The Biodiversity Portfolio Approach to Coastal Valuation in ICZM: A case study from Baile Sear, North Uist, Scotland

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Executive Summary

A novel technique, termed the 'Biodiversity Portfolio Approach' is used here for an assessment of the services provided by the coastal environment of Baile Sear, North Uist, as well as an assessment of the risks faced by this environment. The selected area was split into a number of biomes, and a list of services provided and potential threats were developed after stakeholder consultation in July 2006.

The returns for each service were identified on the basis of the stakeholder discussions, placing values on the coastal biomes using Costanza's approach (Costanza *et al* 1997). The risks were identified on the basis of the stakeholder discussions, placing values using the experiential knowledge of the stakeholders as well as that of the above named workshop managers. The key dynamics of the portfolio are then based on the type of interaction between biome components.

The first aim of this exercise was to assemble a biodiversity portfolio of biomes for the Baile Sear, North Uist, Coast and develop risk return values and a risk-return profile based upon this portfolio. By doing this it is intended to provide the Baile Sear stakeholders and ICZM managers with new insight into management strategies.

The second aim of this paper is to evaluate the sensitivity vs. robustness of the technique. It was found that the technique had a very high sensitivity to area of biomes. This high sensitivity in combination with a potentially high level of error (due to a lack of mapped data for certain biomes) greatly reduced the robustness of the technique. The approach was only moderately sensitive to selection of values with the matrix, however, and had a low sensitivity to selection of the service and

threat criteria. In both these regards the technique can be regarded as being quite robust.

The approach proved useful at comparing services with a very high 'existence' value, such as conservation, with services with a more standard economic measure, such as agriculture. By doing this the biodiversity portfolio technique proves a useful tool for further stakeholder discussion, as well as being potentially useful as a tool for environmental education and understanding and for participatory planning.

The technique also proved useful at establishing that the Baile Sear biodiversity portfolio is highly sensitive to threats, and is therefore an area requiring higher than average levels of environmental protection. Finally, the biodiversity portfolio method is shown to be a useful one for simulating the effect of management decisions.

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[1] This report should be referenced as follows: Carlisle M.A. & Muir D. (2007) *The Biodiversity Portfolio Approach to Coastal Valuation in ICZM: A case study from Baile Sear, North Uist, Scotland*. Corepoint project, University of Aberdeen, Scotland.

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Figures & Tables

1. Introduction

ICZM (Integrated Coastal Zone management) is defined by DEFRA (UK Department of Environment, Food and Rural Affairs) as follows:

"The objective of ICZM is to establish sustainable levels of economic and social activity in our coastal areas while protecting the coastal environment. It brings together all those involved in the development, management and use of the coast within a framework that facilitates the integration of their interests and responsibilities. Successful integrated coastal zone management may involve adopting the following principles:

- A long term view
- A broad holistic approach
- Adaptive management
- Working with natural processes
- Support and involvement of all relevant administrative bodies
- Use of a combination of instruments
- Participatory planning
- Reflecting local characteristics"

The coastline of the Outer Hebrides is over 2,000km in length and forms the predominant landscape feature of the islands. The coastal land, sea lochs and inshore waters of the Western Isles are rich in natural resources, wildlife, cultural and archaeological heritage. Most of the population of the islands live on the coast or nearby and many derive an income from it and the surrounding inshore waters.

Comhairle nan Eilean Siar, the local authority for the region, is committed to ICZM and has led the establishment of a local coastal partnership, the Outer Hebrides Coastal Marine Partnership (known as 'CoastHebrides'). This will enable stakeholders with an interest in economic development, tourism and recreation, the environment, archaeology, erosion and flooding, such as businesses, community organisations and individuals, and statutory agencies, to share information, plan, and help to implement ways of managing the valuable assets on the coast and inshore waters of the Outer Hebrides.

As a local authority Comhairle nan Eilean Siar has a significant role to play in implementing actions and policies that will influence the long-term sustainability and quality of life within the islands. The Comhairle endeavours to ensure its policy decisions and services compliment sustainable development within its area.

The Comhairle therefore has a responsibility to make management decisions, via the planning process, that takes into account ecological and social factors as well as economic factors. In other words, the Comhairle must encourage sustainability in local economic development. This has been widely accepted as being a prime function of any Local Authority's planning service for many years. However there is still much debate as how to combine analytical techniques and planning instruments in order to optimise the achievement of above eight ICZM principles.

In particular, there is still some difficulty in achieving an approach that is both broadly holistic and yet usefully quantitative. According to Turner *et al* 2003, "There is a predominance of single function valuation studies. Studies valuing multiple functions and uses, and studies which seek to capture the 'before and after' states as environmental changes take place, are rare. By and large it is the latter types of analyses that are most important as aids to more rational decision taking in ecosystem conservation versus development situations involving different stakeholders (local, national and global)."

Pearce *et al* (1989) describe the paradigm of use and non-use values in environmental economic theory. Direct use values, such as food and mineral prices, are easily quantified in monetary values. Indirect use values, such as the attractiveness of a landscape resulting in tourism related income, are only slightly more difficult to quantify in monetary values. Non-use values such as existence, option and bequest values have proved considerably more difficult to value, and are still the subject of much academic interest 17 years on.

Many different valuation methods have been used to value environmental services. However each method can produce different results for the same area depending on methodology, lack of data and lack of rigour in the quantification process. The economic values thus derived are therefore easily challenged and so are of questionable use as a tool to support the planning process (Corepoint 2005).

The valuation method used in this study is the 'biodiversity portfolio method'. As described by Figge (2004) "Portfolio theory, like few other economic theories, has dramatically transformed the practical work of banks and insurance companies. Before portfolio theory was developed about 50 years ago, asset managers were confronted with a situation similar to the situation the research on biodiversity faces today".

The theory behind the biodiversity portfolio approach takes the view that the a selected area can be split into a number of biomes. Each of these biomes provide ecosystem services or return, but this return is usually subject to risk. Risk for coastal biomes can be identified using a collection of known threats to the biomes in question and return can be identified by placing values on the coastal biomes using Costanza's approach (Costanza *et al* 1997). The key dynamics of the portfolio are then based on the type of interaction between biome components.

To date, for coastal zones in North-West Europe, this approach has been tested at a national level (Corepoint 2005). There is one example of the approach being tested at a local level (Robinson 2006). However, in order to assess the usefulness of the technique it is necessary to test it at local level in other areas.

The first aim of this paper, therefore, is to assemble a biodiversity portfolio of biomes for the coast of Baile Sear, North Uist, and develop risk return values and a risk-return profile based upon this portfolio.

The second aim of this paper is to evaluate the technique, using sensitivity analysis to determine the sensitivity of the results to:

a.) Changes in the selection of biomes and their resulting changes in surface area;

b.) Changes in the selection of services and threats, and;

c.) Changes in the selection of values within the biome-service and biome-threat matrices.

The third aim is to provide the Baile Sear stakeholders and ICZM managers with new insight into management strategies.

