



Environmental Function Analysis: A decision support tool for integrated sandy beach planning



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ABSTRACT

Worldwide, sandy beach socio-ecological systems are under stress, yet there are few systematic approaches to guide conservation and development planning. Four sandy beaches in the Halifax Regional Municipality (HRM; Nova Scotia, Canada) were evaluated using a modified Environmental Function Analysis (EFA). Our goal was to reduce the severe data requirements of traditional EFA by using more proxy indicators as well as combining indicators into higher-level metrics. We also sought to incorporate landscape-scale evaluation by incorporating adjacent habitats. Twenty ecological and socio-economic indicators were scored according to their performance, normalized, and plotted in a conservation/use development matrix. Results show that beaches near large cities or towns, have already been extensively developed for their recreational use, and are subject to significant environmental degradation. Other beaches were conflicted between recreational, touristic, and/or exploitative opportunities, versus richer biodiversity, habitats, and species of conservation interest. Scenario analysis demonstrates that management strategies which focus on minimizing the invasive nature of park infrastructure and enhance biophysical restoration, can significantly increase beach conservation value, and shift sites into the conservation zone. Provincial government officials applied results to revised management of one of the study beaches. EFA not only provides general observations allowing beaches to be compared and contrasted, but it also gives useful insight on individual beaches, allowing for better-informed decision-making and tailored management. The simplified EFA methodology proposed is user-friendly, provides conclusive results, and offers a cost-effective approach to sandy beach environment evaluation.

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1. Introduction

Coastal environments are increasingly being solicited for their ecosystem goods and services, especially sandy beaches. Today, more than 67% of the world's population lives within 60 km of the coast, a value expected to reach 75% by 2020 (Gray, 1997; Schlacher et al., 2008). Since 75% of ice-free coastal shorelines consist of beach

ecosystems (Brown and McLachlan, 2002), economic development, resource extraction, and recreational demand triggered by population growth are placing unprecedented pressure on the world's beaches (Schlacher et al., 2008). Along with human-induced pressures on the landward side, sea level rise induced by climate change gradually constricts sandy beaches on the seaward side (Defeo et al., 2009; Schlacher et al., 2008).

The various anthropogenic and natural stressors imposed on sandy beaches have led to widespread erosion and degradation of these complex ecosystems with consequences for both social and ecological realms. Sandy beaches are valuable to coastal residents since they support a variety of ecological, social, cultural, and economic goods and services (Schlacher et al., 2008). These environments are not only prime recreational grounds supporting the tourism industry; they also provide important nursery grounds for many fish species, supporting stocks and sustaining local fisheries (Schlacher et al., 2007). Sandy beach ecosystems also offer important functions such as nutrient recycling, water filtration, coastal

Abbreviation: Halifax Regional Municipality, (HRM); Environmental Function Analysis, (EFA); Nova Scotia Department of Natural Resources, (NSDNR); Integrated Coastal Zone Management, (ICZM); Socio-Economic Status, (SES); Rainbow Haven Provincial Park, (RHV); Conrad Beach, (CRD); Lawrencetown Beach Provincial Park, (LTN); Martinique Beach Provincial Park, (MTQ); Nature Conservancy of Canada, (NCC); Nova Scotia Topographic Database, (NSTDB).

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protection, and nesting and foraging sites for vertebrate and invertebrate species including endangered fauna (Schlacher et al., 2007). Therefore, an integrated approach to beach management, with emphasis on minimizing the impacts of human activities and climate change while maximizing the sustainable use of sandy beach ecosystems, is critically needed (Schlacher et al., 2008).

The eastern Canadian province of Nova Scotia has an extensive coastline (7400 km) and its numerous beaches figure prominently in recreation, tourism, and nearshore habitat. Beach management and conservation have been driven mainly by the implementation of the provincial *Beaches Act*, which restricts use and promotes beach conservation, and the *Provincial Parks Act*, which aims at sustainable use of selected beaches for recreational purposes. However, the designation process for protected beaches using these Acts lacks a systematic approach to beach conservation, use, and development planning. Presently, the *Beaches Act* designation procedures policy, which is yet to be approved by the Minister, relies on formal requests from the Minister, Deputy Minister, or Nova Scotia Department of Natural Resources (NSDNR) to initiate an evaluation process and consider individual beaches to be protected or not under the Act. Historically, community organizations and concerned citizens have provided the political legitimacy for these formal requests. Unfortunately, the reactive nature of this approach has left coastal planners with little pragmatic support to fulfill their conservation mandate. In a time where the Government of Nova Scotia is contributing to the design of an Integrated Coastal Zone Management (ICZM) strategy and recognizes that sandy beaches and associated dune ecosystems are under “high risk” (Government of Nova Scotia 2009), the need for a more efficient approach to sandy beach planning has become a priority.

However, before the implementation of any management strategy, indicators and decision support tools need to be developed and applied to inform and guide sustainable development and conservation of beaches (Phillips et al., 2007). One relevant methodological framework is Environmental Function Analysis (EFA) proposed by Cendrero and Fischer (1997). Influenced by the concept of environmental functions (i.e. goods and services) suggested by de Groot (1992), the EFA method is based on assessment of ecological and socio-economic components to lead coastal planning. This framework evaluates and scores environmental quality and development indicators to assess multiple sites simultaneously. These values are then plotted in a conservation/development matrix allowing a comparison of sites with respect to environmental values and conflict levels. Despite the various modifications proposed by coastal planning experts (van der Weide et al. 1999), and sandy beach planning researchers (Micallef and Williams, 2003; Phillips et al., 2007), the EFA methodology still requires input of environmental data that is not readily available in many locations. Also, the number of required indicators is burdensome for local capabilities. Furthermore, many indicators proposed by Cendrero and Fischer (1997) do not apply to the Nova Scotia environment and must be adapted to local conditions.

In this context, the present study, based on previous work (Amyot, 2011) has the following objectives:

- Reduce the data/time burden associated with EFA by providing easily identifiable environmental quality indicators
- Create aggregate indices and proxies to make EFA more practical in data-poor environments
- Select and define environmental quality indicators for different environmental components (ecological and socio-economic), relevant to selected beach environments in Nova Scotia.
- Determine which management decisions (affecting a specific environmental indicator), can be most effective in the conservation/use development potential of beaches.

- Discuss the optimal management action for the selected sandy beaches.

2. Material and methods

2.1. Limitations and proposed modifications

Despite the previously successful application of the EFA framework to guide decision-making for sandy beach management, the absence of accurate local environmental data remains the biggest obstacle to scientifically objective analysis. Lacking indicator data (e.g. local coastal water contamination), researchers have relied on a combination of various qualitative (e.g. bad, moderate, good, best, etc.) and quantitative variables (e.g. %vegetation cover, beach width, etc.) to evaluate environmental quality on sandy beaches (Cendrero and Fischer, 1997; de Araujo and da Costa, 2008; Micallef and Williams, 2004).

