Vulnerability Analysis and Risk Management for Water-Related Hazards

PART I: “Socio-economic valuation of risk perception”

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3. Revealed preferences methods

A. Hedonic pricing

B. Travel cost

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B. Travel cost

- The basic insight underlying travel cost (TC) is that an individual's value for recreation at a site, such as hiking in a park or fishing at a lake, is his or her trip cost of reaching the site
- Viewed in this way, individuals reveal their **willingness to pay for recreational uses** of the environment in the **number of trips** they make and the sites they choose to visit.
- The TC is used to value site access and quality change at recreation sites. An example of site access is the closure of a beach due to an oil spill, where access to the site is lost. An example of a quality change is an improvement in water quality on a lake used for recreation.

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B. Travel cost

- The TC models work much like a demand function for any consumer good.
- Trip cost is treated as the price of the good, and the number of trips taken over a season is treated as the quantity demanded.
- The simple observation that **the closer one lives to a site** (lower price), the **more trips one takes** (higher quantity demanded) is, in effect, viewed as a downward-sloping demand function.
- People reveal their access value of a site in the number of trips taken

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B. Travel cost

- The TC model is a demand model for trips to a recreation site by a person over a season. The trip cost includes travel expenses and time cost necessary. Other factors affecting the visits are age, income, experience in recreation activity, etc. The demand function is:

$$r = f(tc_r, tc_s, y, z)$$

r = n. trips taken; tc_r = trip cost to the site tc_r = trip cost to the substitute site; y = income, z = demographic variables.

- The model is:

$$r = \beta_{tc_r} tc_r + \beta_{tc_s} tc_s + \beta_y y + \beta_z z$$

- The βs are the coefficients to be estimated.

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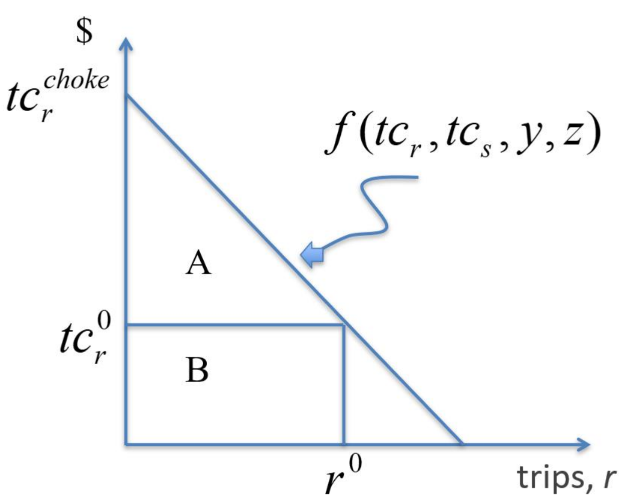
Travel cost demand curve



- If a person faces a trip cost of tc_r^0 she takes r^0 trips.
- The area A is her total consumer surplus for trips to the site: the difference between total WTP for trips (A+B) and total trip cost (B). This is the individual's access value.

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Steps for the implementation of a travel cost study

1. Define the site
2. Develop a sample strategy
3. Define the visitors and their purpose
4. Design and implement the survey
5. Measure travel costs and other costs
6. Model estimation and welfare estimates

1. Define the site

- Boundaries can be are easy to identify (a lake, a park), but in some other cases may not be (a river for fishing, an area for hunting). A solution can be to include most of the area on the basis of **the policy investigated**
- Government agencies, park services, and tourist bureaus often have literature and maps that help in defining sites. Sometimes government agencies managing natural resources have their own site definitions, such as wildlife management units. These often work for a travel cost model.

2. Develop a sample strategy

- Sampling strategies depend on the aim of the study, population of interest and the type of model. Both users and potential users should be taken into account.
- **On-site sampling**: visitors are surveyed at the site. Advantage: sample size can be smaller. Nonetheless, respondents with zero trips will not be considered, partly biasing the demand function, and, if not corrected, the value estimates.
- **Off-site sampling**: respondents are sampled from the general population, by allowing both participants and non-participants. Most of the biases described above can be avoided. Off-site samples can be costly due to the low participation rate.