2. Methods

2.1 Case study area

The location of the study area is shown in ***Figure 1***.

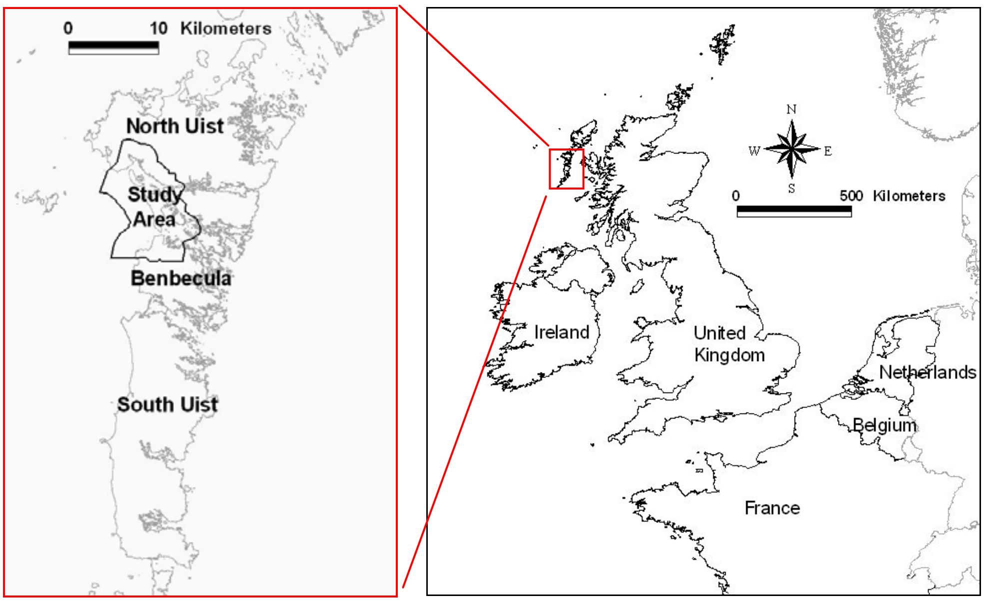

Figure 1. The location of the study area (Baile Sear, North Uist).

Baile Sear is one of the low-lying islands on the western coastline. The physical inter-relationship between land and sea is both complex and dynamic in this area, with rapid erosion in some areas being counter-balanced by dune build-up and migration in others. There are also extensive inter-tidal areas. The geographical boundaries were chosen with these factors in mind, and were set as being the northern and southern limits of the major sediment cell, 3km out to sea and 2km inland (or the watershed, if that were closer). As well as Baile Sear island, also included in the study area are northern Benbecula (most importantly Benbecula airport and the town of Baile Mhanaich), the North Ford inlet sands, Kirkibost island, and southern Paibeil. ***Figures 2*** and ***3*** show the study area.

