of shoreline geomorphology (e.g. rocky beach, sandy beach, cliff, etc.) using Google Earth at a resolution that varied from 2.5 m to 30 m. Each geomorphology type received a rank from 1 to 5 (5 being highest) depending its level of susceptibility to erosion. We created a polygon of sea level change using the reference global mean sea level (GMSL) map produced by the DUACS (Data Unification and Altimeter Combination System) from SSALTO (Segment Sol multi-missions dALTimetrie, d'orbitographie et de localisation précise) that is distributed by Aviso+ (Archiving, Validation and Interpretation of Satellite Oceanographic data) (Fig. A4.1 from Appendix D). Due to data constraints in the study area, the rest of inputs for this model was collected from global data from Sharp et al. (2016) (i.e. bathymetry, relief, continental shelf, and population density) and Tolman (2009) (i.e. wind and wave exposure). We found the Exposure Index with and without mangroves present. The difference between these two values was used to locate where on the coast mangroves offered greatest protection.

After the model generated the different output maps (Figs. A4.2–10 from Appendix D), such as the exposure index, we used the habitat role

Table 2
Ecosystem services that were valued using the ESVD, the number of estimates that were used, and the minimum, maximum, mean and median values per hectare per year of each service that was calculated, as well as the results of the application of these values to the total mangrove extension of the Gulf of Nicoya using the benefit transfer method. All values are in 2015 international dollars.

Ecosystem Service	Value per hectare per year					Gulf of Nicoya		National Assessment	
	Number of estimates	Min Value	Max Value	Mean Value	Median value	Mean Value	Median value	Mean Value	Median value
Provisioning Services									
Food	18	0.06	22,804	2,002	293	39,896,691	5,840,970	72,587,083	10,626,922
Medical/Bioprospecting	3	10	734	258	31	5,144,858	613,949	9,360,432	1,117,003
Fibbers	1			6	6	112,718	112,718	205,076	205,076
Fodder	1			15	15	294,726	294,726	536,218	536,218
Sand, rock, gravel. Coral	2	0.06	104	52	52	1,037,136	1,037,136	1,886,941	1,886,941
Timber and fuel wood	9	52	22,443	2,940	262	351,713,024	6,267,881	639,898,252	11,403,632
Other raw material	7	1	5,328	1,366	233	27,220,649	4,652,300	49,524,597	8,464,283
Total Provisioning Services	**47**	**74**	**139,371**	**21,351**	**945**	**425,419,802**	**18,819,680**	**773,998,598**	**34,240,074**
Regulating Services									
Climate regulation	4	11	2,428	753	287	15,011,447	5,726,869	27,311,467	10,419,328
Coastal protection	8	180	27,638	7,638	2,997	152,187,141	59,708,937	276,885,638	108,633,010
Total Regulating Services	**15**	**777**	**33,187**	**9,856**	**3,970**	**167,198,587**	**65,435,806**	**304,197,105**	**119,052,337**
Cultural Services									
Recreation/tourism	3	52	944	354	65	7,047,295	1,287,048	12,821,680	2,341,624
Total Cultural Services	**3**	**52**	**944**	**354**	**65**	**7,047,295**	**1,287,048**	**12,821,680**	**2,341,624**
Support Services									
Biodiversity protection	5	15	36,313	10,651	116	212,214,578	2,315,253	386,098,120	4,212,315
Total Support Services	**19**	**53**	**381,885**	**64,418**	**1,247**	**212,214,578**	**2,315,253**	**386,098,120**	**4,212,315**
TOTAL	**84**	**955**	**555,387**	**95,979**	**6,226**	**811,880,262**	**87,857,786**	**1,477,115,503**	**159,846,351**

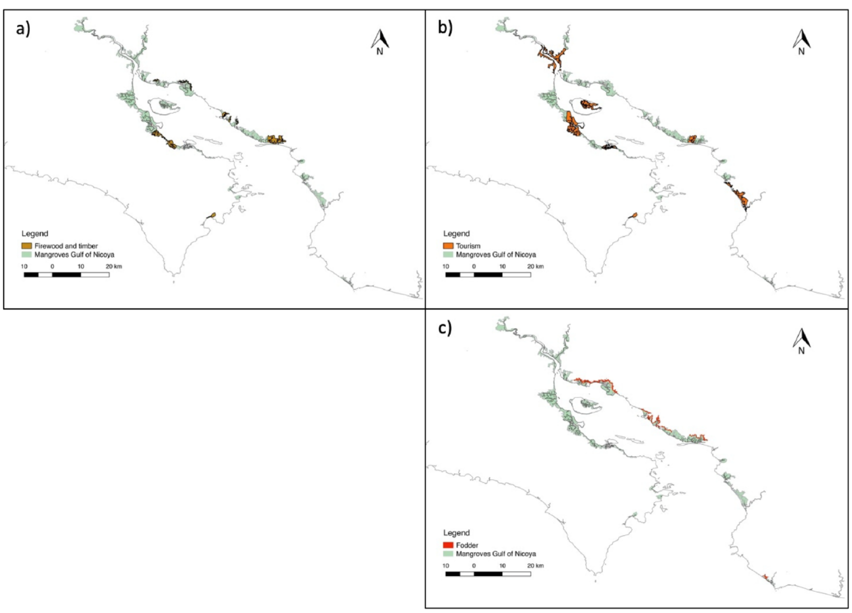

Fig. 2. Maps of three ecosystem services modified by experts. 2a. Locations where firewood and timber are extracted, in the districts of Puntarenas, Chomes, Colorado-Abangares, Lepanto and Paquera. 3b. Locations where touristic activities related to mangroves are developed, in the districts of Puntarenas, Tarcoles, Porozal, Nicoya, Chira Island, San Pablo-Nandayure, and Lepanto. 2c. Locations where fodder is used for cattle, in the districts of Puntarenas, Chomes, Manzanillo and Colorado-Abangares.

Table 3
Results from the expert modified benefit transfer. Zero indicates services that experts considered did not apply for the Gulf of Nicoya, and numbers in blue indicate services that were re-estimated according the areas defined by experts.

Ecosystem service	Modified area (ha)	Mean Value ($)	Median value ($)
Provisioning Services			
Food		39,896,691	5,840,970
Medical/Bioprospecting	0	0	0
Fibers	0	0	0
Fodder	998	14,760	14,760
Sand, rock, gravel. Coral	0	0	0
Timber and fuelwood	2,811	49,618,917	884,259
Other raw material	0	0	0
Total Provisioning Services		**89,530,368**	**6,739,990**
Regulating Services			
Climate regulation		15,011,447	5,726,869
Coastal protection		152,187,141	59,708,937
Total Regulating Services		**167,198,587**	**65,435,806**
Cultural Services			
Recreation/tourism	2,273	804,021	146,838
Total Cultural Services		**804,021**	**146,838**
Support Services			
Biodiversity protection		212,214,578	2,315,253
Total Support Services		**212,214,578**	**2,315,253**
TOTAL		**469,747,554**	**74,637,886**

map for each shoreline segment to classify the total area of mangrove forests of the Gulf of Nicoya into three categories (low, medium and high) depending on the level of protection that mangroves provide. For each category, we assigned a weight (W) as follows: Low = 0.33, Medium = 0.66 and High = 1. These weights were arbitrarily assigned, and therefore our estimates for coastal protection should be interpreted as experimental. We finally multiplied the per hectare value of the coastal protection service (calculated using benefit transfer) by these weights and then by the area of mangroves of each category.

$$CPv = CPvh * W * A \tag{3}$$

where CPv = Coastal protection value, CPvh = Coastal protection value per hectare, W = Weight of mangrove category, A = Area of mangrove category.

3. Results

3.1. Benefit transfer results

The first part of the application of the benefit transfer method, which was the estimation of a per hectare per year value from the ESVD of the ecosystem services provided by mangroves, shows that the ecosystem service with the highest mean value are timber and fuelwood, $17,652/ha/year, followed by biodiversity protection ($10,651/ha/year) and coastal protection ($7,638/ha/year). Other services with high economic value are food ($2,002/ha/year) and raw materials ($1,366/ha/year). Nevertheless, median values provide a different panorama, with coastal protection with the highest value ($2,997/ha/year), followed by timber and fuelwood ($315/ha/year), food ($293/ha/year) and climate regulation ($287/ha/year). We found that one hectare of mangrove can provide average economic benefits of $40,747 per year (median=$4,410/ha/year) through the provision of these 11 ecosystem services valued. By multiplying these values by the mangrove cover in the Gulf, we estimated the economic value of 11 ecosystem services of these mangroves is approximately $812 million per year (median = approximately $88 million/year) (Table 2).

Using the same method, we estimated the total mean value of the ecosystem services provided by the total extent of mangroves in Costa Rica as $1.5 billion per year (median=$160 million/year). Considering the change in national cover of mangroves from 1980 to 2013 (FAO, 2007), we estimate that Costa Rica lost an average $1.1 billion per year (median=$120 million per year) during that period because of the loss of ecosystem services from mangroves.