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3. Define the visitors and their purpose

- People visiting the site may take a day-trip or stay overnight. This is one of the main issues with TC: trips to the site should be of the same length for each person. It is preferable not to mix one day and two or more days trips in the same analysis.
- Issue: multiple recreation uses. People can visit a forest for short walks, hiking, picnicking, mushroom picking, bird-watching, hunting, just resting, etc.
  - One solution: aggregate similar recreation activities (careful!).
  - Second solution: identify the primary purpose of a recreation and ask respondents to report the number of trips taken according to several purposes.

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4. Design and implement the survey

- Adequate survey methodology is crucial.
- The main section of the survey focuses on costs and trips, by explicitly asking questions on the number of trips taken to the site(s) over a specific period of time.
- These questions may be divided by recreation type (fishing, boating, etc.), by day and overnight trips, and/or by multiple- and single-purpose trips.
- Ideally, information should be collected for each trip taken to the sites. However, this is difficult, so often we focus only on information related to the last trip.

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4. Design and implement the survey

- To correctly specify a model, one needs to identify relevant determinants to explain recreation demand. For example, families with many children may be less interested in visiting.
- In recreation studies demographic characteristics are important; people retired and students are generally likely to spend more time than others on outdoor activities.
- Behavioral and attitudinal questions are becoming more important in providing additional information to describe the profile of respondents.
- Use of the Likert scale : *"On a scale from 1 to 5, where 1 means I strongly agree and 5 means I strongly disagree, the activity you do at this campground could as easily be done elsewhere?"*

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5. Travel costs and other costs

- Once the data are assembled and organized, the trip costs to all sites for each respondent are computed. Trip cost is the sum of the expenses required to make a trip.
- Typical costs for a day trip include:
  1. Travel cost
  2. Access fees
  3. Equipment cost
  4. Time cost

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5. Travel costs and other costs

- Travel cost, is typically computed using a per-mile operating cost times round-trip mileage to the site. For example, the American Automobile Association's 2015 average cost per mile for operating a vehicle (average of all sedans) is about 15 cents ($0.15), which includes the cost of gas, maintenance, and tires.
- The round-trip distance to the sites is usually calculated using a software package.
- Tolls, if any, are added to the travel costs.
- Because travel costs may be shared by several people, efforts are sometimes made to apportion the costs. For example, the researcher might ask respondents to report the number of people sharing travel costs on their last trip and divide the cost equally.

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5. Travel costs and other costs

- If sites have an access fee, that fee is included in the trip cost. Sometimes sites will offer annual or weekly passes, senior discounts, or free admission for children. Making adjustments for seniors and children is easy, but accounting for discounts is more difficult and usually ignored. Typically, the daily fee is used.

- Equipment costs are often excluded from the trip cost estimate because they are difficult to estimate and are generally negligible portions of trip cost when accounting for the fact that equipment can be used for multiple visits. Also, they vary a lot for different types of recreational activities, thus making computation difficult.

5. Travel costs and other costs

- One of the most crucial issues is the estimation of the cost of time associated to the trip.

- Time spent traveling to and from the site and time spent on the site constitutes time that could have been devoted to other activities. The value of those lost opportunities (<u>opportunity cost</u>) is the time cost of the trip. Time cost often accounts for a sizable portion of the total trip cost.

- The estimation of the time cost is commonly got by multiplying the hourly wage by the travel time to the site (related to income). A fraction of the imputed wage is sometimes used ranging from one-third to the full wage. Alternative approaches are proposed.

Typical data set for a travel cost model

Respondent code (n.)	Visits made to the site (n.)	Cost of the visit to site (€)	Cost of the visit to substitute site (€)	Age (yrs)	Times per week training (n.)	Family size (n.)
1	4	34	45	45	4	0
2	5	56	100	18	1	1
3	8	75	21	32	2	4
4	3	21	10	19	1	1
.	.	.	.	.	.	.
n	2	34	57	55	2	3

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6. Model estimation and welfare estimates

Count models (instead of OLS) are mostly used for data analyses because:
1. the dependent variable (number of trips) is nonnegative and integer
2. the major fraction of visitors takes zero or small number of trips.

They operate in a probabilistic context.

The basic count data model is a Poisson regression.