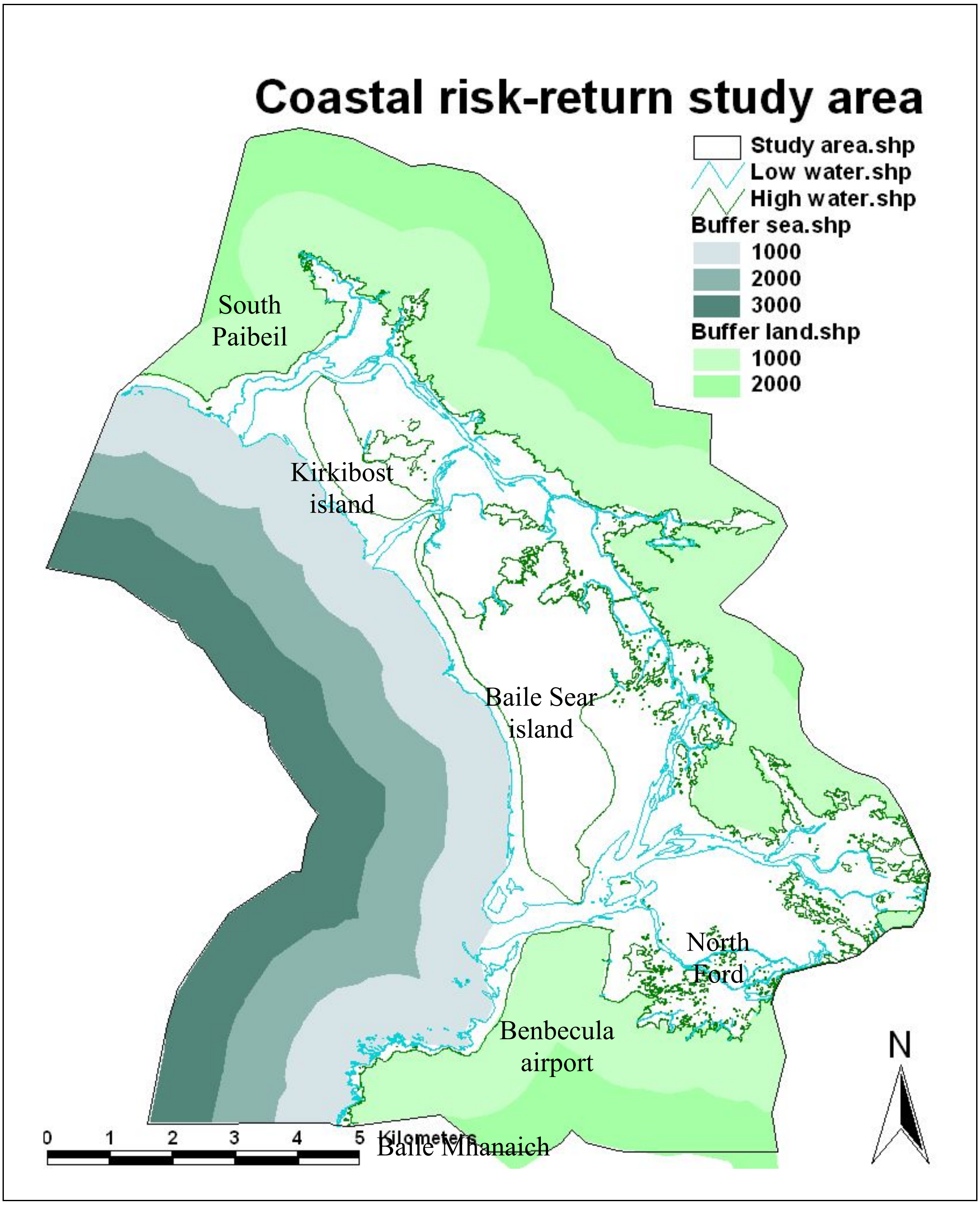

Figure 2: Baile Sear study area: Boundaries

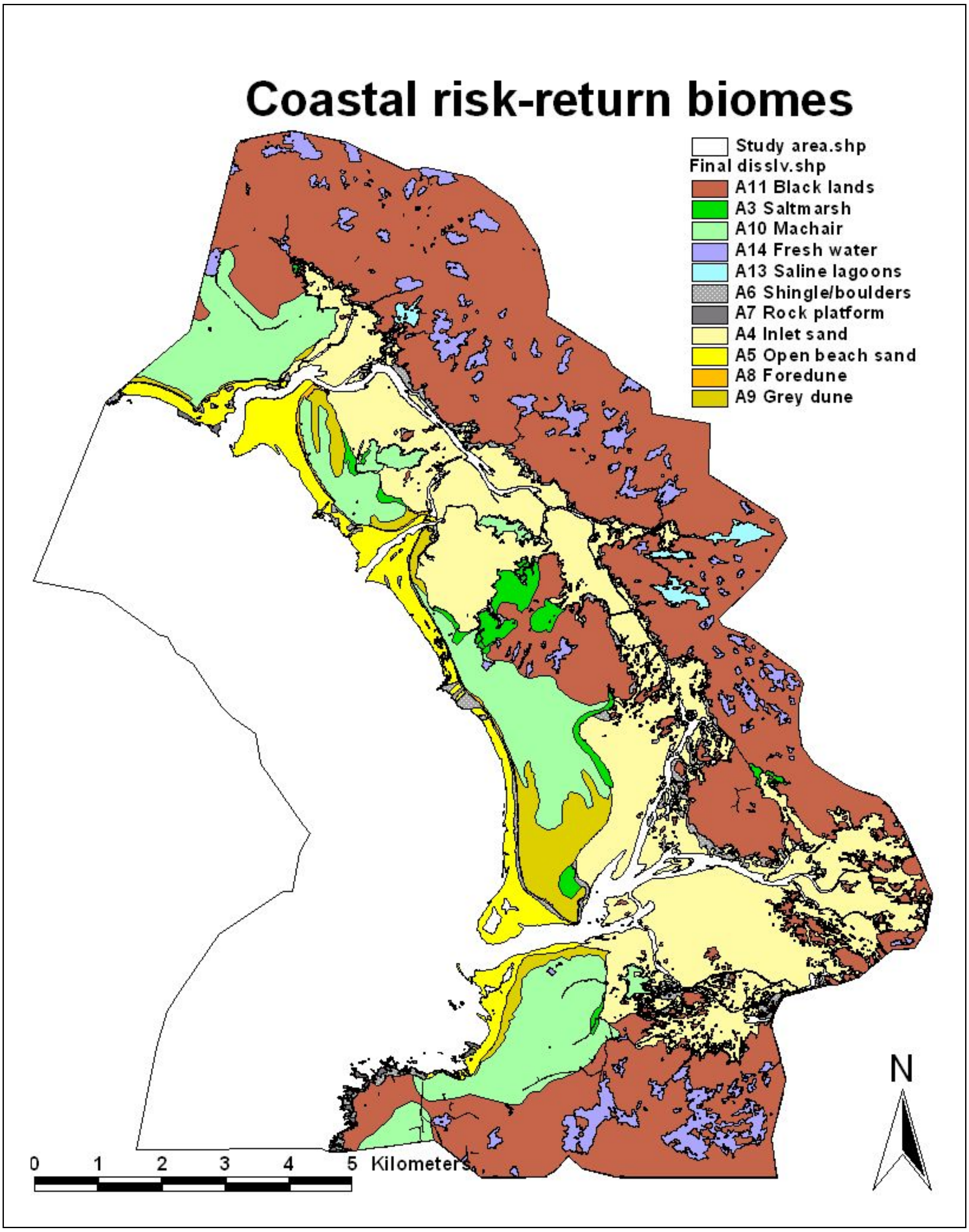

Figure 3. Baile Sear Study Area: Biomes

2.2 Stakeholder discussion

In July 2006, semi-structured workshops were carried out with members of key stakeholder groups for the Baile Sear Study Area. These stakeholder groups were: local residents, mostly crofters (agriculture); national government bodies including SEERAD (agriculture) and Scottish Natural Heritage (conservation); and local industry (quarrying and the local game estate). Through stakeholder discussion the following sets were agreed upon:

(i) A set of biomes which reflect the local resource use and exploitation patterns of the area. These biomes are illustrated in ***Figure 3****;*

Most of the ecosystem categories shown in ***Figure 3*** are self-explanatory. However two are very specific to the local area. These are:
a.) The machair, which is defined as a type of dune pasture, with a high shell content (sometimes 90%), that is subject to local cultivation, and which has developed in wet and windy conditions. It is one of the rarest habitats in Europe, found only in the north and west of Britain and Ireland. Almost half of the Scottish machair occurs in the Outer Hebrides, with the best and most extensive in the Uists, Barra, and Tiree.
b.) The 'black lands', so called because of the dark peaty soils. This biome is of low fertility and is not used for cultivation (unlike the machair), but is extensively used for sheep grazing. It is also an internationally rare habitat of conservation importance.

Costanza *et al* (1997) use 16 biome categories, as shown below:

6. open ocean;
7. coastal estuaries;
8. coastal seagrass/algae;
9. coastal coral reef;
10. coastal shelf;

11. tropical forest;
12. temperate/boreal forest;
13. grass/rangelands;
14. tidal marsh/mangrove wetlands;
15. swamp/floodplain wetlands;
16. lakes/rivers;
17. desert;
18. tundra;
19. ice/rock;
20. cropland;
21. urban.

It was not possible to use exactly the same biomes as Costanza and still have a set of biomes that encompassed the local ecosystem in a meaningful way. For example, there is no Costanza biome that is exactly equivalent to the complex of shell sand based habitats (sand inlet, sand open beach, foredunes, vegetated or 'grey' dunes and the machair), a complex that is almost unique to this area. The very rarity of the coastal shell sand habitats is the reason why they do not appear on a list of global biomes such as Costanza's – and this rarity means that they must appear on the list of biomes for use in this study.

Another issue relates to lack of data. It would certainly be useful to have the locations of the seaweed (algae) beds for the shallow waters part of the study area, but unfortunately this data was not publicly available.

Three major data sources were used in developing ***Figure 3***. The first of these is the Comhairle nan Eilean Siar, who provided the shapefiles for mean high water springs and mean low water springs (allowing definition of the inter-tidal areas), as well as shapefiles for the many fresh water lochans in the study area. The second data source is the MAGIC (Multi-Agency Geographic Information for the Countryside) online public database, which provided useful data on the location and extent of many of the biomes, specifically the inter-tidal biomes of saltmarsh, sand inlet, sand open beach, shingle beach, rock platform and saline lagoons. The foredunes, grey dunes and machair are shown as one category in MAGIC, so the work of W. Ritchie (1971) was used to map the boundaries between these three categories. The black lands and fresh lochs comprise the rest of the terrestrial biomes, and were easily identified from the shapefiles provided by the Comhairle nan Eilean Siar.

(ii) A set of ecosystem services which reflect the local use and dependency upon them.