It is worth noting that these values calculated using benefit transfer, express potential values – the supply of ecosystem services – since they were not related with the local beneficiaries of each ecosystem service. We calculated the demand of some of these ecosystem services with the help of a panel of experts, allowing us to modify the value of ecosystem services of the Gulf of Nicoya and have more accurate results. Specifically, the panel of experts assessed the locations and extensions of the following ecosystem services: 1) medical/bioprospecting, 2) fibers, 3) fodder, 4) sand, rock, gravel and coral, 5) timber and firewood, 6) other raw materials and 7) recreation. Of these seven services, we excluded medical/bioprospecting, fibers, sand, rock, gravel and coral and other raw materials since the experts pointed out that none of these are being demanded/used in the Gulf.

According to the panel of experts, the remaining three ecosystem services are demanded in a small portion of the area of the Gulf of Nicoya, with firewood and timber accounting for 2,811 hectares (14% of the total area of mangroves in the Gulf), tourism 2,273 hectares (11%) and fodder 998 hectares (5%) (Fig. 2).

Having determined which ecosystem services are provided in reality by mangrove forests in the Gulf of Nicoya, we produced a new set of value estimates (Table 3). According to our modified benefit transfer, the highest mean values of the mangroves of the Gulf of Nicoya comes from biodiversity protection ($212 millions/year), coastal protection ($152 millions/year) and timber and fuelwood ($50 millions/year). The highest median values are from coastal protection ($60 millions/year), food ($5.8 millions/year) and climate regulation ($5.7 millions/year), all three ecosystem services valued in this study as well using specific methods.

By applying the expert modified benefit transfer based on seven ecosystem services, we estimated that the mean total value of the mangrove forests of the Gulf of Nicoya is $470 million per year, and a median value of $75 million per year.

Table 4
Ecosystem services ranked by experts depending on their level of provision in each Conservation Area.

Ecosystem service	ACOPAC	ACAT	ACT
Food (fish)	3	3	3
Food (mollusks)	3	3	3
Coastal protection	1–3	2	2

Low = 1, Medium = 2, High = 3

3.2. Results from specific methods

The three ecosystem services we chose to value using this approach in the Gulf of Nicoya were validated by the experts of the three conservation areas from SINAC that are in the Gulf: 1) Central Pacific Conservation Area (ACOPAC by its acronym in Spanish), 2) Arenal Tempisque Conservation Area (ACAT), and 3) Arenal Tempisque Conservation Area (ACT). These services were also ranked by the experts from low to high depending on their level of demand in each part of the Gulf of Nicoya (Table 4).

All interviewees agreed that food, including, fish, mollusks and shrimp, is the most important benefit that local communities received from mangroves. In the case of coastal protection, experts differentiated the service geographically between Puntarenas and the rest of the Gulf due to differences in economic activities and the intensity of urbanization. Climate regulation was not included in this survey since it is not geographically dependent across the study area. Other services that are

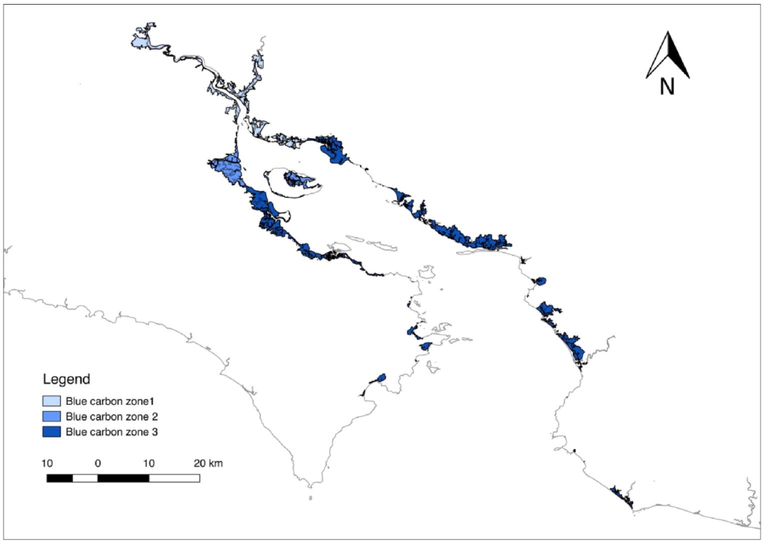

Fig. 3. Distribution of carbon stocks according to its concentration across the Gulf of Nicoya. Darker areas show higher densities of stored carbon.

Table 5
Economic value of the service of carbon stocks disaggregated by blue carbon concentration zones and sites in the Gulf of Nicoya.

Zone	Site	C ecosystem (Mg/ha)	Mean C (Mg/ha)	Area (ha)	C per zone (Mg)	MAC (2015 $/MgC)	Total economic value (2015 $)
1	Buenaventura	413.09	546.83	4,830	2,641,141.66	135.82	358,719,860.91
	Bebedero	601.49					
	Níspero	625.90					
2	Isla Chira	839.96	847.02	3,280	2,778,183.36	135.82	377,332,863.28
	Jesús	854.07					
3	Thiel	1,010.65	1,175.17	11,814	13,883,447.57	135.82	1,885,649,849.22
	Colorado	1,074.39					
	Paquera	1,160.58					
	Puntarenas	1,212.19					
	Lepanto	1,259.46					
	Jicaral	1,333.74					

important in the Gulf of Nicoya are education/research, which is focused on mollusks and the health of the mangrove; and salt production and shrimp aquaculture.

3.2.1. Climate regulation - carbon stocks

From the statistical and geographical grouping of carbon stocks we conducted, we divided the total extension of mangrove in the Gulf of Nicoya in three zones (Fig. 3). Zone 1, the upper part of the Gulf, has the lowest carbon stocks, 547 MgC/ha, and Zone 3 the highest, 1175 MgC/ha. This range of values of carbon stocks follow a latitudinal gradient in the Gulf, probably due to differences in microelevation and hydrodynamics, underlying geomorphology, and salinity from the north end of the area to the mouth of the Gulf at its southern end.

Zone 3 is also the largest in extent, and therefore the zone with the highest total carbon stocks and the highest value, $1,9 billions/year. Zone 2 and 1 are valued in $377 millions and $359 millions respectively. The total economic value of the carbon stock services of the three zones, and, therefore, the entire Gulf, is $2,6 billions (Table 5).

Because our study is focused on the economic valuation of ecosystem services, and services are flows and not stocks, we cannot add these results of carbon stocks to the rest of economic values of ecosystem services. Nevertheless, we considered important to estimate both the biophysical and economic values of carbon stocks in the Gulf of Nicoya for possible future policy decisions. Our estimates can also feed directly into new national natural capital estimates for Costa Rica, which to date do not include this type of information and are, thus, grossly underestimated.

Table 6
Total economic value of the carbon sequestration services based on the Social Cost of Carbon and a mean sequestration rate obtained from the literature.

Sequestration rate ($MgCO_2eq$/ha/yr)	SCC (2015 $/MgC)	SCC (2015 $/MgCO$_2$)	Area (ha)	Total economic value (2015 $)
6.00	87	319	19,924	38,151,655

Table 7
Total monthly catch (kg) and price (2015 USD) of the most important (in terms of catch and value) commercial categories in the Gulf of Nicoya.

Commercial category	TOTAL
First large (kg)	**179,047**
Value/month (USD)	**912,247**
First small (kg)	**406,087**
Value/month (USD)	**1,475,451**
Class (kg)	**350,689**
Value/month (USD)	**663,623**
Spotted rose snapper (kg)	**73,724**
Value/month (USD)	**299,616**
White shrimp (kg)	**71,141**
Value/month (USD)	**1,082,514**

Source: INCOPESCA (2018).

Table 8
The commercial category "Bivalves" disaggregated by species, showing each species catch (kg) and value (2015 USD) in each location of the Gulf of Nicoya in 2015.

Location	Bivalve	Catch (kg)	Mean price (USD/kg)
Berrugate	Clams	4	1
	Piangua	8	21
Chira	Piangua	21	21
Chomes	Clams	612	2
	Chora	516	2
	Mussels	1,340	2
	Piangua	733	21
Colorado	Clams	446	1
	Chora	1,300	1
	Mussels	220	2
	Piangua	1,523	27
Corozal	Clams	244	1
	Piangua	341	24
Isla Venado	Clams	1,132	1
	Chora	130	1
	Piangua	182	27
Islita	Clams	1,390	2
	Chora	50	2
	Mussels	225	3
	Piangua	1,125	20
Jicaral	Clams	20,420	1
	Chora	1,000	2
	Piangua	1,198	28
Las Ramas	Piangua	4	18
Moraga	Clams	50	2
	Mussels	150	2
	Piangua	88	20
Pajaritas	Clams	257	2
Palito	Chora	204	2
	Clams	112	1
	Piangua	126	20
Punta Morales	Clams	423	1
	Chora	96	2
	Mussels	200	2
	Piangua	207	21

3.2.2. Climate regulation - carbon sequestration

Applying the Social Cost of Carbon of 87 $/MgC to a sequestration rate of 6 $MgCO_2$eq/ha/year, the total economic value of the carbon sequestration service is $38,151,655 (Table 6).

3.2.3. Fisheries

The results of the annual value of first large, first small, class, spotted rose snapper and white shrimp are shown in Table 7. The category of first small has the highest annual value, ($1,475,451) and the highest catch (406,087 kg). Although white shrimp have the lowest catch of these five categories, it is the second most valuable of them, since it has the highest monthly mean price per unit of all ($16/kg), which is three times or more the price of the other categories (Table A3.2 from Appendix C).