In our study, a number of modifications to EFA were carried out. First, proxy indicators were selected and described to effectively compensate for the lack of available biological data. Also, equal numbers of ecological-based compared to socio-economic indicators were selected to prevent a bias of conservation over development which typically occurs (Micallef and Williams, 2003; Phillips et al., 2007; van der Weide et al., 1999). Furthermore, to simplify the field investigation and limit overlap, 20 indicators, which utilize easily accessible data were selected.

Data were obtained using Google Earth 2011 (6.1.0.5001), assessed visually, and validated with field observations. Although Google Earth data may have been derived from different years, they are all fairly recent. With Nova Scotia's small population and land mass, land use changes occurring since images were produced would be known to us. Images used were thus considered up to date. Socio-economic and population -related data were obtained from the Nova Scotia Community Counts, a program from the Economics and Statistics division of the Nova Scotia Department of Finance (Government of Nova Scotia 2011). Although the authors recognize that these data sets contain uncertainties, it is beyond the scope of this paper to discuss limitations of third party information sources. Finally, a Delphic approach was used to avoid personal biases, relying on expert opinions in assessing environmental and socio-economic components when hard data were unavailable (Phillips et al., 2007). By applying these modifications to the methodology, it is expected that results yield will provide more practical and wider application of EFA as a beach management tool.

2.2. Selection of environmental quality indicators

The basic categories of environmental components chosen (Tables 1 and 2) have previously been used in the literature (Cendrero and Fischer, 1997; Micallef and Williams, 2003; Phillips et al., 2007; van der Weide et al., 1999). However, new characteristics (e.g. landscape structure, coastal sensitivity) and merged proxy indicators were proposed in order to reduce the time/data burden associated with EFA. Indicators were then aggregated by their relevant environmental components. This was based on past EFA and by subject appropriateness. The descriptions of each new ecological indicator, along with associated assumptions are discussed below, whereas previously used indicators are described only within Table 1.

2.2.1. Ecological indicators

In the following text, we summarize 11 ecological indicators into 6 broad categories (ecological components) as summarized in Table 1. The broad intent of those indicators is also specified in the

Table 1

List of ecological indicators, and associated range description, used in the evaluation of key characteristics of each ecological components.

Ecological components	Characteristics	Indicators	Range description
Coastal water	Aesthetics condition	Floating debris/Litter	(1) Very abundant (2) Abundant; (3) Moderate; (4) Some; (5): Rare/None
	Water quality	Shellfish harvesting closures & River outputs*	(1) Year round closure and/or, large river output(s) surrounded by urban development; (2) Closure every 1–2 years and/or, medium river output(s) surrounded by urban development; (3) Closure every 3–4 years and/or, small river output(s) surrounded by urban development; (4) Closure every 5–7 years and/or, medium/small river output(s) not surrounded by urban development; (5) Seldom closures and/or no river output
Landscape ecology	Ecosystems connectivity	Associated coastal ecosystems*	(1) None/very few, small, and disconnected; (2) Few, medium-large, and disconnected; (3) Many, small, and connected; (4) Many medium-large, and connected; (5) Numerous, medium-large, and connected
	Management	Ecosystems of conservation interest*	(1) None/very few, small, and no conservation interest; (2) Few, medium-large, and no/limited conservation interest; (3) Many, small, and some conservation interest; (4) Many medium-large, and high conservation interest; (5) Numerous, medium-large, and priority conservation interest
Coastal biota	Species diversity and abundance	Beach type	(1) Very reflective ^a ; (2) Mostly reflective; (3) Intermediate; (4) Mostly dissipative; (5) Very dissipative
	Management	Species of conservation interest*	(1) None/very few, and no conservation interest; (2) Few, and no/limited conservation interest; (3) Many, and some conservation interest; (4) Many, and high conservation interest; (5) Numerous, and priority conservation interest
Hazards	Coastal erosion/damage	Dune erosion/boardwalk erosion & damage ^{a,*}	(1) Very eroded dunes & very frequently damaged boardwalks; (2) Fairly eroded dunes & frequently damaged boardwalks; (3) Some erosion to dunes & damage to boardwalks (4) Limited erosion to dunes & damage to boardwalks; (5) No erosion to dunes & damage to boardwalks
	Coastal sensitivity	Coastal sensitivity to sea level rise/flood/storm & migration potential*	(1) High coastal sensitivity & no/limited migration potential; (2) Moderate coastal sensitivity & no/limited migration potential; (3) Moderate coastal sensitivity & some/high migration potential; (4) Low coastal sensitivity & no/limited migration potential; (5) Low coastal sensitivity & some/high migration potential
Geological and topographic features	Quality	Sediment composition and size	(1) Very high abundance of boulders, pebbles, and rocks, & very coarse sand grain; (2) Abundant presence of boulders, pebbles, and rocks, & coarse sand grain; (3) Limited abundance of boulders, pebbles, and rocks, & coarse-medium sand grain; (4) Limited abundance of boulders, pebbles, and rocks & medium-fine sand grain; (5): Very limited abundance of boulders, pebbles, and rocks & medium-fine sand grain
Resources	Landscape	Visual quality	(1) Very limited; (2) Limited; (3) Intermediate; (4) High; (5) Very high

* Novel indicator proposed by the present study.

^a Where dune erosion was greater than boardwalk damage, or vice versa, a conservative evaluation was favored (i.e. lowest associated rating).

Characteristics column. The ecological components are bolded in the text for linkage to Table 1.

Coastal water composition and esthetic qualities have long been used in sandy beach classification and rating systems to ensure health standards and promote particular sites for tourism (de Araujo and da Costa, 2008; Micallef and Williams, 2004). However, local water quality assessments are not done on a regular basis for Nova Scotia beaches. In fact, a common proxy indicator for water quality in the province is shellfish harvesting closures due to sewage contamination (Beaton, 2008). All information regarding past and ongoing shellfish closures in Nova Scotia was obtained by contacting the Communication Branch at Dept. of Fisheries and Oceans Canada. In addition to shellfish closures, river outputs have

been incorporated herein. Rivers surrounded by suburban development are assumed to deliver more runoff including contaminants to coastal waters than rivers surrounded by less development. The presence (or absence) and size of river outputs, along with the density of urban development was evaluated using Google Earth by visual inspection.

Landscape ecology considerations have not been directly addressed in beach EFA. Due to the crucial role of surrounding sandy dunes, wetlands, nearby islands, or any other system on which beaches rely for the exchange of sand (Bird, 1996; McLachlan and Brown, 2006), the structure and integrity of the local landscape should be evaluated. It is assumed that a sandy beach surrounded by other natural coastal habitats, will be more resilient to coastal

Table 2

List of socio-economic indicators, and range descriptions, used to evaluate potential for use, and wellbeing, for the human component. Scaling is described in the range description column.