Costanza *et al* (1997) recommend the use of seventeen ecosystem services. Seven of the Baile Sear services are the same or very closely equivalent: Food production (agriculture), Raw materials (Sand/gravel/rock/peat extraction), Refugia (Conservation interest), Waste treatment (Nutrient/waste absorption), Recreation (Recreation & tourism), Cultural (Cultural/educational) and Disturbance regulation (Flood protection/coastal defence). This leaves ten Costanza ecosystem services not used in this study; gas regulation, climate regulation, water regulation, water supply, soil formation, nutrient cycling, pollination, biological control and genetic resources. There are five extra services used in this study. Three of these represent local Baile Sear interests that the stakeholders considered important enough to be kept separate; Fishing, Angling/shooting and Intertidal gathering. These could have been incorporated into the existing services; Angling/shooting in Recreation, Fishing and Intertidal gathering in with Agriculture in Food production. The last two Baile Sear services - Renewable energy generation and Landtake - are economically very important, but do not have a direct correspondent in Costanza's list.

The ecosystem services were subsequently rated on a scale of 0 to 3 (0 = no or negligible ecosystem service provided; 3 = extensive to complete service provided). The results are shown in ***Tables 1a*** and ***1b***;

*(iii) a set of threats/risks to these biomes/services. The impact of each threat upon each biome was subsequently determined by rating each threat on a scale of 0 to 3 (0 = threat factor has no impact; 3 = threat could destroy biome function). The results are shown in **Tables 2a** and **2b**.*

The proportions of cell values 0, 1, 2 and 3 were calculated for Tables 1 and 2, in order to ascertain any pattern in the distribution. The results are shown in ***Table 3***.

2.3 Risk-return values

The risk to the provision of ecosystem services is dependant upon the area of the biome present and the return value. The risk-return profile of the Baile Sear Study Area was thus determined by calculating the risks to the biomes and the returns of each biome weighted by area using the following equations:

Biome A return = ∑ Biome A return x biome A area

Biome A risk = ∑ Biome A risk x biome A area

The results are ordinal values and are therefore have no units. The values are shown in the penultimate rows and columns of ***Tables 1b*** and ***2b***.

The total service and total risk values are such large numbers that there is a potential for stakeholders to misinterpret them as parametric values. The final columns and rows of ***Tables 1b*** and ***2b*** are therefore the total values (for biome, service and biome, risk) from the penultimate rows and columns normalised to a percentage scale.

2.4 Risk-return profile

The risk-return values are of interest in terms of their proportional contribution to the total (i.e. 100%) service provision and to the total (i.e. 100%) risk. The risk-return profile (normalised) graph was then obtained by plotting normalised return (x) against normalised risk (y). Using the normalised results protects against misinterpretation of the results as parametric values.

The risk-return profile (normalised) is shown in ***Figure 4***. Minor adjustments were made to (i), the set of biomes which reflect the local resource use. The risk-return profile was then re-calculated. This was in order to ascertain the sensitivity of the Biodiversity Portfolio Approach to initial assumptions. The adjusted risk-return profile (normalised) is also shown in ***Figure 4***.

2.5 Trading off risks to maintain returns

To determine viable management options for the biomes to reduce risk yet maximise return, it is essential to know the interaction between each of the biomes. The risk return profile of a portfolio of biomes which respond differently to threats is lower compared to a portfolio with biomes that respond in the same way. Pairwise Correlation (Pearson's *r*) of the risk factors for each biome was used to determine the interaction between the biomes:

Where correlation between any pair of biomes is not significant, then the threat factors of the biomes are not related: These pairs can be termed INDEPENDENT pairs. Where the correlation between any pair of biomes is significant and positive, then the threat factors impact upon the biomes in a relatively similar way to the biomes, thus their response to threats is similar. These are termed ASSOCIATED pairs. Sets of associated biome pairs join to form SECTORS. Where the correlation between any pair of biomes is significant and negative, then the threats which can greatly impact upon ecosystem services in one biome tend to have little impact upon the other biome. There is no positive effect except that one biome is resilient to the threats which impact the other. These are termed PAIRWISE RESILIENT pairs. The results are shown in ***Table 4*** and the relationships between the different biomes are illustrated in ***Figure5***.

Portfolio impact sensitivity was then calculated by the sum of pairings with scoring of:
ASSOCIATED pairs = +1; RESILIENT pairs = -1; INDEPENDENT pairs = 0
This result is shown in ***Figure 5***.

Pairwise Correlation (Pearson's *r*) of the risk factors for each biome was also used to determine the interaction between the threats:

In a similar process to that described above for the biomes, the threats can then be assessed as INDEPENDENT pairs, ASSOCIATED pairs, sets of associated threat pairs joining to form SECTORS and RESILIENT pairs. The results are shown in ***Table 5*** and in ***Figure 6***.

2.6 Simulating management decisions in the Biodiversity Portfolio Approach

Finally, adjustments were made to the risk values in order to simulate the effects of management decisions resulting in resource input to minimise two different risk areas. The two sets of adjusted, but not normalised, risk-return values are shown in

Table 5. Also shown in Table 5, for comparison, are the original, non-normalised risk-return values from Tables 1 & 2.

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3. Results

(Pages 14 to 21)

Table 1a. Estimated ecosystem service values for the biomes present on the Baile Sear Coast. Rating is on an ordinal scale from 0 = negligible ecosystem service provided to 3 = extensive to complete ecosystem service provided.

	BIOMES											
SERVICE	Shallow water	Salt marsh	Sand inlet	Sand open beach	Shingle	Rock platform	Fore dunes	Grey Dunes	Machair	Black lands	Saline lagoons	Fresh lochs
Agriculture	0	1	1	1	0	0	0	2	3	3	0	2
Fishing	3	0	0	0	0	0	0	0	0	0	0	0
Intertidal gathering	0	0	1	1	0	3	0	0	0	0	0	0
Sand/gravel/rock/peat extraction	0	0	0	0	0	0	0	0	0	3	0	0
Conservation interest	1	2	1	1	2	0	3	3	3	3	3	1
Recreation & tourism	1	0	3	3	0	0	3	3	3	3	3	3
Cultural/educational	1	1	1	1	0	0	3	3	3	3	2	2
Flood protection/coastal defence	1	0	0	2	2	0	3	3	0	0	0	0
Nutrient/waste absorption	0	0	0	0	0	0	0	0	3	3	1	1
Re. energy generation	3	0	3	0	0	0	0	0	1	3	0	0
Angling & shooting	1	0	0	0	0	0	0	0	3	3	3	3
Landtake (airport/range/causeways)	1	0	1	0	0	0	3	3	3	0	0	0
Total Service	*12*	*4*	*11*	*9*	*4*	*3*	*15*	*17*	*22*	*24*	*12*	*12*
Area of each biome (sq km)	49.5	1.4	21.9	4.3	3.4	0.3	0.3	2.8	11.7	39.8	0.6	4.5

Table 1b. Product of area x estimated ecosystem service values for the biomes present on the Baile Sear Coast. Rating is on an ordinal scale obtained by multiplying the 0-3 ordinal scale of Table 1a by the area (NOTE: combining ordinal and parametric values always results in ordinal values).