In the case of bivalves, clams are extracted in the highest quantities (25,090 kg), representing 70% of the total extraction of bivalves, but they have the lowest mean price ($1.4/kg) and therefore they account for only 20% of the economic value of this category of organisms. On the other hand, pianguas represents 15% of the annual extractions (5,556 kg), but it accounts for 74% of the economic value due to its high mean price per unit ($22/kg) (Table 8). Because bivalves stay in the same location for the majority of time, in contrast with fish that move around inside and outside the Gulf, it is possible to determine their exact location of extraction, and therefore map the provision of this ecosystem service with high accuracy (Fig. 4).

Looking at the total catches and economic values by species in 2015 in the Gulf of Nicoya, the queen corvina is the species that is fished in the highest quantities of all species assessed (311,771 kg), as well as having the highest economic value ($1,264,579). The Scalyfin corvina is the second most fished species of all (267,892 kg) but has the third highest economic value ($709,818) since white shrimps are the second most valuable species ($1,082,514) (Table 9).

In total, the provisioning service of food (i.e. fisheries) in the Gulf of Nicoya has an economic value of $4,613,471. As established in the methods section, we assumed that the marginal and average products of mangrove area are equal for all species harvested (following Costanza et al. 1989), which results in a catch of 54 kg per hectare of mangrove, and a total value of $222 per hectare.

3.2.4. Coastal protection

The Sea Level Rise map that we produced using data from the AVISO + website (www.aviso.altimetry.fr) (Fig. A4.1 from Appendix 4) shows the northern zone of the Gulf to be the one that is experimenting the highest rise, with 2.93 mm/year in the districts of Chomes, Pitaya, and parts of Puntarenas, and 2.88 mm/year in the districts of Manzanillo, Colorado-Abangares, Mansion and Chira Island. In the middle zone of the Gulf, in the districts of El Roble, Espiritu Santo, San Juan Grande, Paquera and the majority of Tarcoles, sea level is rising at a rate of 2.7 mm/year. Finally, the southern zone of the Gulf has the lowest trends of sea level rise, in the district of Cobano is 2.46 mm/year and in Jaco, one of the most populated beaches of the country, 2.32 mm/year.

The coastal exposure index maps (Fig. A4.8 from Appendix D) show that the districts of Chomes, Pitahaya, Puntarenas, El Roble, Espíritu Santo, San Juan Grande, and Tárcoles as the most vulnerable. On the other hand, Quebrada Honda, Mansión, San Pablo Nandayure, and Lepanto, which are all located in the western side of the Gulf, have the lowest vulnerability index.

Our main outcome map, the habitat role (Fig. A4.10 from Appendix D), is the difference between the coastal exposure map (Fig. A4.8 from Appendix 4) and the coastal exposure without habitats map (Fig. A4.9 from Appendix D), and it was used to classify the total area of mangroves of the Gulf of Nicoya depending on the intensity of the provision of the coastal protection service, showing the highest intensity in the districts of Chomes, Pitahaya, Puntarenas and the majority of Tárcoles, and the lowest intensity in Quebrada Honda and Mansión.

The area categorization of the Gulf of Nicoya using the habitat role map produced by the model, resulted in 5,157 hectares that receive a low protection from mangroves, 8,894 hectares with medium protection, and 5,874 with high protection (Fig. 5). It is important to note again that the protection level that mangroves provide for each location

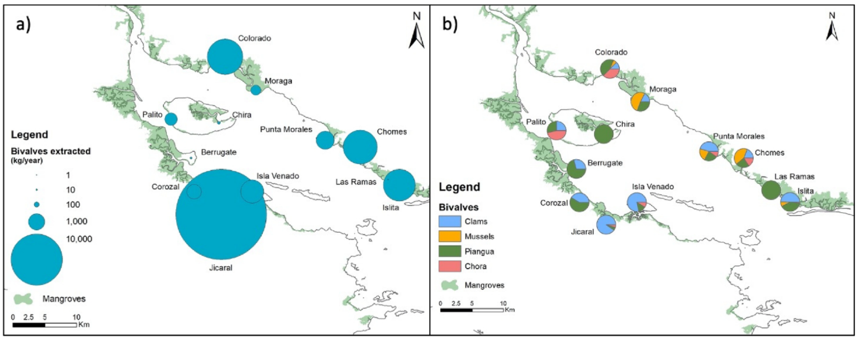

Fig. 4. Proportion of total bivalves extracted (a), and species composition (b) of the total bivalves extracted at each location in 2015. Source: Own elaboration with data from INCOPESCA.

Table 9
Summary of total catch (kg) and value (2015 USD) of each species fished in 2015 in the Gulf of Nicoya.

Species	Total		Total per ha	
	Catch (kg)	Value (USD)	Catch per ha (kg)	Value per ha (USD)
Scalyfin corvina	267,892	709,818	13	34
Sharpnose corvina	106,057	301,408	5	15
Queen corvina	311,771	1,264,759	15	61
Golden croaker	71,637	256,578	3	12
Striped corvina	2,758	7,892	0.1	0.4
Highfin king croaker	438	829	0.02	0.04
Pacific smalleye croaker	14,621	30,912	1	1
Panama kingcroaker	4,632	9,997	0.2	0.5
Yellowfin corvina	14,841	54,579	1	3
Armed snook	40,424	92,036	2	4
Union snook	16,729	32,211	1	2
Blackfin snook	16,374	47,180	1	2
Flathead Mullet	7,878	14,908	0.4	1
Atlantic Tripletail	8,791	16,636	0.4	1
Snook	46,650	203,389	2	10
Sea catfish	2,782	5,265	0.1	0.3
Barracuda	1,546	2,925	0.1	0.1
Spotted rose snapper	73,724	299,616	4	14
White shrimp	71,141	1,082,514	3	52
Clams	25,090	35,943	1	2
Piangua	5,556	133,956	0.3	6
Chora	3,296	5,246	0.2	0.3
Mussels	2,135	4,874	0.1	0.2
Total	**1,116,765**	**4,613,471**	**54**	**222**

is a function of all the variables mentioned in the Methods section that we used as inputs for the model.

We estimated through the benefit transfer modified by modelling method that the total mean value of the coastal protection service is $103 million per year, and a median total value of 40 million per year (Table 10).

3.3. *Final results from the hybrid approach*

Combining the values of the expert modified benefit transfer with the estimates from the more in-depth and specific methodologies, we calculated the mean total value of the ecosystem services assessed from mangrove forests in the Gulf of Nicoya in $408 million per year, and a median total value of $86 million (Table 11).

4. Discussion

4.1. *Comparative analysis between techniques of the hybrid approach*

Because we aimed to value economically a wide range of ecosystem services provided by mangrove forests in the Gulf of Nicoya, we needed to apply a hybrid approach methodology that had never been used in Costa Rica, and possibly elsewhere, combining traditional and innovative methods. Applying this approach yielded the first estimations ever done of these ecosystem services in the Gulf of Nicoya, which represents a clear step forward to communicate and utilize in different financial mechanisms the value of this natural capital.

When the benefit transfer method was used, we presented our results both as mean values and median values because we found a significant variance between the estimates that where extracted from the primary studies, which was the case for all ecosystem services assessed. For example, in terms of per hectare per year values, we found that for fisheries the range of values goes from $1 (Turpie, 2000) to $22,804 (Turner et al., 2003), for timber from $52 (Turpie, 2000) to $22,443 (Gren and Söderqvist, 1994), for coastal protection from $180 (Emerton, 2005) to $27,638 (Barbier, 2007), for tourism from $65 (Tri et al., 2000) to $944 (Cooper et al., 2009), and for biodiversity protection from $15 (Gunawardena and Rowan, 2005) to $36,312 (Bann, 1999).

These results from primary studies vary due to a number of factors, including valuation method, location, population, study site area, GDP/ capita of the country, etc. As more studies become available, it will become possible to estimate the relative influence of these factors on the final results and reduce the variance significantly. For example, De Groot et al. (2012) produced a meta-regression based on 244 studies of the value of inland wetlands including 17 variables that explained 44% of the variance in the valuation estimates. This sort of analysis will have

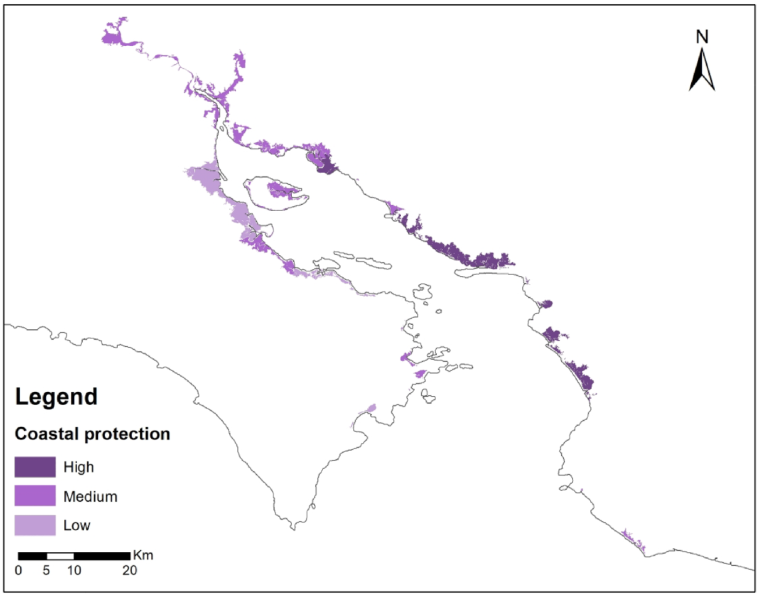

Fig. 5. Total area of mangrove forest of the Gulf of Nicoya classified according to its level of coastal protection.