Socio-economic components	Characteristics	Indicators	Range description
Human dimension	Potential for use	Mining activity	(1) Non-Commercial; (2) Commercial (inactive, off site); (3) Commercial (inactive, on site); (4) Commercial (active & off site) ^a ; (5) Commercial (active & on site).
		Fishing & digging activity	(1) None/very limited; (2) Limited; (3) Moderate; (4) Intense; (5) Very intense.
		Recreation potential ^b	(1) None/very limited; (2) Limited; (3) Moderate; (4) Abundant; (5) Very abundant.
		Parking ^c	(1) None/very limited; (2) Limited; (3) Moderate; (4) Abundant; (5) Very abundant.
		Accessibility ^d	(1) Not accessible/very limited; (2) Limited; (3) Moderate; (4) Accessible; (5) Very accessible.
		Land use ^e	(1) Very limited; (2) Limited; (3) Moderate; (4) Diverse and large-scale; (5) Very diverse and large-scale.
		Coastal development ^f	(1) Absence of structure/very distant; (2) Distant; (3) Moderately distant; (4) Close; (5) Very close/on site.
		Population density ^g	(1) Absence of nearby community/very low; (2) Low; (3) Intermediate; (4) High; (5) Very high.
	Wellbeing	Beach area ^h	(1) Very small; (2) Small; (3) Intermediate; (4) Large; (5) Very large.
		SES score	(1) [−6 to −3]; (2) [−2 to −1]; (3) [0 to 1]; (4) [2 to 3]; (5) [4 to 6].

^a Upland to an adjacent river, waterway, or nearby island.

^b Abundance of other leisure sites (e.g. camping, kayaking route, surfing spots, cycling trail, etc.).

^c Number of parking sites and places.

^d Number of kilometers to the nearest highway.

^e Diversity and size of development (e.g. residential, commercial, aquaculture, etc.).

^f Distance to closest house, building, or engineering structure (e.g. seawall).

^g Individual per kilometer squared (ind/Km²).

^h Length × width (ha).

processes, sea level rise, and human use. This structure is easily estimable from Google Earth, supplemented by our field observations.

On this basis, a new indicator within **Landscape ecology** related to connectivity is the presence (or absence) and size of nearby coastal ecosystems that are actively managed for the purpose of conservation. It is assumed that conservation efforts being implemented on other sites will indirectly improve environmental conditions for adjacent sandy beaches and increase their conservation potential. This indicator follows a similar logic as the abundance and diversity of species of conservation interest (i.e. rare, endangered, endemic, migrating species area, wildlife areas), which increases the conservation value of a site (Cendrero and Fischer, 1997). In this case, a thorough systematic review of each beach site and adjacent regions was completed via observations and consultation to assign appropriate indicator scores.

Marine and terrestrial species abundance and diversity (**Coastal biota**) have been used extensively as indicators of environmental quality (Cendrero and Fischer, 1997; Micallef and Williams, 2003; Phillips et al., 2007; van der Weide et al., 1999). However, the absence of sufficient local data has made its utilization difficult in the present study. Coastal biota composition depends on beach slope, exposure, and sand type (Bird, 1996; McLachlan and Brown, 2006). Therefore, the use of the beach slope/type as proxy indicator for species quantity and quality is proposed. For example, a very steep and narrow beach (reflective) is expected to have low species abundance and diversity, and a highly dissipative beach slope (flat and wide) is expected to support richer species abundance and diversity (Table 1).

Coastal **hazards** including erosion and sensitivity to sea level rise were evaluated using a semi-quantitative approach. The severity of dune/backshore erosion and boardwalk damage was used to derive the coastal erosion/damage indicator score. While field observations were used to determine the level of dune erosion, direct reports from the Parks and Recreational Division of NSDNR defined the frequency of boardwalk restoration work.

Coastal sensitivity to sea level rise data was evaluated on two fronts. Data provided by *The Atlas of Canada* (Natural Resources Canada, 2007) was used to evaluate the “degree to which the

coastline may experience physical changes such as flooding, erosion, beach migration, and coastal dune destabilization”. This federal agency grouped coastal sensitivity data and expressed them in “eco-region” format, allowing estimation of the potential for beaches to migrate inland. For example, an undeveloped backshore (e.g. salt marsh) may be a geomorphologic landscape ready to shelter a migrating beach, compared to a built backshore structure such as a road.

Geological and topographic features such as sediment composition and size have also been used commonly in the EFA methodology. Though sandy beaches with mixed sediment composition may be preferable for species diversity, it is argued that beaches with homogenous, medium-fine grain size are the targeted ecosystem to conserve. Thus, sandy beaches with higher pebble, gravel, or boulder composition are considered less desirable in the context of the present study than finer sand beaches. Field observations of relative sediment composition and sand grain size were used to assign indicator scores for this ecological component.

The last ecological indicator (**Resources**) is subjective because it defines visual quality. However, previous work on EFA of beaches has included this landscape characteristic, most likely as a way to underline the non-consumptive use value of beaches. This also relates to the informative ecosystem function of de Groot (1992) as unique beaches with “unspoiled” natural features are assumed to offer greater conservation values than developed, occupied, or exploited beach sites. Although this appears to overlap with indicators such as litter, it applies more to the original state of the beach rather than subsequent impact. The evaluation of the visual quality of each site was done by observations subsequently corroborated by a group of provincial coastal managers as prescribed by the Delphic approach above.

2.2.2. Socio-economic indicators

All except one of the socio-economic indicators chosen herein have been used in previous EFA (Cendrero and Fischer, 1997; Micallef and Williams, 2003; Phillips et al., 2007; van der Weide et al., 1999). They are based largely on statistical data from government sources. For Table 2, all data requiring distance were measured using Google Earth and all population-related data were

obtained from the 2006 provincial census provided by the [Government of Nova Scotia \(2011\)](#). The novel addition, Socio-Economic Status (SES) is a merger of other indicators including community specific employment rate, educational attainment (high school diploma or equivalent) and median income ([Government of Nova Scotia 2011](#)). Google Maps was used to evaluate land use diversity and size, and business related information in the assessment of recreational potential.