	BIOMES													
SERVICE	Shallow water	Salt marsh	Sand inlet	Sand open beach	Shingle	Rock platform	Fore dunes	Grey Dunes	Machair	Black lands	Saline lagoons	Fresh lochs	**Total value for each service (Sum of Rows)**	***Norm. value for each service (%)***
Agriculture	0	1.4	21.9	4.3	0	0	0	5.6	35.1	119.4	0	9	**196.7**	***8.9***
Fishing	148.5	0	0	0	0	0	0	0	0	0	0	0	**148.5**	***6.7***
Intertidal gathering	0	0	21.9	4.3	0	0.9	0	0	0	0	0	0	**27.1**	***1.2***
Sand etc. extraction	0	0	0	0	0	0	0	0	0	119.4	0	0	**119.4**	***5.4***
Conservation interest	49.5	2.8	21.9	4.3	6.8	0	0.9	8.4	35.1	119.4	1.8	4.5	**255.4**	***11.5***
Recreation & tourism	49.5	0	65.7	12.9	0	0	0.9	8.4	35.1	119.4	1.8	13.5	**307.2**	***13.8***
Cultural/educational	49.5	1.4	21.9	4.3	0	0	0.9	8.4	35.1	119.4	1.2	9	**251.1**	***11.3***
Flood protection	49.5	0	0	8.6	6.8	0	0.9	8.4	0	0	0	0	**74.2**	***3.3***
Nutrient/waste absorb	0	0	0	0	0	0	0	0	35.1	119.4	0.6	4.5	**159.6**	***7.2***
Re. energy generation	148.5	0	65.7	0	0	0	0	0	11.7	119.4	0	0	**345.3**	***15.6***
Angling & shooting	49.5	0	0	0	0	0	0	0	35.1	119.4	1.8	13.5	**219.3**	***9.9***
Landtake	49.5	0	21.9	0	0	0	0.9	8.4	35.1	0	0	0	**115.8**	***5.2***
Total service value S for each biome (Sum of Columns)	**594.0**	**5.6**	**240.9**	**38.7**	**13.6**	**0.9**	**4.5**	**47.6**	**257.4**	**955.2**	**7.2**	**54.0**	**TOTAL 2220**	***TOTAL 100%***
Normalised value(S/2220) for each biome (% scale)	***26.8***	***0.3***	***10.9***	***1.7***	***0.6***	***0.0***	***0.2***	***2.1***	***11.6***	***43.0***	***0.3***	***2.4***	***TOTAL 100%***	

Table 2a. Estimated risk values to ecosystem biomes from systemic and non-systemic threats. Rating is on a scale from 0 = threat factor has no impact to 3 = threat could destroy the biome function.

	BIOMES											
THREAT	Shallow water	Salt marsh	Sand inlet	Sand open beach	Shingle	Rock platform	Fore dunes	Grey Dunes	Machair	Black lands	Saline lagoons	Fresh lochs
Erosion (inc. climate change storms)	0	0	1	3	2	0	3	3	2	0	0	0
Flooding (inc. sea level rise)	0	3	0	0	0	0	0	2	3	3	1	1
Saline intrusion	0	0	0	0	0	0	0	0	3	3	1	3
Tourism & recreation impact	0	0	0	0	0	0	3	3	1	1	0	0
New causeways & other infrastructure	3	0	3	0	0	0	0	0	0	0	0	0
Agricultural change	0	0	0	0	0	0	1	3	3	3	0	0
Pollution (inc. oil spills)	1	3	3	2	2	1	1	0	1	1	2	1
Invasive species	0	0	0	0	0	0	0	3	3	3	1	0
Marine & terrestrial litter/dumping	0	0	0	1	3	0	3	3	0	0	0	0
Overgathering of shellfish/ overfishing/ disturbance of seabed	0	0	1	1	0	3	0	0	0	0	0	0
Total Risk	*4*	*6*	*8*	*7*	*7*	*4*	*11*	*17*	*16*	*14*	*0*	*5*
Area of each biome (sq km)	49.5	1.4	21.9	4.3	3.4	0.3	0.3	2.8	11.7	39.8	0.6	4.5

Table 2b. Product of area x estimated risk values for the biomes present on the Baile Sear Coast. Rating is on an ordinal scale obtained by multiplying the 0-3 ordinal scale of Table 2a by the area (NOTE: combining ordinal and parametric values always results in ordinal values).

	BIOMES													
THREAT / RISK	Shallow water	Salt marsh	Sand inlet	Sand open beach	Shingle	Rock platform	Fore dunes	Grey Dunes	Machair	Black lands	Saline lagoons	Fresh lochs	**Total value for each risk (Sum of Rows)**	***Norm. value for each risk (%)***
Erosion (inc. climate change storms)	0	0	21.9	12.9	6.8	0	0.9	8.4	23.4	0	0	0	**74.3**	*5.9*
Flooding (inc. sea level rise)	0	4.2	0	0	0	0	0	5.6	35.1	119.4	0.6	4.5	**169.4**	*13.5*
Saline intrusion	0	0	0	0	0	0	0	0	35.1	119.4	0.6	13.5	**168.6**	*13.4*
Tourism & recreation impact	0	0	0	0	0	0	0.9	8.4	11.7	39.8	0	0	**60.8**	*4.8*
New causeways & other infrastructure	148.5	0	65.7	0	0	0	0	0	0	0	0	0	**214.2**	*17.0*
Agricultural change	0	0	0	0	0	0	0.3	8.4	35.1	119.4	0	0	**163.2**	*13.0*
Pollution (inc. oil spills)	49.5	4.2	65.7	8.6	6.8	0.3	0.3	0	11.7	39.8	1.2	4.5	**192.6**	*15.3*
Invasive species	0	0	0	0	0	0	0	8.4	35.1	119.4	0.6	0	**163.5**	*13.0*
Marine & terrestrial litter/dumping	0	0	0	4.3	10.2	0	0.9	8.4	0	0	0	0	**23.8**	*1.9*
Overgathering of shellfish/ overfishing	0	0	21.9	4.3	0	0.9	0	0	0	0	0	0	**27.1**	*2.2*
Total threat value R for each biome (Sum of Columns)	**198.0**	**8.4**	**175.2**	**30.1**	**23.8**	**1.2**	**3.3**	**47.6**	**187.2**	**557.2**	**3.0**	**22.5**	**TOTAL 1258**	***TOTAL 100%***
Normalised value (R/1258) for each biome (% scale)	***15.7***	***0.7***	***13.9***	***2.4***	***1.9***	***0.1***	***0.3***	***3.8***	***14.9***	***44.3***	***0.2***	***1.8***	***TOTAL 100%***	

Table 3: Percentage contribution of values 0-3 in Tables 1a & 2a.