Table 10
Summary table of the mean and median total value of the coastal protection service of mangroves in the Gulf of Nicoya, classified by the levels of protection established through the modeling using INVEST.

Level of coastal protection	Mean value per ha (2015 $/year)	Median value per ha (2015 $/year)	Area under each level of protection (ha)	Weight	Mean total value (2015 $/year)	Median total value (2015 $/year)
Low	7,638.00	2,997.00	5,156.96	0.33	12,998,323.96	5,100,285.01
Medium	7,638.00	2,997.00	8,893.76	0.66	44,834,155.66	17,592,035.16
High	7,638.00	2,997.00	5,873.86	1.00	44,864,542.68	17,603,958.42
Total			**19,924.58**		**102,697,022.30**	**40,296,278.58**

to wait for more studies of mangrove values. In the meantime, we simply state the range of estimates, their mean and median values in order to communicate the uncertainty in our current estimates

It is also key to note that when we use the benefit transfer technique, we are estimating the potential value of ecosystem services for a region since we are assuming that the total area of that region provides these services (i.e. assuming that there are beneficiaries throughout the entire region under valuation), and for this reason we adjusted our estimates with the help of a panel of experts. The results of the expert modified benefit transfer represent 58% of the initial mean value calculated by benefit transfer, and 85% of the median value, which shows the impact of removing or modifying the value of several ecosystem services, or even in cases such as timber and fuelwood that its difference in value between the ones obtained using benefit transfer and expert modified benefit transfer is equal to 37% of the total value estimated with the former method.

Having estimated economic values using both benefit transfer methods proved to be helpful to have more accurate results, plus it was a tool for capacity building for the experts that participated in this exercise. Nevertheless, by conducting a more detailed analysis for three ecosystem services, we were able to compare these results with the ones obtained in the previous two valuation methods used, showing very similar results in the case of the median value of fisheries, $5.8 million dollars using benefit transfer and $4.6 million dollars with specific methods. This confirms that, if done properly, benefit transfer can be a good first approximation to the value of ecosystem services when time and budget are limited.

In the case of coastal protection, our results obtained using InVEST varied in relation with the results applying the benefit transfer in a similar way that our results varied between transfer techniques, because we differentiated between potential areas and actual areas receiving the benefits, resulting in a 67% of the mean and median value calculated

Table 11
Combined results of the three different methods used to estimate the economic value of the ecosystem services of the mangroves of the Gulf of Nicoya. Numbers in black were estimated through benefit transfer (except subtotals and totals), numbers in blue were estimated using expert modified transfer and numbers in green were estimated using specific methods.

Ecosystem service	Mean Value	Median value
Provisioning Services		
Food	4,613,471	4,613,471
Medical/Bioprospecting	0	0
Fibers	0	0
Fodder	14,760	14,760
Sand, rock, gravel. Coral	0	0
Timber and fuelwood	49,618,917	884,259
Other raw material	0	0
Total Provisioning Services	**54,247,148**	**5,512,490**
Regulating Services		
Climate regulation	38,151,655	38,151,655
Coastal protection	102,697,022	40,296,279
Total Regulating Services	**140,848,677**	**78,447,933**
Cultural Services		
Recreation/tourism	804,021	146,838
Total Cultural Services	**804,021**	**146,838**
Support Services		
Biodiversity protection	212,214,578	2,315,253
Total Support Services	**212,214,578**	**2,315,253**
TOTAL	**408,114,424**	**86,422,515**

using traditional benefit transfer (the proportional difference of mean and median value in relation with the transfer estimates are equal because the variables that we modified, area and its protection capacity, were the same in quantity in both cases).

The results from climate regulation are the most dissimilar between valuation methods, probably due to variables such as the carbon sequestration rate estimated or selected from the literature, and the economic value assigned to each ton of carbon. In neither case, carbon storage or carbon sequestration, we chose the market prices approach, as it was done in a previous study on mangroves from the Gulf of Nicoya conducted by Arguedas-Marín (2015), because these "prices are generally lower in value since consumers participating in carbon markets are not in a position or are willing to pay the full price required to supply the benefits of carbon storage or sequestration" (Jerath et al., 2016, pp 165), while MACs and SCC are calculated using economic models that combines biophysical factors or climate change and socio-economic aspects of economic growth under different climate change scenarios.

In terms of the total economic values of the ecosystem services assessed in the Gulf of Nicoya, if we compare the combined results from the expert modified benefit transfer and the results from the specific methods with the results from the traditional benefit transfer, the median total value represents 98% of the original estimates from benefit transfer, which supports the argument that that if benefit transfer is conducted carefully it can yield good approximations of the actual value of ecosystem services.

Considering only the median values, the combined total value of climate regulation and coastal protection accounts for 91% of the total value of ecosystem services in the Gulf of Nicoya. Moreover, adding the third most valuable service, fisheries, which represents 5% of the total median value, means that using specific methods we were able to estimate the value of 96% of the total median value of ecosystem services in the Gulf.

Lastly, considering again the median total value of ecosystem services from mangroves in the Gulf of Nicoya, it represents 0.16% of the GDP in Costa Rica in 2015, which is also the exact equivalent of the total national budget of the Ministry of Environment of Costa Rica in 2015 (Ministerio de Hacienda de CR, 2015). Furthermore, taking in consideration the recent estimation of the total national expenditure of Costa Rica in environmental protection, which is 0.19% of the GDP (CEPAL, 2018), our estimates of the total median value of ecosystem services from mangroves would be equal to 85% of that expenditure.

4.2. Policy implications in Costa Rica

Our findings can be used for decision makers in charge of the design of the new PES in Costa Rica to prioritize which ecosystem services this scheme should include. We recommend that in the case of mangroves, the ecosystem services of climate regulation, coastal protection and food (i.e. fisheries) should be the focus of the conservation and restauration strategies that the new scheme will finance for these ecosystems. Moreover, the value of these three ecosystem services can guide the identification process of potential buyers of ecosystem services, strengthening in this way the financial mechanism of the program.

Furthermore, our study supports other policies, strategies and initiatives in Costa Rica on wetlands conservation and restoration. One example of these efforts is the work that the Central Bank of Costa Rica is conducting on environmental accounting. Specifically, our results can be incorporated in the ongoing project on the System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting (SEEA Experimental Ecosystem Accounting), since we developed vital information to be implemented in this framework such as the measurement of the ecosystem (i.e. mangroves) and the biophysical and economic assessment of the services it provides.

Another example is the National Wetlands Policy 2017–2030 which Costa Rica launched in 2017, with the goal "to manage integrally the wetland ecosystems of Costa Rica to contribute to the national development by conserving their ecological integrity and sustainable use of the ecosystem services they provide for current and future generations". To accomplish this goal, the policy established the following 2 axes of action that are related to ecosystem services and their valuation: 1) "Wetland ecosystem conservation, and its goods and services"; and 2) "Development, ecosystem services provision, and climate adaptation".

Our study contributes mainly to axis 2 and, more specifically, to the following guidelines and activities of the National Wetlands Policy:

- Guideline 2.1 "Scientific and traditional knowledge of the supply of ecosystem services from wetlands". Under the guideline's activity of "Map and determine which productive activities are consistent with the sustainable uses of wetland ecosystems, by analysing the relationship between supply and demand of goods and services", we estimated the economic value and mapped ecosystem services such as fisheries and tourism, providing information on the dependence that these productive activities have on mangroves.
- Guideline 2.4 "Incentives that promote the adoption of good practices, in order to protect the ecological integrity of wetland ecosystems". One of the guideline's activities aims to "create a fund or a financial program for the conservation of wetland ecosystems in the Municipalities", which can use our economic estimates to assess the

cost-benefit analysis of establishing this fund, as well as to develop financial mechanisms based on our estimates of the value of the ecosystem services from mangroves in the Gulf of Nicoya.

- Guideline 2.5 "Sustainable use, related to the mitigation and adaptation of wetland ecosystems and human populations". In particular, the activity of "Develop and implement a blue carbon strategy" will be highly benefitted from our findings, especially because we determined that 91% of the economic value of mangroves in the Gulf of Nicoya comes from ecosystem services directly related to climate change mitigation and adaptation (i.e. climate regulation and coastal protection). Our results provide a clear understanding on both the biophysical and socio-economic variables that should be considered to develop a strategy to protect and enhance blue carbon ecosystems such as mangrove forests.

We do not aim here to provide an extensive list of laws, policies and initiatives that our study supports, but to illustrate how economic valuations such as the one conducted here can help to put in practice many governmental actions towards wetlands protection under an ecosystem approach, as well as to stimulate the creation of innovative policies and programs such as "blue payments for ecosystem services".