2.3. Indicators evaluation and normalized calculations

After each ecological and socio-economic indicator was scored (1 = lowest/worst – 5 = highest/best as defined in [Tables 1 and 2](#)) the results were shared with a group of provincial planners from Nova Scotia Department of Natural Resource. These experts reviewed each scoring, provided feedback, and consensus with the proposed scores in a Delphic approach. The results were then normalized (Ns). By dividing the sum of the score allocated to each indicator ($s_1, s_2, s_3, \dots s_i$) by the total maximum score for each characteristic (x).

$$Ns = \sum s_i / x$$

For example, at Rainbow Haven, coastal water quality was measured through two indicators: the combination of shellfish closure frequency & river outputs (scored 2 out of 5), and litter (also scored 2 out of 5). Their sum (4) was then divided by the maximum value (5 + 5 = 10) as $4/10 = 0.4$, resulting in a normalized score. Similarly, the total score of all indicators for the conservation value and socio-economic potential were summed and divided by the maximum value. For example, all ecological components, on Conrad beach had a total indicator score of 40 (3 + 4 + 5 + 5 + 3 + 5 + 3 + 4 + 4 + 4 = 40), which was divided by the maximum possible value (i.e. score of 5 on 5 for the 10 indicator = 50). Thus, $40/50 = 0.8$. This is the normalized score for the conservation value of Conrad beach. This normalization process is crucial in the absence of a weighting system because it permits standardization of the environmental indicators, which allows characteristics to be compared between sites and highlights the components of low value for further scrutiny ([Phillips et al., 2007](#)). The normalized score were then plotted into a conservation/use development matrix, following the original EFA methodology.

2.4. Scenario analysis

After a score-based analysis of how each environmental component affects each sandy beach, a scenario analysis can be used to determine which management decisions can most

effectively alter the conservation/use development potential of beaches and direct them toward a designated goal. This is most relevant to the case of sandy beaches found within the conflict field of the conservation/development matrix.

Management options will vary according to each conflict beach conservation and development indicators scores. These strategies should affect the parameter(s) with the most potential for change. For example, “a ban on mining” on a particular beach site would change its potential for use (Mining indicator) from a “5” to a “1”. Management options should also take into consideration the ICZM plans' goals and objectives, defined by regional authorities and local communities.

In this scenario analysis, management option compared include: a dune restoration program, reduction in digging intensity, and combination of both strategies. Each scenario was applied to the selected conflict beach and indices were altered accordingly to their potential for change. This evaluation of the level of influence a particular management strategy has on any given indicator was done using professional judgment and best coastal management practice.

2.5. Study area

A case study of four sandy beaches found in the Halifax Regional Municipality (HRM) was selected for the application of the modified EFA framework and includes: Rainbow Haven Provincial Park (RHV), Conrad Beach (CRD), Lawrencetown Provincial Park (LTN), and Martinique Beach (MTQ). These all have some protected status as detailed below. Each beach site legal designation, key, physical and socio-economic characteristics are presented in [Table 3](#). Though all beaches are subject to similar oceanic and wind-driven processes coming from the Atlantic Ocean, ([Fig. 1](#)) local socio-ecological characteristics amongst sites are quite variable.

2.5.1. Rainbow Haven Beach (RHV)

RHV (44°38'42"N 63°25'13"W) is a provincial park characterized by sand and cobble sediment with backshore sand dunes. RHV is only 18 km from downtown Halifax, making it one the most popular beaches in the HRM region. To support visitors, RHV provides two parking lots of approximately 450–500 places. While one of these parking lots is situated on the backshore of the beach, they are both found within the beach-associated coastal wetland. RHV has boardwalks, which pass through the sand dunes, giving three access points to the beach. It also provides visitor facilities such as toilets, canteen, change house, and picnic tables. Litter is a constant problem at this beach and regular beach

Table 3

List of demographic, and socio-economic data associated with each community. The legal designation(s), along with the total beach area, also influence the development potential of beach sites.

Beach	Rainbow Haven	Conrad	Lawrencetown	Martinique
Designation	Provincial park	Park reserve, Protected beach	Provincial park, Protected beach	Provincial park
Community	Eastern Passage	Lawrencetown	Lawrencetown	Musquodoboit Harbour
Beach area ^a	7.5	12.25	8.2	22.4
Population density ^b	278.6	83.6	83.6	12.8
Median annual income ^c	32,835	35,020	35,020	28,683
Education attainment ^d	84.2	87.7	87.7	79.3
Unemployment ^e	28	26.7	26.7	42.4

^a Hectare (ha).

^b Individual per kilometer squared (ind/km²).

^c Canadian dollars (\$CAN).

^d Individuals who obtain at least, a high school diploma (grade 12+).

^e Percentage (%).

Source: [Government of Nova Scotia \(2011\)](#).



Fig. 1. Location of beaches selected for the case study on the Eastern Shore of Nova Scotia. (Images from Google Maps). RHV: Rainbow Haven; CRD: Conrad; LTN: Lawrencetown; MTQ: Martinique.

cleanup is necessary. Coastal erosion is also an important issue at this site where old and buried sand fences are reminders of past beach restoration efforts. This lifeguard-supervised beach is also situated near a camping site, cycling routes, and other recreational facilities. Finally, RHV beach is surrounded by human development including residential construction, parking lots, connecting roads, and hard engineering structures, which obstruct the view of the Atlantic Ocean.

2.5.2. Conrad beach (CRD)

CRD ($44^{\circ}38'43''\text{N}$ $63^{\circ}22'37''\text{W}$) possesses a complex and large natural backshore composed of sand dunes, salt marshes, semi-permanent ponds, and an estuary, covering approximately 115 ha of coastal wetland. Also, this region is well known to provide habitat for endangered piping plovers. With only 10 spaces, the parking lot is not meant to receive many visitors at any one time. Furthermore, because it lies within a low marshland, the parking lot is sporadically closed during stormy periods for safety reasons, further limiting access to the beach. Aside from the unique boardwalk that gives access to the beach, there are no other facilities provided at this site.

2.5.3. Lawrencetown Beach (LRT)

LRT ($44^{\circ}38'37''\text{N}$ $63^{\circ}20'18''\text{W}$) is 26 km from Halifax, and is the most popular beach in the area. The sand and cobble beach face is supported by a well-vegetated sand dune system. However, Highway 207, which gives direct access to the beach's parking lots, dissects the dunes from the coastal wetland backshore. These four parking lots, which are all constructed along the coastline, provide beach visitors with a total of approximately 250 places. In addition, each parking lot offers two boardwalks, which cross over the sand dunes and give access to the beach. However, because of heavy storm related damage, only six of them are in usable condition. LRT also provides recreational amenities such as a change house, toilets, canteen, and picnic tables. This beach is most popular for its constant waves and surf, where strong rip tides and currents necessitate lifeguard supervision. In fact, LRT is famous as a board surfing location. A camping site is also found within a few kilometers of this beach.