Value	Return count	Risk count	Total count	% of total count	% of counts 1-3
3	36	25	61	23	55
2	8	6	14	5	13
1	21	15	36	14	32
0	79	72	151	58	N/A
Sum	144	118	262	100%	100%

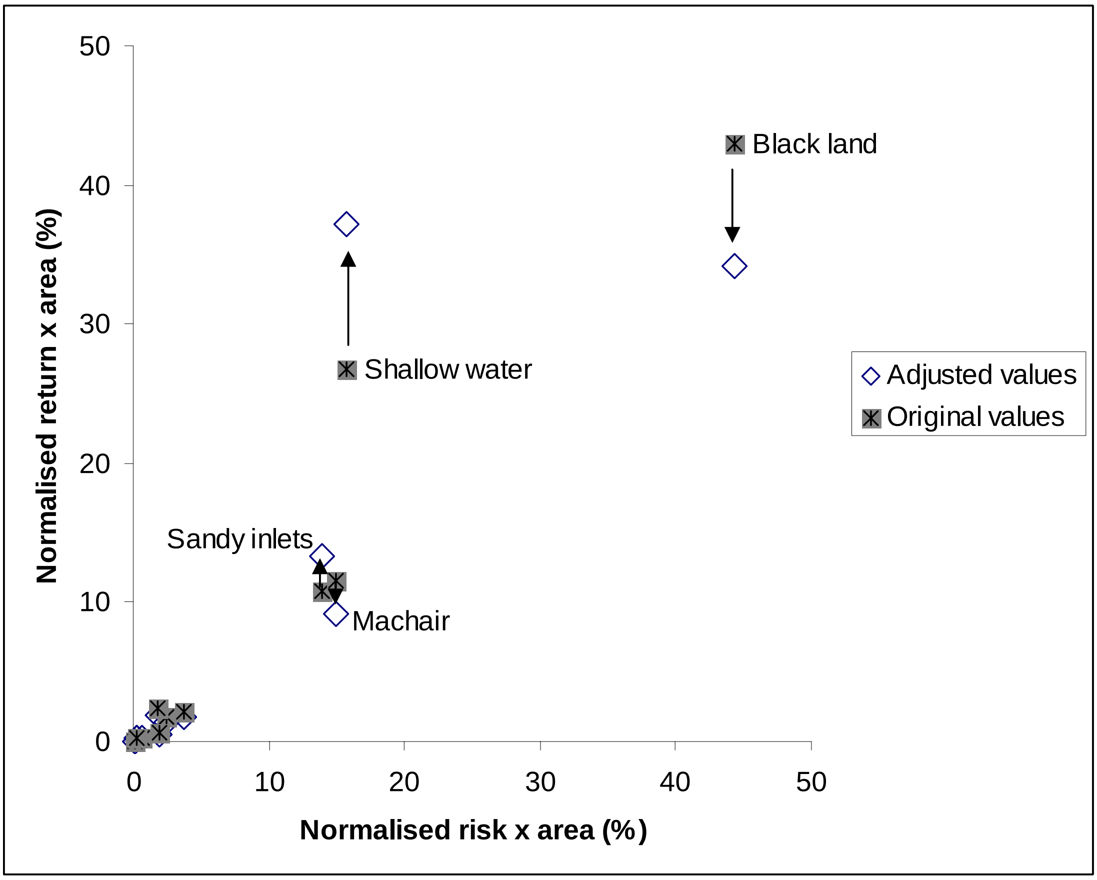


Figure 4. Normalised and adjusted risk-return profile for Baile Sear.

Table 4. Pairwise correlation (Pearson's r) of the threat factors (Table 2a) for each of the BIOMES.

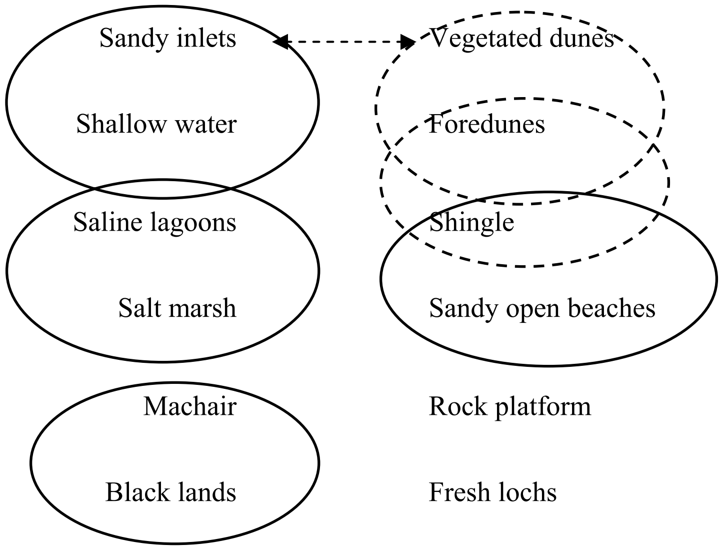
	Shallow water	Salt marsh	Sand inlet	Sand open beach	Shingle	Rock platform	Foredune	Vegetated Dunes	Machair	Black lands	Saline lagoons	Fresh lochs
Shallow water	1											
Salt marsh	0.055	1										
Sand inlet	**0.823 ****	0.300	1									
Sand open beach	-0.087	0.149	0.375	1								
Shingle	-0.079	0.136	0.187	**0.733 ****	1							
Rock platform	-0.071	0.055	0.262	0.239	-0.079	1						
Foredune	-0.285	-0.231	-0.185	0.482	**0.650 ***	-0.285	1					
Vegetated Dunes	-0.523	-0.247	**-0.641 ***	0.007	0.199	-0.523	**0.613 ***	1				
Machair	-0.460	0.156	-0.522	-0.249	-0.369	-0.460	-0.276	0.319	1			
Black lands	-0.370	0.221	-0.518	-0.572	-0.523	-0.370	-0.476	0.166	**0.898 ****	1		
Saline lagoons	0.000	**0.745 ****	0.256	0.074	0.068	0.000	-0.401	-0.368	0.349	0.440	1	
Fresh lochs	-0.118	0.271	-0.093	-0.162	-0.148	-0.118	-0.375	-0.497	0.423	0.480	0.566	1

** = r>0.708, highly significant at 0.01 threshold, * = 0.576<r<0.708, significant at 0.05 threshold, r< 0.576, not significant

Table 5. Pairwise correlation (Pearson's r) of the biome factors (Table 2a) for each of the THREATS.