5. Conclusions

This study constitutes the first of its kind in comparing results of economic valuation of ecosystem services of mangroves using a hybrid "three-tier method". Starting with traditional benefit transfer, we added expert modified benefit transfer and finally specific and more detailed estimations. Our study supports the use and accuracy of properly conducted benefit transfer. To the best of our knowledge this is the first hybrid integration of benefit transfer with the INVEST modelling tool.

We demonstrated that mangrove forests play a critical role in climate change mitigation and adaptation strategies, and at the same time provide many services that have a positive impact on the well-being of the local communities that depend on these ecosystems. Furthermore, mangroves are crucial for communities that can be far from their location, such as in the case of the provision of food which is consumed throughout Costa Rica.

Our estimates can be used as the bases for policies and strategies towards wetlands conservation and social well-being, and they also can be the basis for future research on social-ecological systems in order to better understand both the dependence of society on mangrove forests in Costa Rica and in other parts of the world as well as the human impacts on those services.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

List of ecosystem services provided by mangroves according to several studies.

	MEA (2005)	Russi et al, 2013 (TEEB)	Vo et al (2012)	Salem and Mercer (2012)	Mehvar et al. (2018)	Moberg and Ronnback (2003)	Mukherjee et al. (2014)	Barbier et al. (2011)	Spalding (2010)
Provisioning	Food	Food	Food	Commercial fishing and hunting	Fisheries	Seafood, honey, sugar, fruits, alcohol, vinegar	Fisheries (food), fisheries (aquaculture), honey	Food	Fisheries
	Fibber, timber, fuel	Raw materials	Wood products (timber, fibber, fuel)	Harvesting of natural materials	Raw materials	Tannins, lime, timber, thatch, firewood, fur, animal fodder	Wood, timber, fodder	Raw materials	Timer/ fuelwood
	X	Ornamental resources	X	X	X	X	X	X	X
	Biochemical products	Medicinal resources	Medicines	X	X	Traditional medicine	Pharmaceuticals	X	Medicines
	Genetic materials	Genetic resources	Genetic materials	X	X	Genetic resources	X	X	X
	X	(Fresh) water supply	X	Improved water quality	Water filtration	Water catchment and groundwater recharge	X	X	X
	X	X	X	X	X	Aquarium industry products	X	X	X
	X	X	X	X	X	Sustaining the livelihood of coastal communities	X	X	X
	X	X	X	X	X	Habitat for indigenous people	X	X	X

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(*continued*)

	MEA (2005)	Russi et al, 2013 (TEEB)	Vo et al (2012)	Salem and Mercer (2012)	Mehvar et al. (2018)	Moberg and Ronnback (2003)	Mukherjee et al. (2014)	Barbier et al. (2011)	Spalding (2010)
	X	X	X	Energy resources	X	X	Energy resources	X	X
Regulating	Climate regulation	Climate regulation	Carbon storage	Reduced global warming	Carbon sequestration	Carbon dioxide sink	Carbon sequestration	Carbon sequestration	Carbon sequestration
	X	X	Microclimate regulation	X	X	X	X	X	X
	Biological regulation	Biological control	X	X	X	X	X	X	X
	Pollution control and detoxification	Waste treatment/ water purification	Air pollution reduction	Waste disposal	Contaminant storage and detoxification	Trap sediments and pollutants	Pollution abatement, environmental risk Indicator	Water purification	Biofiltration
	Erosion protection	Erosion prevention	X	X	Shoreline stabilization and erosion control	Erosion control	X	Erosion control	Erosion control
	Natural hazards	Moderation of extreme events	X	Storm protection	Storm protection and wave attenuation	Storm protection	Coastal protection	Coastal protection	Coastal protection
	X	X	X	Flood protection	Flood control	Flood protection	X	X	X
	X	Regulation of water flows	Watershed protection	X	Regulation of water flow	Interrupts fresh water discharge	Protection from salt intrusion and/or sedimentation	X	X
	X	Influence on air quality	X	X	Oxygen production	Oxygen production	X	X	X
	X	X	X	X	X	Nutrient filter	Water bioremediation		X
	X	Pollination	X	X	X	X	X	X	X
Cultural	Spiritual and inspirational	Inspiration for culture, art & design / Spiritual experience	Cultural uses	X	Artistic value	Cultural, spiritual and artistic values	X	X	X
	Recreational	Recreation/ tourism opportunities	Recreational uses	Recreation, tourism. Recreational fishing and hunting.	X	Support recreation	Ecotourism and recreation	Tourism, recreation	Recreation
	X	X	X	Appreciation of species existence	X	X	X	X	X
	Aesthetic	Aesthetic information	X	X	Aesthetic	X	Aesthetic value	X	X
	Educational	Cognitive information (education & science)	Educational uses	X	Educational opportunities	Educational and scientific information	X	Education, and research	X
	X	X	X	Existence, bequest, option values	X	X	X	X	Non-material values
Supporting	Biodiversity	Lifecycle maintenance (a.k.a. biodiversity)	Biodiversity	X	Nursery and habitat for fishes and other marine species	Nursery, feeding and breeding ground. Maintenance of biodiversity	Fisheries (nursery)	Maintenance of fisheries (nursing)	Biodiversity
	Soil formation	Maintenance of soil fertility	X	X	X	Top soil formation	X	X	X
	Nutrient cycling	Nutrient cycling	Nutrient cycling	X	X	Export of organic matter	X	X	X

Appendix B

Experts interviewed for the validation of the list of ecosystem services

Name	Expertise	Meeting place	Date of meeting
Francisco Pizarro	Marine biologist in charge of the management plan for Chira Island	Heredia, Costa Rica	April 11th, 2018
Jamileth Cubero	Mangrove projects - Central Pacific Conservation Area	Puntarenas, Costa Rica	April 16th, 2018
Lara Anderson	Mangrove projects –Tempisque Conservation Area	Guanacaste, Costa Rica	April 16th, 2018
Celso Alvarado	Mangrove projects – Arenal Tempisque Conservation Area	Guanacaste, Costa Rica	April 16th, 2018
Pilar Arguedas	Mangrove projects – INCOPESCA	Puntarenas, Costa Rica	April 20 h, 2018




Appendix C. Statistics on artisanal fisheries from the Gulf of Nicoya

Appendix D Input and Output maps from INVEST Coastal Vulnerability Model.

Table A3.1
Total catch (kg) in the Gulf of Nicoya by artisanal fisheries for 2015. Data is aggregated by commercial category.

Commercial category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
First large	13,253	24,203	18,507	19,477	7,112	2,174	1,807	24,183	25,321	17,555	11,613	13,842	179,047
First small	46,844	45,461	56,887	35,964	9,564	3,825	3,062	36,013	55,640	38,722	40,682	33,423	406,087
Class	35,865	32,767	40,488	42,621	19,439	11,043	22,107	26,693	41,291	25,213	20,742	32,420	350,689
Junk	42,572	36,262	44,691	43,398	20,534	14,092	13,534	27,686	36,740	29,480	31,024	26,350	366,363
Golden croaker tail	8,535	6,756	12,425	10,629	6,731	4,031	3,565	10,243	9,886	11,855	10,748	6,708	102,112
Coral Hawk fish	608	1,528	1,064	387	1,667	2,798	4,158	3,442	3,058	2,180	4,034	520	25,444
Snapper	6,136	4,022	7,175	4,787	1,978	2,709	2,419	1,571	4,645	2,237	1,547	3,813	43,039
Spotted rose snapper	6,112	5,420	6,838	11,067	9,473	5,641	3,478	5,341	6,916	4,775	6,464	2,199	73,724
Pacific red snapper	19	230	58	355	192	979	302	136	71	600	0	714	3,656
Mahi Mahi	12,495	1,319	44	402	1,294	101	39	10	1,794	7,148	855	0	25,501
Marlin	0	0	0	0	0	0	0	0	0	0	0	0	0
White marlin	0	0	0	0	0	0	0	0	0	0	0	0	0
Striped Marlin	0	0	0	0	0	0	0	0	0	0	0	0	0
Sailfish	84	0	76	95	0	144	118	0	107	840	59	0	1,523
Sword fish	47	0	0	0	0	1,134	0	0	0	0	0	0	1,181
Wahoo	0	0	0	0	0	0	0	0	0	0	0	0	0
Sardine	64	0	775	1,025	0	0	150	0	0	0	0	0	2,014
Tuna	14,540	26,452	24,157	30,394	12,282	5,969	23,982	18,215	18,300	16,981	9,890	16,038	217,200
Ballywoo	0	0	0	0	0	0	0	0	0	0	0	0	0
Cazon	287	935	1,064	960	747	575	941	758	490	486	344	232	7,819
Posta	0	0	45	0	282	0	67	154	118	25	0	0	691
Maco	0	0	0	0	0	0	0	0	0	0	0	0	0
Treacher	0	0	0	0	0	0	0	0	118	122	0	0	240
White shrimp	12,346	10,008	6,560	6,669	1,711	60	5	10,233	7,104	5,325	4,204	6,916	71,141
Brown shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Pink shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Kolibri shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern nylon shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Royal shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Atlantic seabob	55	22	14	9	2	0	0	0	13	0	1	1	117
Prawn	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacific prawn	128	23	80	40	4	0	8	10	30	34	0	56	413
Caribbean prawn	0	0	0	0	0	0	0	0	0	0	0	0	0
Squid	0	0	8	0	0	0	0	0	359	334	0	5	706
Octopus	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	728	2,488	2,327	1,581	1,107	0	0	6,096	5,394	6,335	7,148	2,899	36,103
Cambute	0	0	0	0	0	0	0	0	0	0	0	0	0
Shark fin	0	0	0	0	0	0	0	0	0	0	0	0	0
Filet	86	100	578	89	0	0	0	19	104	184	104	124	1,388
Buche	2	4	12	5	23	0	0	0	0	0	0	0	46
Crab	1,590	2,310	1,418	20	8	0	0	0	43	3,102	2,598	58	11,147
Turtles	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: INCOPESCA, 2018

Table A3.2
Total monthly catch (kg) and price (2015 USD) of the most important (in terms of catch and value) commercial categories in the Gulf of Nicoya.