2.5.4. Martinique Beach (MTQ)

MTQ ($44^{\circ}41'31''\text{N}$ $63^{\circ}07'32''\text{W}$) is situated 55.3 km away from the city of Halifax. The first beach section is not all crown land. In fact, half of the west portion of this small beach is privately owned, and flanked by residential development and a seawall. On the 0.15 km long crown-owned section, there is a boardwalk; three access paths, and a small parking (10 spaces). The largest portion of the beach is found 300 m further down the beach access road, which continues for nearly 1 km along the backshore, at the landward edge of the dune system. This small road gives access to eight different boardwalks, and seven parking lots for which hold a maximum 10 places each. The long beach road and widespread parking lots not only erode the back dunes, but also disconnect the beach from its sandy backshore, made up of a highly productive coastal wetland and scattered islands.

Musquodoboit Harbour Outer Estuary is an important for wetland conservation area, and protected under the *RAMSAR Convention on Wetlands*. This 1925 ha of wetlands include a complex landscape of intertidal mudflats, salt marshes, bogs and ponds, which are protected by the barrier beach against waves (NSDNR, 2011a). Given its strong tidal currents, the harbour remains ice-free allowing eelgrass (*Zostera*) and marsh fauna to proliferate, providing an oasis for staging and wintering bird species (Ramsar Convention on Wetlands, 2000). The endangered piping plover is also known to nests between two breached dunes on the far east of MTQ.

Another site of conservation interest found near Martinique beach includes Bayers Island, which was acquired by the Nature Conservancy of Canada (NCC) in 2009 for its abundant mudflats and eelgrass beds (NCC, 2009).

3. Results

3.1. Indicator scores and beach comparison

The tabular results consist of two broad categories (Ecological and Socio-economic value; Table 4). Under each of these two headings are 7 aggregate indices consisting of mostly paired variables. The *Human Dimension* category is somewhat different since one of the subvariables (*Potential for use*) consists of aggregating 9 use variables.

Table 4

Value allocation and normalized score for sandy beaches investigated. RHV: Rainbow Haven; CRD: Conrad beach; LRT: Lawrencetown; MTQ: Martinique.

Environmental components	Characteristics	Indicators	Evaluation of Characteristics			
			RHV	CRD	LRT	MTQ
Coastal water	Water quality	Shellfish harvesting closures & River outputs	2	3	3	3
		Esthetics condition	2	4	2	3
		Normalized score	0.4	0.7	0.5	0.6
Landscape ecology	Ecosystems connectivity	Associated coastal ecosystems	2	5	2	4
		Ecosystems of conservation interest	2	5	2	5
		Normalized score	0.4	1	0.4	0.9
Coastal biota	Species diversity and abundance	Beach type	3	3	3	4
		Species of conservation interest	3	5	3	5
		Normalized score	0.6	0.8	0.6	0.9
Hazards	Coastal erosion/damage	Dune erosion/boardwalk damage	3	3	1	2
		Coastal sensitivity to sea level rise/flood/storm and migration potential	2	4	2	4
		Normalized score	0.5	0.7	0.3	0.6
Geological and topographic features	Quality	Sediment composition and size	3	4	2	4
		Normalized score	0.6	0.8	0.4	0.8
Resources	Landscape	Visual quality	1	4	2	5
		Normalized score	0.2	0.8	0.4	1
		Total	23	40	22	39
		Normalized score for conservation values	0.46	0.8	0.44	0.78
Socio-economic components	Characteristics	Indicators	Evaluation of Characteristics			
			RHV	CRD	LRT	MTQ
Human dimension	Potential for use	Mining	n/a	n/a	n/a	n/a
		Fishing, digging	n/a	n/a	n/a	5
		Recreation potential	5	2	4	2
		Parking	5	2	4	4
		Accessibility	5	4	5	2
		Land use	4	3	4	2
		Coastal development	5	3	4	2
		Population density	5	4	4	2
	Wellbeing	Beach area	3	3	3	5
		Socio-economic status	4	4	4	3
		Total	36	25	32	27
		Normalized score for socio-economic potential	0.9	0.625	0.8	0.6

These single variables are the primary source of data for each beach. Various levels of aggregation reduce the dependence of indicators on single variables and allow broader comparisons collated from these sources. As expected, examination of the individual variables shows that the more isolated beaches (CRD and MTQ) have higher values among ecological variables, while RHV and LRT have higher values in the socio-economic variables (Table 4).

Among the individual non-normalized variables, there was only a single value of 1, for LRT susceptibility to erosion/damage, due to the proximity of the boardwalk and parking lot to the dunes. There were however, a number of scores = 5, related to conservation, management, and visual appeal for both CRD and MTQ. Among the aggregate pairs, there was usually agreement between the two variables in raw scores.

The normalized scores for the aggregate indices are more easily compared among beaches graphically (Fig. 2) and certain trends are apparent. For example, it is clear from Fig. 2 that the *Resources* component at RHV (0.2) is substantially lower than all other sites analyzed (0.4–1.0). The low score allocated to the *Visual quality* indicator at RHV (1 out of 5) explains this poor performance. Another ecological component that stands out for its low score is the *Hazards* component in LRT (0.3), explained by high coastal sensitivity to sea level rise, dune erosion, and boardwalk damage.

As suggested by the individual scores, it is also apparent from this histogram that CRD and MTQ have higher normalized scores for all ecological components than RHV and LRT. The difference is especially significant for the components of *Landscape ecology* and *Resources*. In fact, CRD and MTQ scored about 2× higher than RHV and LRT for *Landscape ecology*, and received scores of 0.8 and 1 for

Resources while RHV and LRT received a low normalized score of 0.2 and 0.4 respectively.

On the other hand, the latter sandy beaches show higher normalized scores for the *Human dimension* component than CRD and MTQ. This graph also shows that the normalized score of RHV and LRT for *Human dimension* are often equal or in a very close range of one another. In fact, both beaches scored 0.4 for *Landscape*

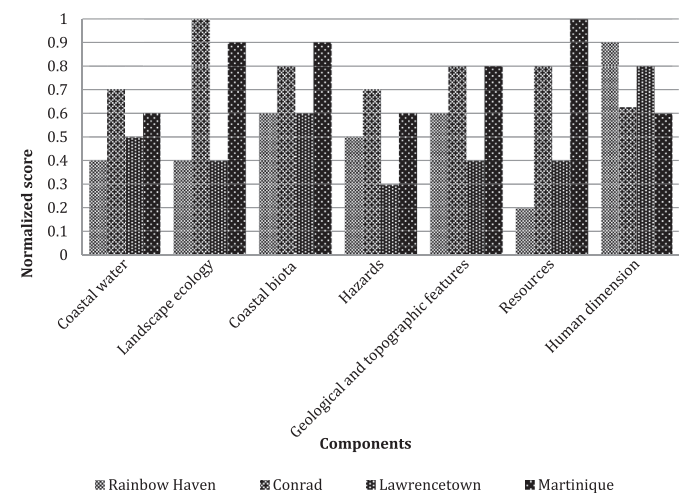


Fig. 2. Normalized score allocation to ecological and socio-economic components. Comparison environmental quality components between the four sandy beaches studied. Lower scores signify poor performance or worse conditions.

ecology, 0.6 for *Coastal biota*, while normalized scores of all other environmental components are no more than 0.2 apart.