	Erosion	Flooding	Saline intrusion	Tourism	Infrastructure	Agric. changes	Pollution	Invasive species	Litter	Over-harvesting
Erosion	1									
Flooding	-0.164	1								
Saline intrusion	-0.288	0.579	1							
Tourism	**0.628***	0.200	-0.039	1						
Infrastructure	-0.233	-0.386	-0.291	-0.270	1					
Agric change	0.322	**0.683***	0.492	**0.667***	-0.291	1				
Pollution	-0.225	-0.115	-0.301	**-0.60*9**	0.258	**-0.601***	1			
Invasive species	0.169	**0.734****	0.542	0.491	-0.291	**0.949****	-0.526	1		
Litter	**0.780****	-0.251	-0.424	**0.667***	-0.291	0.186	-0.301	0.034	1	
Overharvesting	-0.138	-0.417	-0.315	-0.291	0.043	-0.315	0.056	-0.315	-0.239	1

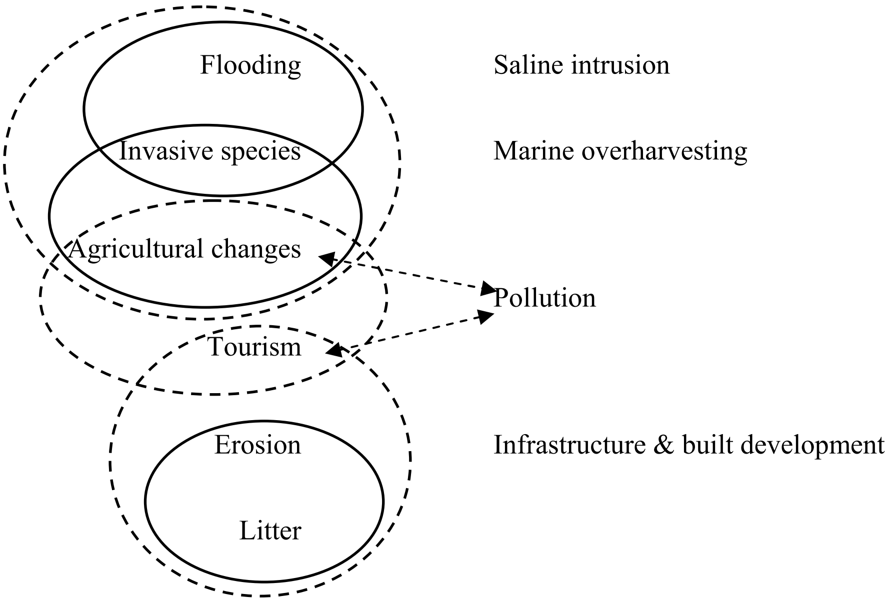
** = r>0.728, highly significant at 0.01 threshold, * = 0.589<r<0.728, significant at 0.05 threshold, r< 0.589, not significant



Solid line – highly significant associated biomes, Dashed line – significant associated biomes
Dotted arrow – significant resilient biomes

Portfolio impact sensitivity = 5 (6 x ASSOCIATED pairs - 1 x RESILIENT pair)

Figure 5. Relationships between different biomes for Baile Sear.



Solid line – highly significant associated threats, Dashed line – significant associated threats
Dotted arrow – significant resilient threats

Figure 6. Relationships between different threats for Baile Sear.

	Original return	Original risk	Adjusted Return #1	Adjusted Risk #1	Adjusted Return #2	Adjusted Risk #2
Shallow water	594.0	198.0	***544.5***	***49.5***	594.0	198.0
Salt marsh	5.6	8.4	5.6	8.4	5.6	8.4
Sand inlet	240.9	175.2	***219.0***	***109.5***	240.9	175.2
Sand open beach	38.7	30.1	38.7	30.1	38.7	30.1
Shingle	13.6	23.8	13.6	23.8	13.6	23.8
Rock platform	0.9	1.2	0.9	1.2	0.9	1.2
Foredune	4.5	3.3	4.5	3.3	4.5	***3.0***
Vegetated Dunes	47.6	47.6	47.6	47.6	***42.0***	***36.4***
Machair	257.4	187.2	257.4	187.2	257.4	***152.1***
Black lands	955.2	557.2	955.2	557.2	955.2	***437.8***
Saline lagoons	7.2	3.0	7.2	3.0	7.2	3.0
Fresh lochs	54.0	22.5	54.0	22.5	54.0	22.5
TOTALS	**2219.6**	**1257.5**	**2148.2**	**1043.3**	**2214.0**	**1091.5**
	Ret/Ris = 1.8		**Ret/Ris = 2.1**		**Ret/Ris = 2.0**	

Table 6: The effect of management decisions on the risk-return values

4. Discussion

4.1 Sensitivity of technique to selection of biomes

Figure 4 illustrates the risk-return profile for Baile Sear. The effect of a large land area is considerably more important to the risk-return profile value for a given biome than the effect of a large risk or return value. Because of this, only four biomes have substantial risk-return values – the black lands, shallow waters, sandy inlets and the machair. All other biomes, including the biome vegetated dunes (which has the highest risk value, 17, and the third highest service value, also 17), are grouped in the bottom left corner of the graph. This indicates a very high sensitivity to the area of the biomes.

For most of the terrestrial biomes the geographical boundaries are clearly defined and uncontested. The very large biome of shallow waters, however, could potentially be further subdivided, according to the substrate (sandy, muddy, rocky or shingle). There is no trawling in the shallow water biome, only creeling for prawns (*Nephrops norvegicus*) and lobsters. Both these species prefer specific habitats. According to the Marine Life Information Network for Britain and Ireland "There are many records of *Nephrops norvegicus* populations <20 m in Scottish Sea Lochs. They live in shallow burrows and are common on grounds with fine cohesive mud which is stable enough to support their unlined burrows", and also "Lobster *Homarus gammarus* are found on rocky substrata, living in holes and excavated tunnels from the lower shore to about 60 m depth". It could therefore be inferred that prawn creels are only put down in the muddy areas and lobster pots in the rocky areas. The active area supporting this service has therefore probably been overestimated, leading to an overestimation of the return value for shallow waters.

4.2 Sensitivity of technique to selection of services and of threats

As a thought experiment, 3 extra services were added to the matrix in Table 1a. These were:

a.) Fish nursery (value 3 being given to shallow waters)
b.) Renewable energy generation – tidal (value 3 being given to shallow waters and sandy inlets)
c.) Renewable energy generation – wave (value 3 being given to shallow waters and sandy inlets)

The results are shown as the adjusted values in Figure 3. This shows that the proportional return of the shallow waters biome, has, as expected, increased from 25% to 37%. The black land biome has concomitantly decreased from 44.5% to 34%. Given that there was an increase of number of services from 12 to 15 (an increase of 25%, all focused on increasing the value of the shallow waters biome), this appears to demonstrate a relatively low sensitivity to the initial selection of services.

As the threat/risk criteria are in the same mathematical relationship to the output as the service criteria, the above result also supports the statement that there will be a relatively low sensitivity to the initial selection of threats

4.3 Sensitivity of technique to selection of values

The final columns of Tables 1b and 2b show the normalised total service and risk respectively.

The highest service value is 15.6% for renewable energy generation, followed by 13.8% for tourism, and 11.5% for conservation. Agriculture is only placed 6th, with

8.9%. This may not be in accordance with traditional understanding of the economic importance of different services. There are three reasons why this may be so:

a.) It may be because a particular service – for example conservation interest – has always been difficult to evaluate using classical economics and so has traditionally had its importance undervalued.

b.) It may be because values are given that reflect potential, rather than current use – for example, there are at present no extensive renewable energy generation schemes, so if the shallow waters, sandy inlets and black lands are assigned a value of 1, rather than 3., then renewable energy generation has a total service value of 6.2%, putting it at 8th place rather than 1st.

c.) Finally, in some cases it may be because the traditional understanding is, in fact, wrong.