Commercial category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
First large (kg)	13,253	24,203	18,507	19,477	7,112	2,174	1,807	24,183	25,321	17,555	11,613	13,842	**179,047**
Price (USD)	6	6	6	6	5	6	5	4	3	4	5	6	
Value/month (USD)	76,260	148,663	119,902	124,242	37,440	12,751	9,803	92,754	85,792	69,311	55,425	79,905	**912,247**
First small (kg)	46,844	45,461	56,887	35,964	9,564	3,825	3,062	36,013	55,640	38,722	40,682	33,423	**406,087**
Price (USD)	4	4	4	4	3	3	3	3	3	3	4	4	
Value/month (USD)	174,907	169,323	226,917	146,781	33,147	12,931	10,652	123,083	165,789	126,043	147,613	138,264	**1,475,451**
Class (kg)	35,865	32,767	40,488	42,621	19,439	11,043	22,107	26,693	41,291	25,213	20,742	32,420	**350,689**
Price (USD)	2	2	2	2	2	2	2	2	2	2	2	2	
Value/month (USD)	61,985	58,629	77,683	81,618	39,812	25,393	51,242	47,613	70,294	44,321	40,372	64,660	**663,623**
Spotted rose snapper (kg)	6,112	5,420	6,838	11,067	9,473	5,641	3,478	5,341	6,916	4,775	6,464	2,199	**73,724**
Price (USD)	5	4	5	4	4	3	4	4	4	4	4	5	
Value/month (USD)	28,057	23,929	32,023	48,302	33,179	19,542	12,380	21,119	27,513	18,099	24,584	10,888	**299,616**
White shrimp (kg)	12,346	10,008	6,560	6,669	1,711	60	5	10,233	7,104	5,325	4,204	6,916	**71,141**
Price (USD)	17	17	18	19	18	14	28	13	13	13	13	13	
Value/month (USD)	206,984	169,174	117,449	128,252	30,558	860	139	132,027	89,647	67,168	52,740	87,517	**1,082,514**

Source: INCOPESCA (2018).

Table A3.3
The commercial category "Class" disaggregated by species, showing each species catch (kg) and value (2015 USD) in the Gulf of Nicoya in 2015.

Species	% Sp	Catch (kg)	Value (USD)
Scalyfin corvina	43	151,363	286,431
Sharpnose corvina	14	48,210	91,230
Queen corvina	14	48,141	91,098
Armed snook	9	31,498	59,605
Union snook	5	16,411	31,054
Pacific smalleye croaker	4	12,757	24,141
Atlantic Tripletail	3	8,791	16,636
Flathead Mullet	2	7,878	14,908
Blackfin snook	2	7,073	13,385
Panama kingcroaker	1	3,924	7,425
Yellowfin corvina	1	3,451	6,530
Snook	1	3,075	5,818
Sea catfish	1	2,782	5,265
Golden croaker	1	2,128	4,027
Barracuda	0.4	1,546	2,925
Striped corvina	0.3	1,224	2,316
Highfin king croaker	0.1	438	829
Total	100	**350,689**	**663,623**

Source: Marín (2018).

Table A3.4
The commercial category "First small" disaggregated by species, showing each species catch (kg) and value (2015 USD) in the Gulf of Nicoya in 2015.

Species	% Sp	Catch (kg)	Value (USD)
Scalyfin corvina	29	116,528	423,387
Queen corvina	29	115,991	421,434
Golden croaker	17	69,510	252,552
Sharpnose corvina	14	57,847	210,178
Snook	4	16,726	60,773
Blackfin snook	2	9,301	33,795
Armed snook	2	8,926	32,431
Yellowfin corvina	2	6,832	24,824
Pacific smalleye croaker	0.5	1,864	6,771
Striped corvina	0.4	1,535	5,576
Panama kingcroaker	0.2	708	2,572
Union snook	0.1	318	1,157
Total	100	**406,087**	**1,475,451**

Source: Marín, 2018

Table A3.5
The commercial category "First large" disaggregated by species, showing each species catch (kg) and value (2015 USD) in the Gulf of Nicoya in 2015.

Species	% Sp	Catch (kg)	Value (USD)
Queen corvina	82	147,640	752,226
Snook	15	26,849	136,797
Yellowfin corvina	3	4,558	23,224
Total	100	**179,047**	**912,247**

Source: Marín (2018).

Table A3.6
The commercial category "Bivalves" disaggregated by species, showing each species catch (kg) and value (2015 USD) in the Gulf of Nicoya in 2015.

Bivalve	Capture (kg)
Clams	25,090
Piangua	5,556
Chora	3,296
Mussels	2,135
Total	**36,077**

Source: Duran (2018).

Table A3.7
List of species that were selected to be valued in this study, indicating its scientific name and family, as well as the references that indicate that they use mangroves during their life cycle.

Common name (English)	Scientific name	Family	References
Scalyfin corvina, Weakfish	*Cynoscion squamipinnis*	Sciaenidae	Rönnbäck (1999)
Cachema weakfish, Sharpnose corvina	*Cynoscion phoxocephalus*	Sciaenidae	Rönnbäck (1999)
Queen corvina, Whitefin weakfish	*Cynoscion albus*	Sciaenidae	Rönnbäck (1999)
Golden croaker, Tallfin croaker	*Micropogonias altipinnis*	Sciaenidae	Rönnbäck (1999)
Striped corvina, Striped weakfish	*Cynoscion reticulatus*	Sciaenidae	Rönnbäck (1999)
Berrugato real, Highfin king croaker	*Menticirrhus nasus*	Sciaenidae	Rönnbäck (1999)
Pacific smalleye croaker	*Nebris occidentalis*	Sciaenidae	Rönnbäck (1999)
Panama kingcroaker	*Menticirrhus panamensis*	Sciaenidae	Rönnbäck (1999)
Stolzmann's weakfish, Yellowfin corvina	*Cynoscion stolzmanni*	Sciaenidae	Rönnbäck (1999)
Armed snook	*Centropomus armatus*	Centropomidae	Rönnbäck (1999)
Union snook	*Centropomus unionensis*	Centropomidae	Rönnbäck (1999)
Blackfin snook, Pacific blackfin	*Centropomus medius*	Centropomidae	Rönnbäck (1999)
Flathead Mullet, Black True Mullet	*Mugil cephalus*	Mugilidae	Rönnbäck (1999)
Atlantic Tripletail	*Lobotes surinamensis*	Lobotidae	Carpenter (2001)
Black Robalo, Black Snook	*Centropomus nigrescens*	Centropomidae	Rönnbäck (1999)
White snook	*Centropomus viridis*	Centropomidae	Rönnbäck (1999)
Sea catfish	*Notarius troscheli*	Ariidae	Rönnbäck (1999)
Mexican Barracuda, Barracuda	*Sphyraena ensis*	Sphyraenidae	Rönnbäck (1999)
Spotted rose snapper	*Lutjanus guttatus*	Lutjanidae	Rönnbäck (1999)
White shrimp	*Litopenaeus*	Penaeidae	Rönnbäck (1999), Goti (1991)
Piangua	*Anadara multicostata*	Arcidae	Morton (2013)
Piangua	*Anadara similis*	Arcidae	Morton (2013)
Piangua	*Anadara tuberculosa*	Arcidae	Morton (2013)
Rockmussel	*Modiolus capax*	Arcidae	Morton (2013)
Chucheca	*Grandiarca grandis*	Arcidae	Morton (2013)
Chora mussel	*Mytella guyanensis*	Mytilidae	Morton (2013)
Clam	*Polymesoda inflata*	Corbiculidae	Morton (2013)
Green clam	*Polymesoda radiata*	Corbiculidae	Morton (2013)
Sandy clam	*Donax californicus*	Donacidae	Morton (2013)
White clam	*Leukoma asperrima*	Veneridae	Morton (2013)
White clam	*Protothaca grata*	Veneridae	Morton (2013)

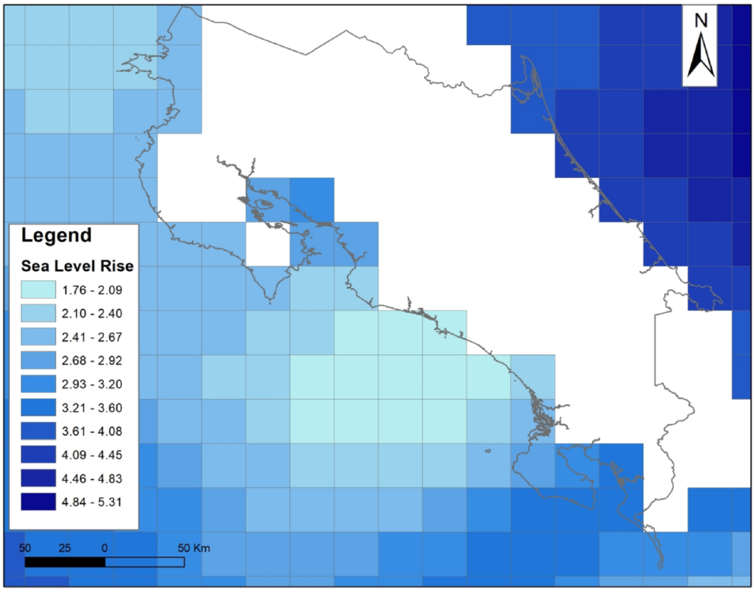

Fig. A4.1. Mean sea level rise in Costa Rica in mm/year. Darker areas show higher sea level rise. The Gulf of Nicoya is experiencing a medium sea level rise compared to the other areas of the country.