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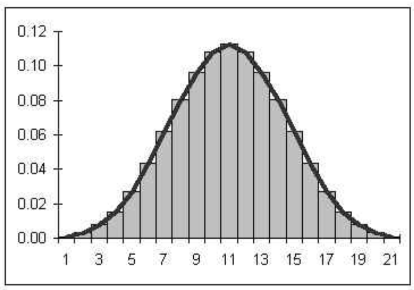
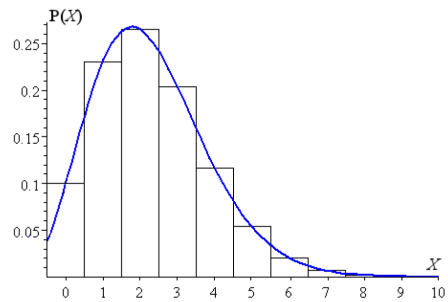
6. Model estimation and welfare estimates

Normal distribution
(Linear regression)



Poisson distribution
(Poisson regression)



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6. Model estimation and welfare estimates

- The probability of observing an individual taking r trips is:

$$\Pr(r) = \frac{\exp(-\lambda) \bullet \lambda^r}{r!} \qquad (1)$$

- λ is the expected number of trips and it is assumed to be a function of the variables specified in the demand model. To ensure nonnegative probabilities, λ takes a log-linear form:

$$\ln(\lambda) = \beta_{tc_r} tc_r + \beta_{tc_s} tc_s + \beta_y y + \beta_z z \qquad (2)$$

- Substituting (2) in (1) provides the probability of observing an individual take r trips as a function of the variables (trip cost, …).

- The parameters are estimated by maximum likelihood.

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6. Travel cost modelling

Value estimates can be expressed in several ways: as a mean seasonal value per person, as a total seasonal value for the population and as an average per trip per person.

The average per trip per person value through the Poisson regression is:

$$V_{\hat{t}} = \frac{(\hat{\lambda}_n / -\hat{\beta}_{tc_r})}{\hat{\lambda}_n} = 1/-\hat{\beta}_{tc_r}$$

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Case study:

Estimating the costs and benefits of protecting a coastal amenity from climate change-related hazards: Nature based solutions via oyster reef restoration versus grey infrastructure (Heynes et al., 2022)

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Motivation

- The costs associated with storm surges and rising sea levels in low lying coastal areas have been increasing in recent years and are likely to rise even further in the future due to a projected increase in the severity and frequency of extreme weather events.
- In the absence of adaptation, the IPCC (2019) forecasts that more intense and frequent extreme sea level events will lead to an expected increase in annual flood damages globally by 2–3 orders of magnitude by 2100.
- Therefore, in line with the implementation of the UN Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015) and the EU 2021 Adaptation Strategy (EC, 2021), policy makers will need to pay much closer attention to the role of coastal flooding and damage preventative actions

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Motivation

- Risk reducing options for coastal communities may include hard engineering solutions (referred to as grey infrastructure), Nature Based Solutions (NBS) or hybrid solutions involving an element of both
- One form of NBS - active ecosystem restoration - is seen as an increasingly important intervention to counteract the degradation of marine and coastal ecosystems and to assist in climate change adaptation
- Active ecosystem restoration entails the recovery of a damaged ecosystem via planting of nursery-grown seedlings, direct seeding, and/or the manipulation of disturbance regimes (for example, thinning and burning) to speed up the recovery process, often at a high cost to establish structural features of the vegetation

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Motivation

- The paper adopts the travel cost method to estimate use values associated with a coastal walking trail vulnerable to climate related events and compares to the costs of ensuring its continued existence either via hard engineering solutions or through the restoration of a protective oyster reef bar.
- This comparison also facilitates the demonstration of the cost effectiveness of NBS for climate adaptation compared to the grey alterative – information that is needed for climate adaptation and flood management planning.