In addition to the environmental components, the aggregate normalized score for overall conservation value and use/development potential was plotted for each sandy beach (Fig. 3). This graphical illustration clearly shows which beaches have higher conservation value and lower development potential (require protection), and which ones have lower conservation value and higher development potential (favor development). Specifically, CRD and MTQ have higher conservation value and lower development potential, while RHV and LRT have lower conservation values and higher development potential.

The highest-level grouping is shown as a bivariate comparison for the beaches (Fig. 3). This initial analysis of results suggests that higher protection status be granted to Martinique and Conrad beach. However, the conservation/use development matrix (Fig. 4) illustrates a degree of conflict at both Martinique and Conrad beach. While this suggests a deeper socio-ecological analysis to assist beach management at these sites, the dedication of Rainbow Haven and Lawrencetown to use and development is unambiguous.

We emphasize that the conservation vs. use/development dichotomy is meant to preserve conservation potential rather than advocate further development. For example, a beach with low conservation scores may have more fragmented or compromised landscape with limited further conservation possibility. In this case, the beach is a more suitable candidate for further development such as visitor access compared to a beach with higher conservation potential.

RHV reaches the highest human dimension score of all beaches studied. This is not unexpected due to its proximity to Halifax, accessibility from the highway, large parking lots, and abundant recreational facilities. In addition, high population density, elevated socio-economic status, and abundant coastal development make this particular site prone to use and development, leading this beach site well into the development region of the conservation/use development matrix (Fig. 4). The fractured coastal landscape, poor water quality (Government of Nova Scotia 2009), and close proximity of residential development also contribute to a low conservation potential.

Conrad beach falls in the conflict field of the conservation/use development matrix (Fig. 4). Conrad's higher population density, easy accessibility, and elevated socio-economic status would

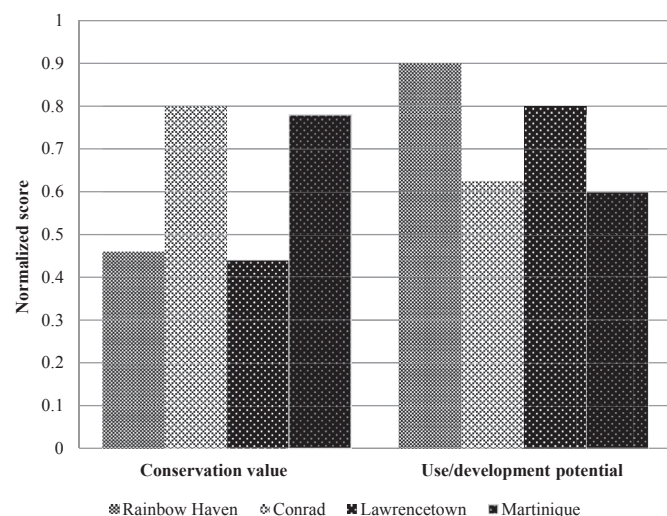


Fig. 3. Beach comparison based on ecological and socio-economic components. Sandy beach evaluation based on conservation value and use/development potential.

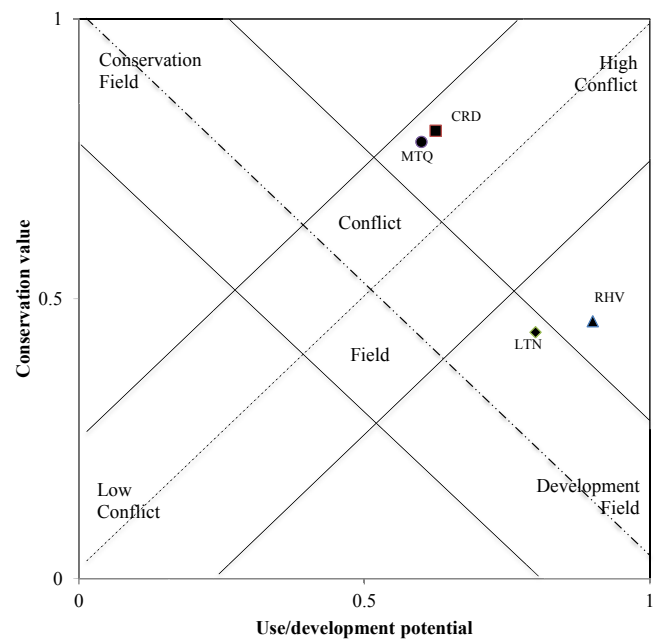


Fig. 4. Position of RHV: Rainbow Haven; CRD: Conrad beach; LRT: Lawrencetown; MTQ: Martinique within the conservation/use development matrix.

suggest substantial potential for recreational use. However, limited parking and the near absence of recreational facilities, holds back full development potential. In addition, high ecological values associated with coastal landscape connectivity, limited coastal development, and presence of the endangered piping plover opposes further use and development.

Lawrencetown beach conservation initiatives associated with its legal protection are overwhelmed by its intense recreational use, intrusive coastal development, high sensitivity to sea level rise, and low migration potential, leading this protected site to fall well into the development field of the matrix (Fig. 4). The popularity of its surf, ready accessibility, and large amount of parking combined with dense local population, with relatively high socio-economic status, explains this high use/development potential. In addition, the urban design associated with its recreational facilities and public roads fragment the sand dune system, which has accelerated the erosion process, negatively affecting its cumulative conservation value. Though Lawrencetown beach is recognized as possible piping plover nesting grounds (NSDNR, 2011b), it is argued that this fragile species will less likely choose such a highly disturbed site. Furthermore, the large amount of cobble sediment found in beach sediments is thought to be unsuitable for these sandy beach-nesting birds.

Martinique Provincial Park falls within the conservation but also the conflict field of the conservation/use development matrix. Martinique's high conservation value is associated with the high quality and abundance of its associated coastal ecosystems (e.g. seagrass meadows, salt marshes, bogs, mud flats, etc.), the presence of piping plovers and other endangered wildlife, the high conservation interest of its adjacent ecosystems (Bayers Islands, Musquodoboit Harbour, and Martinique Game Sanctuary), exceptional visual quality, and high migration potential. However, the advanced state of dune erosion, accentuated by the multiple boardwalks, parking lots, and beach access road, seriously hampers Martinique conservation value. Development potential is relatively high in part due to intense invertebrate digging activities and large beach area, which suggests a greater carrying capacity for beach users. However, its use and development potential is also impeded by low

population density, long distance to the nearest highway (12.2 km), limited coastal development, and lower diversity of land-uses. Overall the difference between conservation value and use/development potential is too small to avoid conflict.