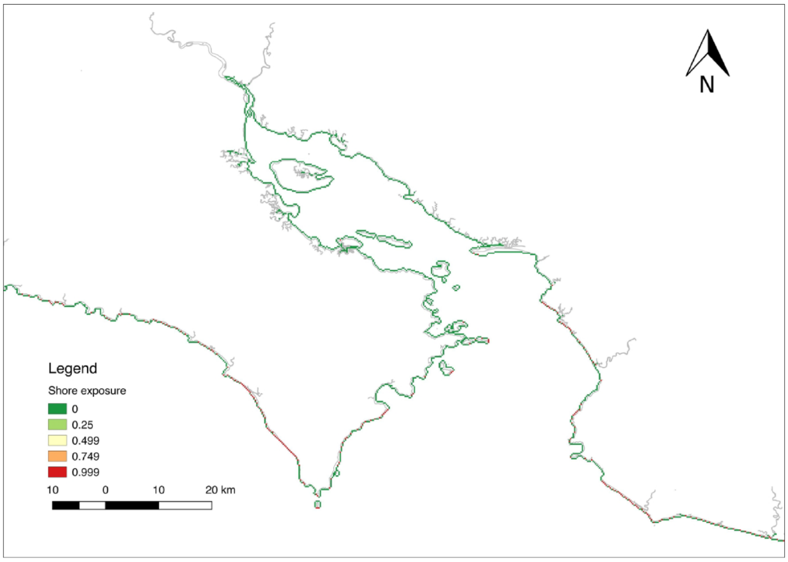

Fig. A4.2. Shore exposure, a raster where the cells corresponding to the shoreline segments are either 0 if sheltered or 1 if exposed.

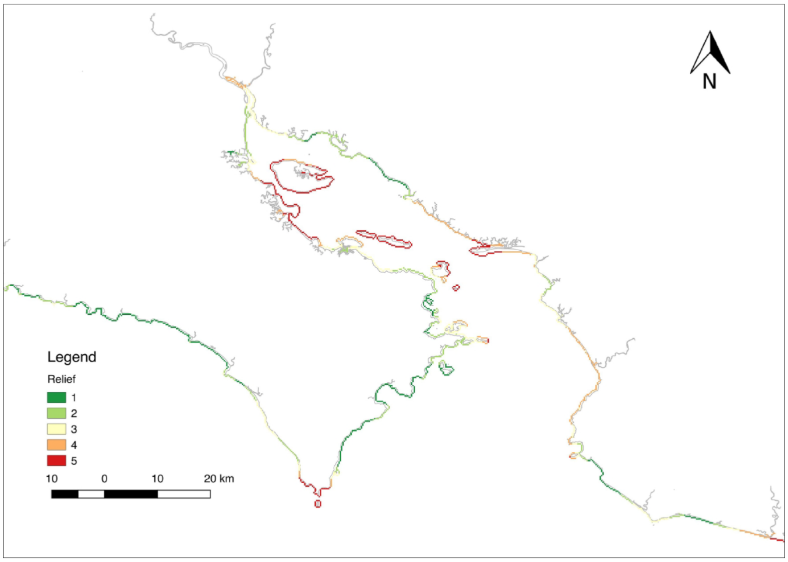

Fig. A4.3. Relief, a raster where shore segments are valued from 1 to 5 depending on the average elevation around that cell. Lower values indicate lower elevations.

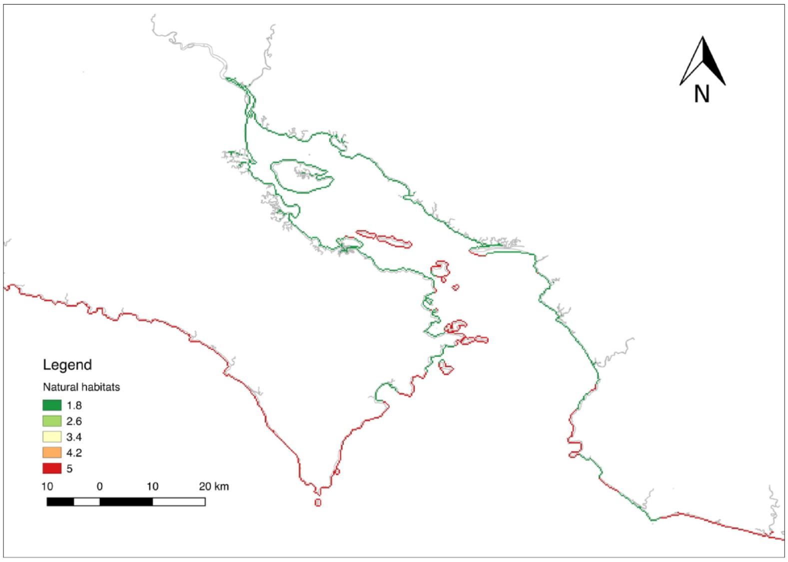

Fig. A4.4. Natural habitats, a raster where shore segments are valued according to the natural habitats that are present there, which in this case are all mangroves.

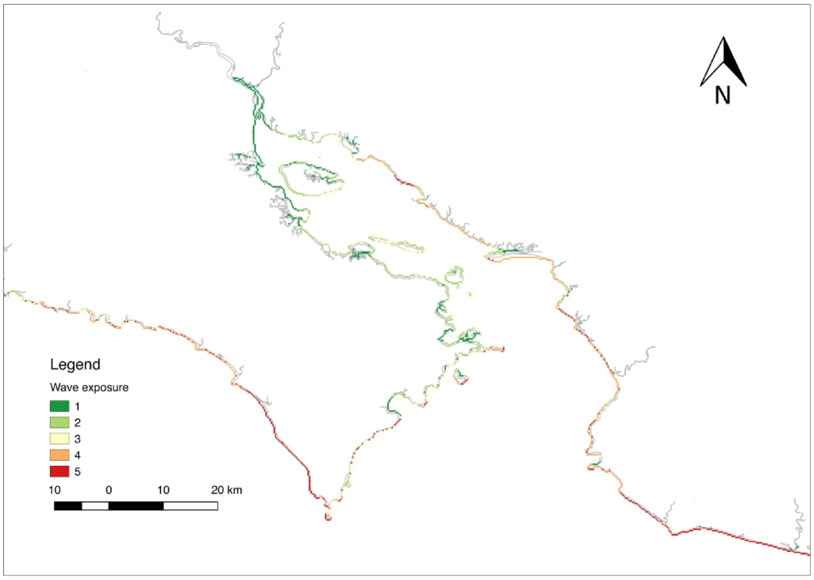

Fig. A4.5. Wave exposure, a raster where shore segments are ranked in a similar way to wind exposure, but according to their exposure to wave.

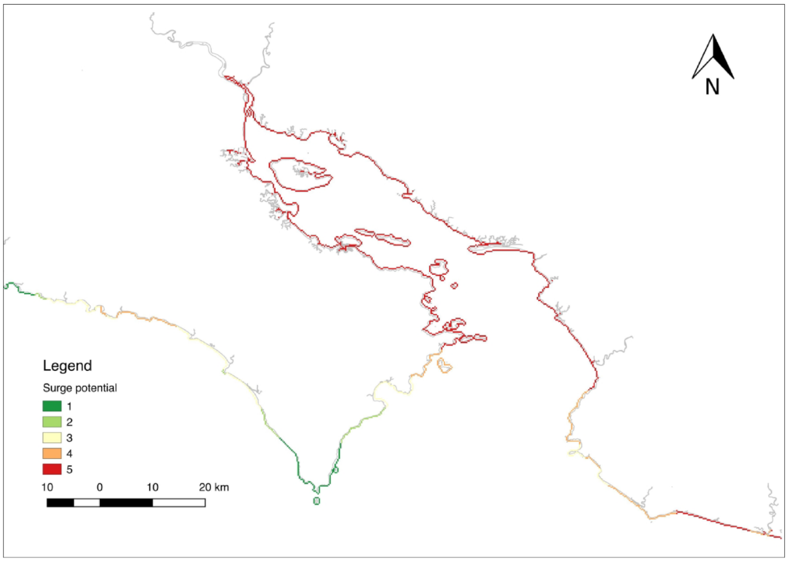

Fig. A4.6. Surge potential. a raster where segments are ranked according to their exposure to potential surge. First, the exposed segments are assigned a rank in equal proportion between 1 and 5, depending on their distance to the edge of the continental shelf. Then, these values are propagated along the sheltered coast. Isolated coastline segments (such as islands) are assigned the rank of the closest (already ranked) segment.