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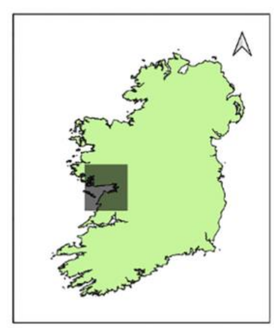
Study area

- The study was carried out at a coastal walking trail, on Galway Bay on the west coast of Ireland.
- It is located in the outskirts of Galway City, approximately 3 km from Oranmore village.
- The trail extends from a single lane road that runs adjacent to the Galway Bay Sailing Club, the Galway Bay Golf Resort and to the Renville recreational forest park



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Study area

- Analysis of the flooding and erosion potential of Ireland coastline has been carried out by the Irish Office of Public Works in recent years (OPW, 2019).
- The results suggest that the coastline in Renville Bay is highly vulnerable to coastal flooding (defined as a greater than 1 in 200 chance of coastal flooding in any given year) and without any remedial action is likely to see significant levels of erosion by 2050.
- Because of the golf course that lies behind the wall inshore of the path, it is not possible in the short to medium term to move the trail back from its current location so inwards adaptation is unlikely.
- The local council regularly puts up signs at the start of the gravel trail warning walkers of storm damage.

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Study area

- Galway Bay was at the center of a region where the native oyster was abundant since prehistoric times. However, similar to native oyster stocks worldwide these once highly productive reefs have been overharvested and the remaining stock in Renville Bay are close to functional extinction.
- Work on restoring the native oyster in Galway Bay has started and is being led by the Marine Institute and the community-based organisation Cuan Beo
- In late 2020 the group distributed 200 t of empty pacific oyster (*Magallana gigas*) shell covering an area of 50 m radius and 1 m height on to the seabed. The project team are currently monitoring the settlement of the substrate and plan to seed it with native oyster stock.

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Risk management options

- Two options are considered for protection of the coastal walking trail in from storm damage:
  1. a shoreline coastal defence barrier in the form of a revetment or sea wall
  2. a restored oyster reef bar where a raised bed of oysters is once more put in place along the length of the shoreline adjacent to the gravel path
- Seawalls are vertical, sloped or stepped walls usually constructed of concrete or masonry directly on the landforms of the coast. Their primary purpose is to reduce the impacts of tides and waves
- Revetments on the other hand are an armouring layer applied to a sloping surface of an embankment or shoreline. These can be permeable or impermeable. The function of permeable revetments is to reduce the erosive power of the waves by means of wave
- As a natural coastal defence alternative oyster reefs can function as natural breakwaters for vulnerable coastlines as they are structures that interact with tidal and wave energy to reduce shoreline erosion. They also have the added advantage that they automatically adjust to sea level rise as they can grow vertically faster than sea levels are expected to rise

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Data collection

- In order to obtain information relating to the demand for recreational walking along the Renville coastal path, an on-site survey of users was conducted in June and July 2018.
- The sample comprised of 207 individuals aged 17 plus.
- In carrying out the survey, walkers were approached on the road between the parking lot and the start of the gravel coastal path. The participants were not necessarily taking a walk on the coastal trail that particular day. In some cases, they might have been entering the forest park close by instead. In all cases, however the respondents indicated that they had used the trail at least once in the previous 12 months. In total, 207 surveys were completed.
- A focus group discussion involving 8 users of the site and pilot testing of the questionnaire were carried out to ensure that the questions asked were fully understandable by participants.

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Data collection

- Respondents to the survey were first asked about the **purpose of their trip** and their **visitation rate in the previous 12 months**.
- Information was also collected on the **time and distance travelled** (one-way) from home to the site in addition to the **mode of transportation used** (car, bike, walk, other). To verify and compare travel data, individuals were then asked to indicate an approximate home location on a digital map, which automatically geocoded the point of residence.
- Recreationalists were also asked to indicate whether the Renville coastal walk was their preferred walking site, and to indicate on the digital map their next most preferred site for undertaking their recreational pursuits. This facilitated the calculation of **travel cost to the next most preferred alternative site**.
- Finally, **socio-demographic information** relating to age, gender, marital status, highest education level achieved, employment status, sports, recreation and environmental organisation membership, and **income** was also gathered from the survey.

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Travel cost computation

- In calculating the round trip travel cost to the coastal walking trail the Automobile Association (AA) of Ireland's calculations for the marginal costs of motoring for a car of average size was used (€0.21 per km).
- For those who indicated they cycled or walked to the site, nominal operating cost estimates of €0.047 and €0.041 per km from Gössling et al. (2019) were used respectively.
- Any monetary valuation of the opportunity cost of the leisure time spent on-site or travel time to the site in the travel cost calculation is omitted. It is not believed that this will lead to any bias in the resulting estimates as the users of the site are mainly from local communities and are frequenting the site in what is their free time from work.