The biodiversity portfolio technique thus provides a valuable tool for examining the service return, providing a basis for further stakeholder discussion and deepening the understanding of the direct and indirect economic return. In some cases – for example comparing the 8.9% service return of agriculture with the 13.8% service return of recreation and tourism – it may be possible to compare actual economic data in order to confirm or refute the service values and placings.

The highest risk value is 17% for causeways and other infrastructure, followed by 15.3% for pollution. Flooding, saline intrusion, agricultural change and invasive species have similar risk values of around 13%. Litter is placed 10th, with a risk value of 1.9%. In Table 2a, Litter is given a value of 0 for the shallow water biome, but it can be argued that the issue of marine litter is relevant here and that it should be given a value of at least 1. Doing so increases the risk value to 5.6%, and increases the placing to 8th.

It can be concluded that the technique is moderately sensitive to selection of values, though this is only important for those biomes with extensive geographical areas.

4.4 Sensitivity of technique to stakeholder simplification (nominalization).

Table 3 shows the proportional contribution of values 0-3 in the two tables derived directly from stakeholder workshops (Tables 1a and 2a). 58% of values are zero, 14% are 1, 5% are 2 and 23% are 3. This illustrates a slight tendency in stakeholders to categorise each valuation *nominally* (two classes only – yes, there is a value/no, there is no value) rather than *ordinally* (scalar, multiple classes). In other words, having agreed that a particular biome does provide a service or is exposed to a threat, there was then a tendency to rate that service or threat as being the highest value possible, i.e. 3.

This tendency to nominalization diminishes the amount of variability in the dataset. The high percentage of values set at zero is not the problem. This merely reflects the fact that many biomes only contribute to a small number of services or threats. For example, shingle beaches only contribute to conservation and coastal protection services. The optimum spread of non-zero values, with the most variability, would be 33% of non-zero values for each of 1, 2 and 3. In this case, the proportion of non-zero values set at 1 is 32%, close to the ideal. The problem, therefore, is in the high number of non-zero values set at 3 (55%), rather than 2 (13%).

In order to avoid this problem in future workshops it is recommended that the workshop facilitator calculate the percentages after the initial set of valuations, and if necessary come back to the stakeholders requesting selection of those cells which should have their values reduced from 3 to 2.

4.5 Portfolio sensitivity to threats

It can be seen from Figure 4 that the Baile Sear portfolio is highly sensitive to threats, with 6 associated pairs and only 1 resilient pair, leading to a portfolio impact sensitivity rating of 5.

Figure 4 also shows that there is one complex sector of biome relationships, that of the dynamic shore system. This encompasses the progression from sandy open beaches and shingle beaches to foredunes and then to vegetated dunes. There are also three simple sectors, of one biome pair each – sandy inlets/shallow waters, saline lagoons/saltmarsh, machair/black lands.

Doing the same analysis on the threats gives Figure 6, which shows one very complex sector of threats incorporating flooding, invasive species, agricultural changes, tourism impact, storm erosion and litter. The first three of these threats – flooding, invasive species and agricultural change – are very significantly associated, and make up a sub-sector comprising 39.5% of the total risk. Any management strategy that aims to deal with one of these threats, in order to protect the machair biome, for example, must also deal with the other threats in the sub-sector.

4.6 Simulating management decisions in the Biodiversity Portfolio Approach

Management scenario 1 is that there is an embargo on further causeways or other major infrastructure elements built on the inlet sands or shallow waters. This brings down the return (Table 6, column 3) as well as the risk (Table 6, column 4). The ratio of return to risk rises from 1.8 to 2.1.

Management scenario 2 is that financial incentives are put in place to maintain agricultural activity at the optimum balance for maintaining the machair and black lands. Additionally it is postulated that agricultural activity ceases on the vegetated dunes (one of the main threats being erosion due to livestock activity). Again, this brings down the return (Table 6, column 5) but also the risk (Table 6, column 6), and the return/risk ratio rises from 1.8 to 2.0.

It can be seen from this exercise that the Biodiversity Portfolio Approach is a useful one for simulating the effect of management decisions.

5. Conclusion

The biodiversity portfolio method succeeds as a technique valuing multiple functions and uses, being both broadly holistic and specifically quantitative. However the usefulness of the technique depends on its robustness, its ability to stand up to challenge. Robustness can be defined here as being the combination of sensitivity and measurement accuracy or levels of error due to mis-categorization. Low sensitivity plus high measurement accuracy/low levels of error is the most robust combination, and low sensitivity plus low measurement accuracy/high levels of error is still reasonably robust. However, a low sensitivity level is also the least informative - a certain amount of sensitivity is required in order to obtain enough variation for the technique to be informative. Therefore the ideal is high sensitivity plus high measurement accuracy/low error.

The discussion sections show that the technique is highly sensitive to the selection of biomes. This is actually due to the very high sensitivity to the area of biomes. This in turn is dependent on the availability of data – in this instance lack of data on shallow water substrates certainly had a major effect. Therefore the technique has a very high sensitivity to geographical data, in combination with a potentially high level of error (low measurement accuracy) with regard to that geographical data, and this must be taken into account in any future application. This is the least robust aspect of the method.

The technique showed a moderate sensitivity to selection of values within the matrix. In this study values were selected after consultation with stakeholders on a group basis, so consensus was achieved prior to the assignation of values. If going through the exercise with groups of stakeholders with very different interests it may be that the values will be subtly different, but because of the merely moderate sensitivity this should rarely lead to a major difference in the matrix as a whole. The reason for any such major difference will be very easy to identify, and an ICZM manager could then work on achieving a consensus value for this 'sticking point'. Additionally, because of the moderate sensitivity, the tendency for stakeholders to over-use the highest value and under-use the middle values is not a serious problem. The moderate sensitivity in combination with a low measurement accuracy leads to a medium level of robustness for this aspect of the method.

The final part of the sensitivity analysis was the sensitivity to selection of services and threats. The sensitivity was low, and this was the most robust aspect of the method.

By providing estimates of % contribution for each ecosystem service and each ecosystem threat, the biodiversity portfolio technique proves a useful tool for further stakeholder discussion. Results such as those obtained here, with 11.5% service contribution from conservation vs. 8.9% from agriculture, may be in conflict with established belief. This will be difficult to prove one way or the other with this particular pair of services, conservation having a great deal of non-monetary 'existence value'. However, if it proves possible to compare actual economic data for other services – agriculture and tourism, for example – then this has the potential to support or refute the estimates of % contribution for the other services.

The method may indeed prove useful as an educational tool as well. Both the dataset itself and the arithmetic required to undertake the initial analysis of the dataset are very simple and highly transparent. It could therefore be an important tool for participatory planning.

The technique has proved useful at establishing that the Baile Sear biodiversity portfolio is highly sensitive to threats. It is therefore an area requiring higher than average levels of environmental protection. Finally, the biodiversity portfolio method is shown to be a useful one for simulating the effect of management decisions.

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