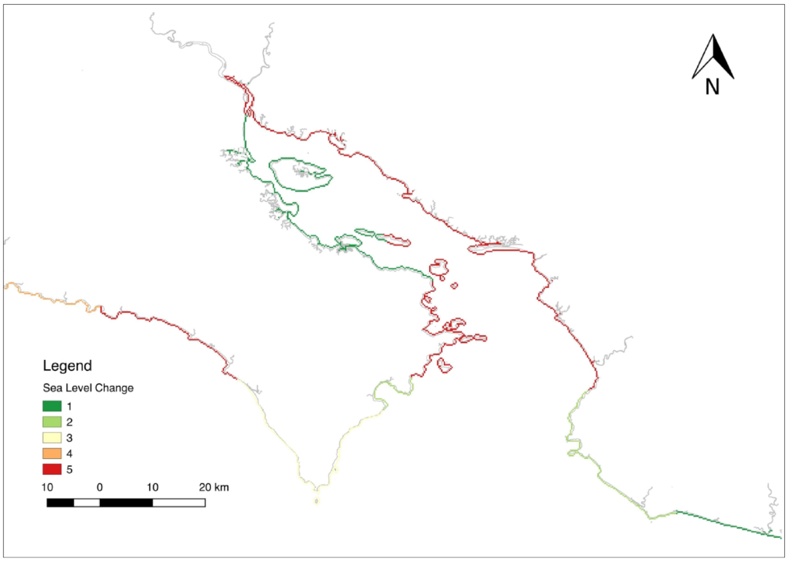

Fig. A4.7. Sea level change, a raster with segments ranked in equal proportion between 1 and 5 based on the sea level rise value from the input shapefile.

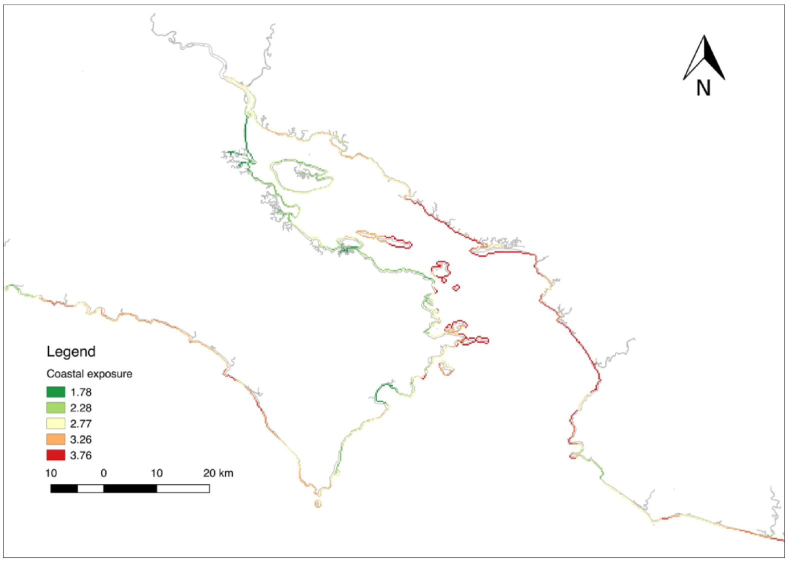

Fig. A4.8. Coastal exposure index raster. Coastal areas in red means higher vulnerability, and in green lower vulnerability. This model output takes in consideration both ecological and social-economic factors.

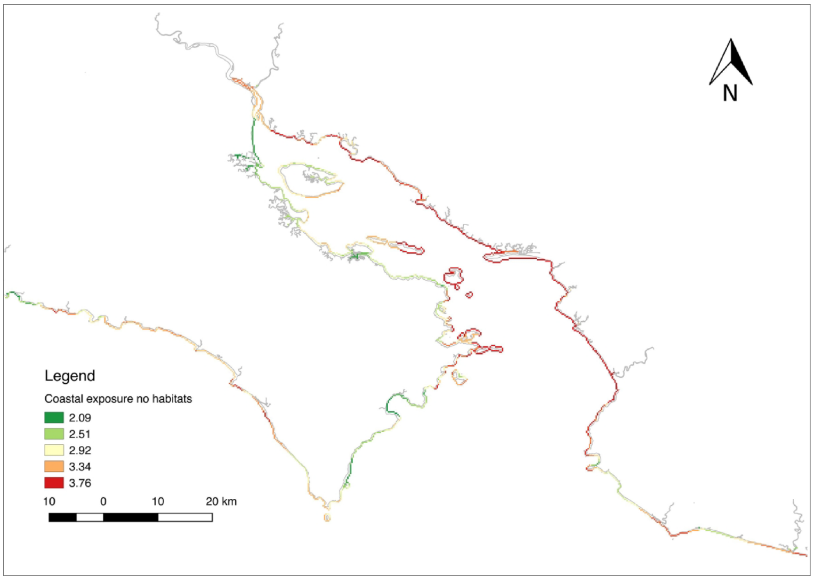

Fig. A4.9. Coastal exposure without taking into consideration habitats, raster containing values computed from the same equation as the coastal exposure raster except the natural habitats layer has been replaced by the constant 5.

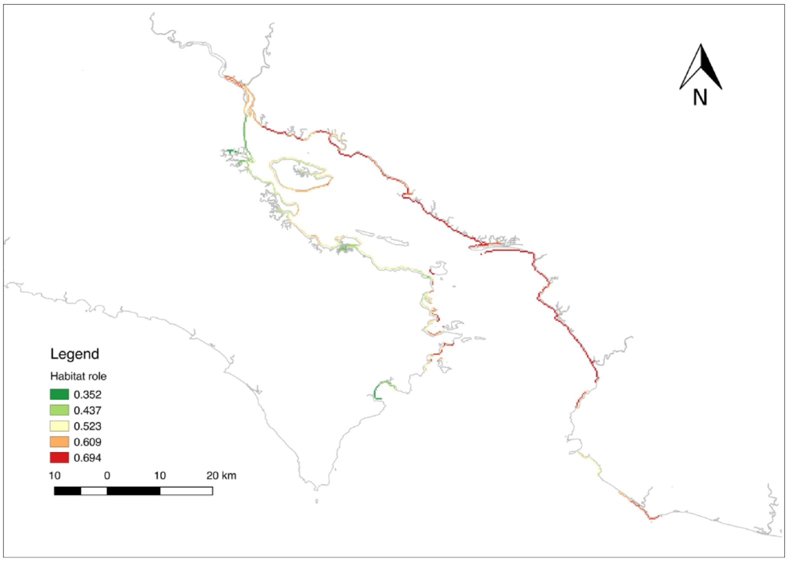

Fig. A4.10. Habitat role, raster difference between the coastal exposure map and the coastal exposure without habitats map.

Appendix E

Table A5.1
Summary table comparing the results of the three different methods used to estimate the economic value of the ecosystem services of the mangroves of the Gulf of Nicoya. Numbers in black were estimated through benefit transfer (except subtotals and totals), numbers in blue were estimated using expert modified transfer and numbers in green were estimated using specific methods.

Ecosystem Service	Benefit transfer		Expert Modified transfer		Expert Modified transfer + Specific methods	
	Mean Value	Median value	Mean Value	Median value	Mean Value	Median value
Provisioning Services						
Food	39,896,691	5,840,970	39,896,691	5,840,970	4,613,471	4,613,471
Medical/Bioprospecting	5,144,858	613,949	0	0	0	0
Fibers	112,718	112,718	0	0	0	0
Fodder	294,726	294,726	14,760	14,760	14,760	14,760
Sand, rock, gravel. Coral	1,037,136	1,037,136	0	0	0	0
Timber and fuelwood	351,713,024	6,267,881	49,618,917	884,259	49,618,917	884,259
Other raw material	27,220,649	4,652,300	0	0	0	0
Total Provisioning Services	**425,419,802**	**18,819,680**	**89,530,368**	**6,739,990**	**54,247,148**	**5,512,490**
Regulating Services						
Climate regulation	15,011,447	5,726,869	15,011,447	5,726,869	38,151,655	38,151,655
Coastal protection	152,187,141	59,708,937	152,187,141	59,708,937	102,697,022	40,296,279
Total Regulating Services	**167,198,587**	**65,435,806**	**167,198,587**	**65,435,806**	**140,848,677**	**78,447,933**
Cultural Services						
Recreation/tourism	7,047,295	1,287,048	804,021	146,838	804,021	146,838
Total Cultural Services	**7,047,295**	**1,287,048**	**804,021**	**146,838**	**804,021**	**146,838**
Support Services						
Biodiversity protection	212,214,578	2,315,253	212,214,578	2,315,253	212,214,578	2,315,253
Ecosystem Service	Benefit transfer		Expert Modified transfer		Expert Modified transfer + Specific methods	
	Mean Value	Median value	Mean Value	Median value	Mean Value	Median value
Total Support Services	**212,214,578**	**2,315,253**	**212,214,578**	**2,315,253**	**212,214,578**	**2,315,253**
TOTAL	**811,880,262**	**87,857,786**	**469,747,554**	**74,637,886**	**408,114,424**	**86,422,515**

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