3.2. Scenario analysis

A scenario analysis is most relevant here for Conrad and Martinique beach found within the conflict field). Because Rainbow Haven and Lawrencetown Beach both lie within the development field, there is a less pressing need for further analysis of these sites.

Since Conrad and Martinique Beach are found closest to the conservation field, it is suggested that either an increase in their conservation value or reduction in their use/development potential would most effectively remove the beaches from the conflict field. However, in the case of Conrad Beach, this seems to be impractical. First, with the exception of water quality, which scored 3, all its ecological components scored high (4 or 5), and changing any of them would not push Conrad out of the conflict field. Second, socio-economic factors that are most important in use/development potential are all related to environmental components that are not easily changed, nor that are socially desirable to change (i.e. socio-economic status, population density, accessibility to highway). Even if the parking were removed, this would only bring down the use/development potential of Conrad by 0.025, which is insubstantial. In these circumstances, it is suggested that Conrad Beach is in a state of sustainable use, and that management initiatives to move it to the conservation field would be ineffective. Nonetheless, since the score of environmental indicators may change over time, this stable state could also change.

Since this pattern is not observed at Martinique beach, scenario analysis would provide further insights into management alternatives. For example, management action that could improve the conservation value of Martinique would be to invest in a dune restoration program that would include vegetation planting, removal of the beach access road and of the majority boardwalks that fracture the dune system. Properly restored dunes would increase coastal connectivity, reduce coastal sensitivity to sea level rise, reduce dune erosion, and potentially increase species abundance and diversity. These changes could improve the total ecological score for Martinique beach to approximately 43/50 pushing out of the conflict zone and into the conservation field (see Fig. 5). Though this option might be time consuming and costly, it does not limit human use, except to reduce vehicle access.

Another option that should be considered would be to decrease use and development potential by significantly reducing clam and bait digging intensity (from a 5/5 to a 1/5). This would also relieve Martinique from the conflict field, and move it into the conservation field. However, there may be serious socio-economic impacts on the local community that depend on this resource for their livelihood. Neither of these options alone would create conditions where Martinique would move far into the conservation field.

4. Discussion

4.1. Comparative analysis

These results are consistent with previous EFA's on sandy beach systems. In fact, as Phillips et al. (2007) emphasized, beaches near large cities or towns, which have already been extensively developed for their recreational use, are in the use/development quadrant of the matrix. As a result, these sites would benefit from enhanced recreational facilities and services, while other better ecologically suited beaches would benefit from conservation efforts.

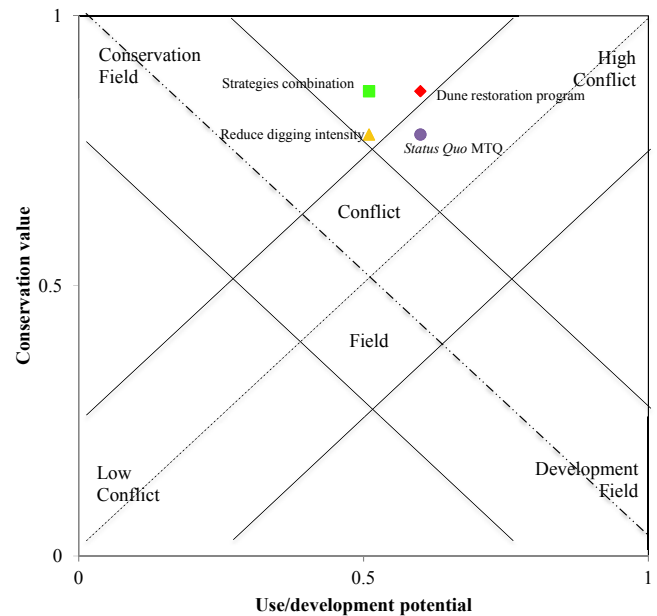


Fig. 5. Scenario analysis for MTQ: Martinique Beach using the conservation/use development matrix.

In this case study, it is suggested that both Rainbow Haven and Lawrencetown Beach Provincial Parks would benefit from further beach development and facilities restoration/embellishment. This is not to say that beach use and development may be done without regards to the natural sphere of the beach system. In fact, as pointed out by van der Weide et al. (1999), beaches that are managed for development should go through environmental impact assessment procedures to ensure that impacts are within “acceptable limits”. It is also argued that only sustainable development proceed including low impact infrastructure and activities such as changing rooms, surfboard rental, canteen, toilets, outdoor showers, etc.

For beaches in the conflict field of the matrix, Phillips et al. (2007) and Micallef and Williams (2003) concluded that these sites occur where high recreational and tourism facilities are available, and where wildlife is thriving. In the case of Conrad Beach, recreational facilities on the beach site are absent (no toilets or canteen), but its proximity to other tourist conveniences near Lawrencetown could potentially increase visitor flow. However, it is suggested that the high demand for beach access associated with a large local population, high accessibility, and elevated socio-economic status, is actually more significant in driving Conrad's use/development potential. Similarly for Martinique Beach, one of the main factors affecting the use/development score is not its recreational potential. Though some recreational facilities are present, it is actually the large beach area and the intense digging activity present in the lagoon behind the beach site that most contribute to the use/development potential score. However, in both cases the high ecological score is readily associated with rich biodiversity and presence of endangered species.

Due to the diversity of local characteristics affecting sandy beaches in Nova Scotia, it is difficult to assign a general pattern that would explain why beaches appear in the conflict field of the conservation/use development matrix. In fact, van der Weide et al. (1999) suggested that a deeper analysis of the socio-ecological conflict be done prior to adopting any type of management actions that would push the site either toward the conservation or development side. The *status quo* can either lead to balance

between the two realms (sustainable beach use), or to ecological degradation of the system (Phillips et al., 2007).

4.2. Users' perceptions considerations

Stakeholder participation is an essential element of any successful integrated coastal zone management initiative. This is especially true for local communities who have a strong socio-economic and cultural bond to their shoreline. In Canada, the public participation is limited to consultations on the participatory ladder.

In cases where there is a strong top-down approach persists and resources are insufficient, coastal planning tools must be adapted. Here, we argue that marine managers should still have access to planning tools to at the least initiate a discussion on possible conservation or development sites. EFA is not meant to provide all the answers, but perhaps to address imminent challenges and propose possible solutions to common issues. EFA methodology should be used as a “conversation starter” and active a continuous dialogue with local communities.

The authors also recognize that EFA should include an indicator that would underline social-cultural perspectives. However, beach surveys and other interviews required in these evaluations necessitate much time and resources. The EFA methodology is meant to be rapid, cost effective, and applied without any particular expertise. Therefore, the social science know-how, ethical reviews, and data analysis related to such process would make it impractical for low capacity beach management programs or organizations.

