General Protocol for Calculating the Basis of Monetary Legal Claims for Damages to Coral Reefs by Vessel Groundings and an application to the northern Red Sea

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ABSTRACT

Coral reefs are an important source of goods and services to human societies, but they are currently being affected by a host of human activities. Economic valuation methods can be employed to calculate losses in human welfare associated with anthropogenic coral reef degradation, and the charges to be paid by those responsible as compensation for damaging the ability of coral reefs to provide a flow of goods and services. The grounding of boats and ships is a widespread occurrence affecting the biodiversity of coral reefs. Injury to coral reefs by groundings can range from relatively minor injuries to the degradation of the structural complexity of the reefs. The natural recovery of coral reefs from severe groundings can take centuries, and artificial restoration methods are often employed. The economic value of damages caused by groundings consists of the costs of injury assessments, restoration programs, monitoring of the restoration programs, and the lost values of the ecosystem from the onset of damage until the reestablishment of its pre-damage condition. This protocol discusses the economic foundations for estimating compensating payments for damages to coral reef resources, and establishes the basis for legal claims against parties responsible for damage caused by boat and ship groundings at Eilat, Israeli Red Sea.

1. THE ECONOMIC VALUE OF CORAL REEFS

Mainstream economics postulates that human well-being (economic welfare) is functionally linked to the consumption of goods and services. The benefits that human beings receive from ecosystem processes are referred to as ecosystem services (Hueting et al. 1998; Scott et al. 1998), and the economic value of an ecosystem is the measure of the welfare provided by the flow of its goods and services.

Coral reefs provide a wide array of goods and services to human societies (Table 1). In order to estimate losses in economic welfare associated with anthropogenic coral reef degradation, the impact of human activities on the reefs' flow of goods and services must be converted into economically meaningful measurements.

Table 1: Goods and services provided by coral reefs (modified from Spurgeon 1992 and Moberg and Folke 1999).

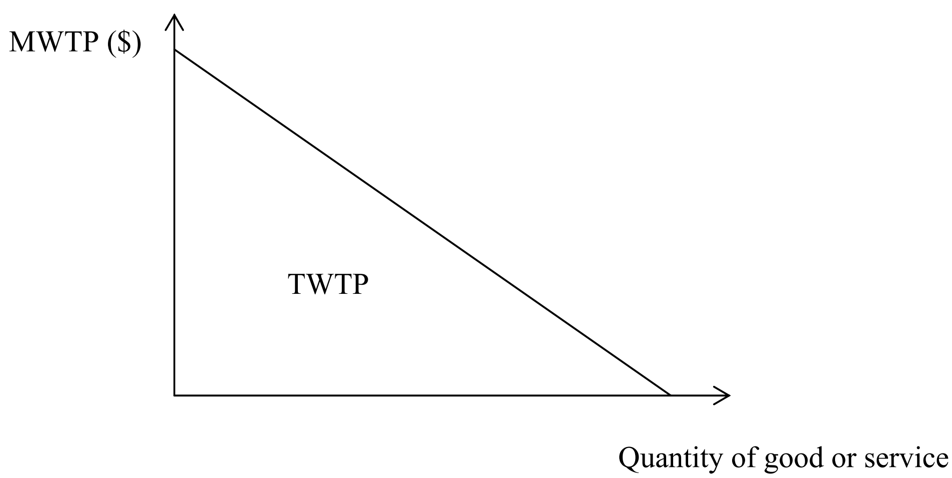
1. Fisheries
2. Raw materials for pharmaceutical and other industries
3. Resources for curio and jewelry
4. Resources for aquarium trade
5. Tourism and recreation
6. Aesthetic value
7. Cultural, religious and spiritual values
8. Shoreline protection
9. Materials for construction
10. Waste assimilation
11. Climate regulation

Humans enjoy coral reefs through the consumptive and non-consumptive use of coral reef resources. In consumptive use, the quantity and/or quality of the resource is reduced, as in the extraction of fishery resources. Non-consumptive use does not affect the quantity or quality of the resource, and can be realized through the enjoyment of public goods (where use by one person does not limit the possibility of use by others) such as underwater landscapes, or through coral reef services like shoreline protection and climate regulation.