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Grey solutions cost estimation

- Data obtained from official sources and a review of the literature

Type	Source	Capital Costs€/m	Renville (1070 m) total capital cost (€)
Rock armour	UK Environment Agency	2121–9427	2,269,585–10,087,048
Impermeable revetments and seawalls	Scottish Natural Heritage	4624–11,560	4,947,847–12,369,618
Impermeable revetments and seawalls	UK Environment Agency	1099–8483	1,176,822–9,078,343
Permeable rock revetments	Scottish Natural Heritage	2312–6936	2,473,923–7,421,771
Permeable rock revetments	UK Environment Agency	1021–4477	1,092,763–4,791,347

For the CBA, the average of the midpoint of all options is taken and a total initial capital cost of €5,570,907 is assumed. An additional annual maintenance cost of €68,480 from year 1 onwards is assumed based on Norton et al. (2018).

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Nature based solution cost estimation

- Estimation based on costs of previous oyster restoration projects

Feature	Value
Reef size (1070 m by 6 m)	0.642 ha
Reef height	1 m
Reef material	Pacific oyster shell
Seeding rate per hectare	100,000
Cost of reef material (substrate) purchase and placement with mesh[a]	€246,000
Cost of seed	€1155.6
Monitoring and maintenance labour costs per annum	€12,640
Total cost to establish in year 0[b]	€259,756

[a] This estimate is based on the average of the Harris Bay and Essex Native Oyster Initiative estimates in Table 5. However conversations the oyster restoration scientists in the bay suggested a reef height of 1 m so we doubled the costs per hectare estimates used allowing for some economies of scale in moving from the 0.3 m in the estimates from Table 5 to 1 m.

[b] Additional maintenance equipment costs of €2500 are assumed from year 1 onwards.

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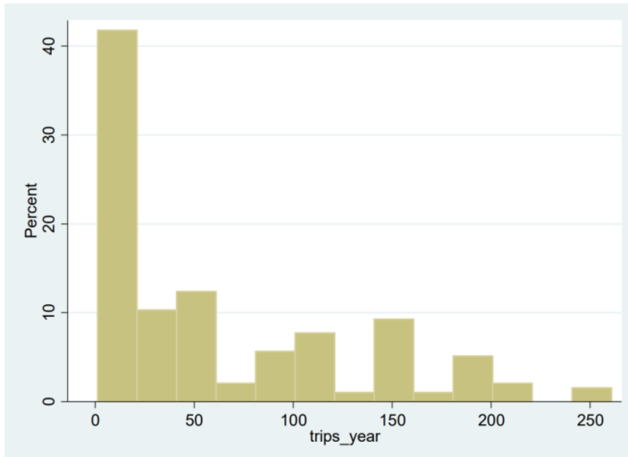
Results – Distribution of number of trips



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Results – travel cost model estimates

Parameter	Coefficient (Standard error)
Travel cost per trip	−0.089*** (0.019)
Obligation free days per year	0.002** (0.001)
Gross income (€'000)	−0.007** (0.003)
Most preferred walking site	0.088 (0.211)
Female	0.101 ((0.163)
Married	0.020 (0.189)
Third level education	−0.110 (0.228)
Member of sport, recreation or environmental organisation	0.048 (0.164)
Travel cost per trip to substitute site	0.017* (0.010)
Aged 25–34	0.473 (0.332)
Aged 35–44	0.580* (0.334)
Aged 45–59	0.747** (0.336)
Aged 60+	1.042*** (0.362)
Main purpose of trip	0.068 (0.244)
Constant	−12.454 (127.2)
Alpha	1.278
Log likelihood	−953
AIC statistic	10.11
Wald χ^2 Statistic (14 d.f.)	55.37

Standard errors in parenthesis. *** indicates significance at 1%, ** 5%, * 10%.

$$CS_{perTrip} = \frac{1}{-\widehat{\beta}_{TC}}$$

1/-(-0.089)=11.24

Expected trips and benefit	Value
Expected annual trips	57,123
Consumer surplus per trip (€)[a]	11.24 (7.81–19.38)
Willingness to pay per trip (€)[b]	16.92 (11.71–26.37)
Aggregate consumer surplus (€)	642,063 (446,130–1,107,044)

[a] 95% confidence intervals in parenthesis.
[b] Willingness to pay per trip is the addition of actual travel cost to the site and estimated consumer surplus per trip. Aggregate consumer surplus equals observed annual trips*CS per trip. Expected annual trips is from a people counter placed at the trail for 12 months.