4.3. Sources of errors and uncertainties in EFA

There are various methodological and fundamental limitations associated with the use of EFA to evaluate conservation values and use/development potential sandy beaches. First, the number of indicators used (20) is considerably lower than what other authors have employed (78 by Cendrero and Fischer (1997); 55 by van der Weide et al. (1999); 43 by Micallef and Williams (2003); 53 by Phillips et al. (2007)), leading to coarser results. Though many indicators proposed by the original work of Cendrero and Fischer (1997) were considered irrelevant for Nova Scotia (e.g. volcanic eruptions, tsunami frequency, earthquake magnitudes), others might provide further insight (e.g. local water pollution content, turbidity, terrestrial and marine biomass, erosion rates). However, the absence of hard biological and environmental data made their inclusion impossible and proxy indicators were used instead, increasing uncertainty associated with environmental quality evaluations.

The absence of baseline data for ecological components also creates an inequality between socio-economic and ecological indicators. All socio-economic indicators were supported by updated NSDNR GIS data (derived from the Nova Scotia Topographic Database [NSTDB]), Nova Scotia Community Counts statistics (derived from 2006 census maps), or direct measurements using Google Earth. In contrast, most ecological indicators were compiled using available management reports, field observations, and expert opinions, except for *Coastal sensitivity to sea level rise* data, obtained from the NRC Atlas of Canada, and *Species of conservation interest*, obtained from NSDNR GIS species at risk layer. Thus, these important biological and environmental information gaps, and the difference in the quality of data assessed between ecological and socio-economic components, are potential sources of uncertainty.

Though methodological limitations related to environmental data deficiencies can be improved with field research and coastal resource inventories, the fundamental constraint on interpretation of indicators is less easily resolved. For example, Cendrero and

Fischer (1997), van der Weide et al. (1999) and Micallef and Williams (2003) have all categorized renewable and non-renewable resources such as sand, as ecological components, partly because these resources are protected and extraction is restricted. Thus, their integrity would increase a site's conservation value. On the other hand, Phillips et al. (2007) argued that if these natural resources were made available through development policies, their presence would increase the use/development potential for a region (e.g. sand mining, oil extraction). In the case of Nova Scotia, sand extraction does occur and though restricted under the *Beaches Act*, the Minister can use discretionary power and allow mining activity. Thus, the mere presence and abundance of sand does not guarantee conservation. On the other hand, the Government of Nova Scotia has recognized sandy beaches and dunes as rare ecosystems that require conservation. In these circumstances, non-renewable resources (sand and other beach sediments) are represented in EFA as both as a socio-economic component (under sand mining) and as a non-extractive conservation values (under geological and topographic features).

Unemployment rate is yet another indicator that may be open to interpretation. Phillips et al. (2007) have argued that high unemployment rates support use and development potential because they offer available labor markets to new businesses and socio-economic benefits to the hosting region. In contrast, it is argued that our high economic status indicator (includes low unemployment) supports use and development potential, due to more participation in recreational activities, tourism, and purchased services.

4.4. Practical application

This scenario analysis, along with key management recommendations (e.g. integrated beach management plan and proactive conservation strategy, improved beach park management practices, etc.), was presented to the NSDNR Parks Division in August 2011. In March 2012, the NSDNR implemented a sustainable park planning and management action plan for Martinique Beach Provincial Park.

The Martinique Beach Provincial Park Concept Plan Draft proposes a use-based zoning strategy, delineating spaces for specific activities, to ensure sustainable recreational use and environmental protection as defined by the *Provincial Parks Act*. These zones include (1) an Environmental Protection Zone, where strict conservation measures will apply, but interpretative and scientific activities will be permitted (representing 70% of the park), (2) a Resource Conservation Zone, where protection will be granted to highly sensitive ecosystem components while allowing low impact recreational activities (representing 20% of the park), and (3) a Recreational Development Zone, where dense recreational use and infrastructure development will be authorized (representing 10% of the park) (NSDNR, 2012).

In addition, the draft management plan suggests a “Park Re-development Concept” that shadows the dune restoration program option proposed by the EFA scenario analysis herein. In other words, the beach access road, majority of the six parking lots, and associated boardwalks will be removed while the dune system will be restored with endemic vegetation (NSDNR, 2012). The main park entry road will be redirected to the first pocket beach, where a seawall is present. This will restrict negative impacts of coastal development to an area that is already affected, and limit its spread to more sensitive areas. This road will then lead to a new and larger parking lot, and connect to a recreational hub with visitor facilities (public changerooms and washrooms), a park office, and interpretive booths, which will then join to the unique beach access point (NSDNR, 2012). In this example, EFA has been used to demonstrate its usefulness in providing both practical solutions to

beach planning, and successful recommendations for integrated sandy beach management in Martinique Beach Provincial Park. Monitoring and evaluation of results from this plan will provide essential insights on the value of scenario analysis using the EFA method.

5. Conclusions

The absence of a systematic approach to the designation of sandy beach protection under the *Beaches Act*, can lead to ineffective beach conservation strategy. The protection status of Lawrencetown Provincial Park is a prime example of a low conservation valued beach attributed a protected designation. Though the efficiency of the *Beaches Act* has been criticized (Beaton, 2008; Jacques Whitford Environment Limited, 2003; Piper and Bowen, 1976), it is the only provincial legislation to conserve oceanic sandy beaches. However, for sandy beach conservation planning to be comprehensive, it must take an integrative landscape approach to coastal conservation, which includes adjacent wetlands, islands, lagoons, etc.

The EFA proposed in this research is an improvement over previous versions. First, reducing the number of environmental quality indicators and components has made the use of EFA more practical and effective for coastal planners. Second, in the absence of more data, combining environmental indicators decreases their reliance on single measures. Introducing new environmental characteristics such as Management and Landscape connectivity embodies the integrative nature of sandy beaches, both at the social and ecological level. Finally, the indicators proposed can be monitored at low-cost, are relevant for other coastal management policy, and are easy for decision-makers and the general public to interpret, all of which are essential characteristics of environmental status (Frederiksen et al., 2007).

Since this research project was presented in the 10th International Coastal Zone Canada Conference 2012 in Rimouski, Quebec, other research, based on similar principals have been published (McLachlan et al., 2013). The use of conservation and socio-economic indices to inform beach management and planning processes has been proven to be successful in Nova Scotia (Amyot, 2011), South Africa, Australia, Uruguay and Chile (McLachlan et al., 2013).

The sandy beach environment is a complex socio-ecological system that is threatened by various key human activities and natural processes. This is in part because beaches are narrow ribbons of habitat, easily accessible by the public, and with high recreational appeal. Though the input provided by EFA framework (and other similar methods) is only part of the solution needed to address the various problems faced by the coastal environment, it can be a substantial contributor to ICZM by providing the basis for discussions of conservation, use/development, and conflict.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at doi: 10.1016/j.ocecoaman.2014.10.009.

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