Coral reef resources also possess "passive use" or "non-use" value (Krutilla 1967), in which people derive satisfaction from preserving coral reef resources without using them, and only through the knowledge that they exist. Sources of passive use value have been alternatively explained as ethical concerns towards nature (Kopp 1992), or as the awareness that abstaining from using the resource will allow others in current or future generations to use it (Krutilla 1967; Krutilla and Fisher 1975; McConnell 1997).

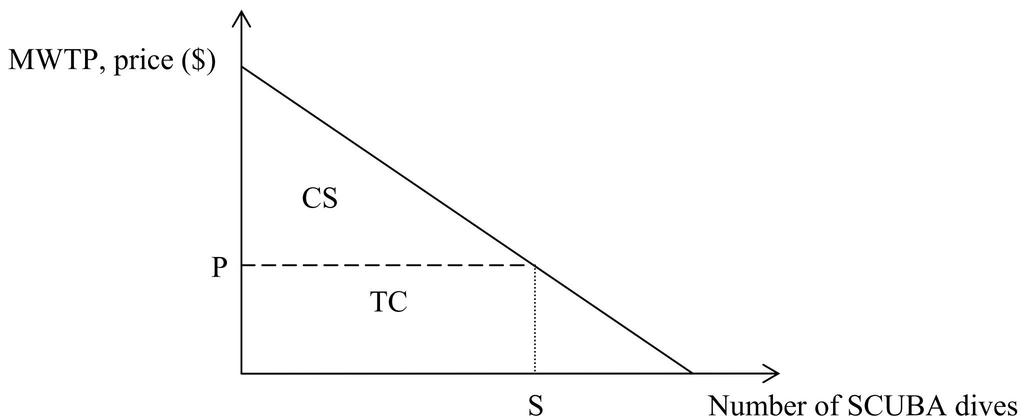
The marginal willingness to pay (MWTP) for the use of a good or service by an individual is related to the utility (satisfaction) derived from its use. Empirical evidence supports the theory of diminishing marginal utility, which states that for most goods or services, increases in the quantity used will lead to decreases in the utility generated by each additional unit (marginal utility). Thus, the familiar demand curve for a commodity has a negative slope (Fig. 1). For each additional unit of a good or service, MWTP is reduced. The area below the curve represents total willingness to pay (TWTP), and is a commonly used approximation of the economic value of the good or service. A "social" demand curve can be constructed by aggregating individual MWTP measurements for a given good or service.

Figure 1: The demand curve expressed as the marginal willingness to pay (MWTP) for an increasing quantity of a good or service, and the total willingness to pay (TWTP).



Market, or equilibrium prices represent implicit agreements between the users of goods and services, whose preferences are expressed in their demand curves, and suppliers, who will make decisions on the levels of output that they will make available based on cost and profit considerations. For a coral reef example, consider a SCUBA diver who uses the services of a diving club (e.g., equipment rental and transportation) in order to make a recreational dive on a coral reef. Fig. 2 represents this individual's demand curve for SCUBA diving at a particular reef area. It can be seen that if the service price is P, the diver's recreational use of the reef area (the number of dives) will be S. Below this quantity of use, the diver's MWTP will be higher than the price he/she has to pay; his/her use will rise until the MWTP for the last unit consumed (S, in this case the last dive made at the site) will be the same as the price. The total costs of diving will be equal to the rectangle TC, which is equal to the product of the cost per dive and the number of dives made.

Figure 2: A typical demand curve for a good or service. When marginal willingness to pay (MWTP), or price, equals P, the quantity demanded will be S and consumer surplus will be equal to triangle CS. Total costs of purchasing the good or service will be the area of rectangle TC.



The net utility or consumer surplus (CS) of this individual diver will be the total willingness to pay for diving at quantity S minus the total costs, which equals the area of the triangle CS. Variation in consumer surplus is a commonly used economic index to measure positive (benefits) or negative (costs) effects on human welfare brought about by changes in the quality of environmental assets such as coral reefs.