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Cost benefit analysis

- After calculating the annual recreational benefit value associated with the coastal walking trail and the costs of the alternative approaches to its protection from storm surges, a cost–benefit analysis (CBA) over a 20 year time horizon is carried out.
- As the benefits and costs take place over multiple years, a standard discounting procedure is employed to calculate the net present value (NPV) of the benefit and costs for each scenario.
- Based on a Social Rate of Time Preference methodology, the standard test discount rate (r) for application in economic appraisal of current and capital expenditure proposals carried out in accordance with the requirements of the Irish governments Public Spending Code is used in the analysis. This is set at 5%.
- Finally, a sensitivity analysis is carried out to evaluate how robust the findings of the CBA are under a number of alternative assumptions. These include employing a higher discount rate, applying lower estimates of the benefits and capital costs used for the hard engineered solution and the situation where not all the recreational use value is lost following damage

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Cost benefit analysis results

Scenario	Protection option	Discount rate	Annual benefits	Annual cost yr 0[a]	PV benefits	PV costs	BC ratio
CBA	Oyster Reef	5	642,063	259,796	8,643,587	448,474	19.27
	Revetment	5	642,063	5,570,907	8,643,587	6,424,319	1.34
1	Oyster Reef	5	446,130	259,796	6,005,896	448,474	13.39
	Revetment	5	446,130	5,570,907	6,005,896	6,424,319	0.93
2	Oyster Reef	7	446,130	259,796	5,172,438	420,189	12.31
	Revetment	7	446,130	5,570,907	5,172,438	6,296,385	0.82
3	Revetment	7	446,130	2,392,188	5,172,438	3,117,666	1.65
4[b]	Oyster Reef	7	446,130	259,796	5,172,438	1,479,591	3.50
5[b]	Oyster Reef	7	223,065	259,796	2,586,219	1,479,591	1.75

[a] Annual capital cost for the revetment is zero after year 0. Maintenance costs of €68,480 for the revetment is assumed from year 1 onwards. Monitoring and maintenance costs remain the same for the oyster reef option in all years.
[b] Scenario 4 and 5 assumes coastal trail maintenance costs of €100,000 per annum in addition to the placement cost of the oyster reef in year 0. Scenario 5 also assumes that only half the recreational use value is lost.

- Protecting the walking trail produces a positive net present value (NPV) under both protection options. However the oyster reef nature based solution has the lowest PV cost and a benefit cost ratio of 19.27 (in the base scenario) compared to a ratio of just 1.34 when the grey infrastructure alternative is employed and is therefore the more attractive option from an economic perspective.

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Implications

- The results of a travel cost model suggest that the coastal walking trail has considerable recreational use value to local communities in the area.
- Based on the results the restoration of native oyster reefs should also be considered as a possible avenue to reduce the now unavoidable costs associated with coastal protection and adaptation.
- Given the public funding that will be required to deal with these challenges policy makers and planners in coastal areas will be required to demonstrate cost effectiveness in the options chosen.
- As demonstrated in the study there is a compelling case for embedding NBS in climate adaption and flood management planning as the costs can be much lower than more conventional approaches as well as providing other ecosystem service benefits.

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Implications

- Traditional grey infrastructure such as removable flood-barriers, rock armour, breakwaters, revetments and sea walls will continue to be an important option to deal with coastal flooding.
- However, policy makers should give a much higher degree of consideration to blue nature based infrastructure options such as restored oyster reefs, salt marshes and kelp forests. Such restoration options, either on their own or in combination with a reduced grey infrastructure requirement, not only can help to mitigate the impacts of climate change-related natural hazards but also deliver multiple additional ecosystem services that traditional grey infrastructure alone does not, such as water purification, increased biodiversity, carbon sequestration and increased scenic value.
- Given the additional ecosystem services that can result and the increasing demand for coastal protection options due to climate change, nature-based solutions are attractive but lack the associated cost-benefit information to support policy makers. Valuation study are crucial to fill this gap.

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