<u>Economic consequences of attribute damage</u>

Coral reefs worldwide are suffering from a decline in biodiversity due to a variety of human activities and stressors. Table 2 reviews studies that have linked human activities and stressor doses to responses by coral reef health parameters. Besides the activities presented here, overfishing and destructive fishing methods have also been responsible for reef degradation worldwide. It has been predicted that up to 70% of coral reefs will disappear during the next four decades (Wilkinson 1996). The coral reef system of the Gulf of Aqaba/Eilat is particularly vulnerable to anthropogenic stressors due to its location near the northern limits for coral reefs (Fishelson, 1995), and its low rate of water exchange with the main body of the Red Sea.

Table 2: Quantitative studies on effects of anthropogenic activities and stressors on coral reefs (from Wielgus et al., 2002).

Stressor(s)	***Dose***	***Variable***	***Response of Variable***	***Geographic Location***	***Study***
Boating impacts	5-260 boat trips	Coral damage	104% increase	Florida	Tilmant 1987[1]
Nutrients	Increases in a eutrophication index	Coral diversity	Up to 250% decrease in diversity	Caribbean	Tomascik and Sander 1987
Nutrients	0.07-1.52 mg Chlorophyll Am^{-3}	Coral diversity	40-60% reduction	Indonesia	Edinger et al. 1998[2]
Nutrients	20µM urea + 2µM phosphate	Coral growth	>50% decrease	Great Barrier Reef	Kinsey and Davies 1979
Nutrients	3.8-7.9 mg SPM/l	Coral growth	Up to 29% decrease	Caribbean	Tomascik and Sander 1985
Nutrients	Increases in a eutrophication index	Coral growth	Up to 55% decrease	Caribbean	Tomascik 1990
Nutrients	2-15 µM ammonium; 0.1-2.0 µM phosphate	Coral growth	Up to 90% decrease[3]	Hawaii	Stambler et al. 1991[4]
Nutrients		Coral growth	Up to 50% decrease	Caribbean	Marubini and Davies 1996[4]
Nutrients	1. 20 µM ammonium 2. 4 µM phosphorus 3. 20 µM ammonium + 4 µM phosphorus	Coral growth	1. 10-20% decrease 2. 29% increase 3. 30% increase	Great Barrier Reef	Steven and Broadbent 1997
Nutrients	10 and 20 µM ammonia; 2 µM phosphorus	Coral growth	0-75% decrease	Northern Red Sea[5]	Ferrier-Pagès et al. 2000
Oil pollution	0-406 µg/g dry wt	Coral growth	1.4-12.1% decrease	Caribbean	Guzmán et al. 1994

1 Calculations with data from Tilmant and Schmahl (1981)
2 Effects on other attributes were studied qualitatively
3 From Ferrier-Pagès et al. (2000)
4 Laboratory experiment
5 Laboratory experiment carried out at the Monaco Oceanographic Museum with Red Sea corals
6 A threshold was calculated for number of dives

Diving impact	0-25,000 dives/yr.	Coral damage	0-25% of corals	South Africa	Schleyer and Tomalin 2000
Diving impact	1000-4000 dives/3 mo.	Coral damage	8-70% of corals	Northern Red Sea	Zakai and Furman 2002 (in press)
Diving impact	400-19,000 dives per year	Coral damage	3-17% of corals	Northern Red Sea and Caribbean	Hawkins and Roberts 1997[6]
Diving impact	20-400 dives in 6 months	Coral damage	2-18% of soft corals; 1-11% of stony corals	Caribbean	Chadwick-Furman 1997
Sedimentation	0.4-300 mg/cm^2 /day$^-$	Coral growth	Up to 44% decrease	Caribbean	Cortés and Risk 1985
Sedimentation	5-250 mg cm^2 /day	1. Live coral cover 2. Coral species richness 3. Coral colony size	1. 21% decrease 2. 98% decrease 3. 64% decrease	Hawaii	Pastorok and Bilyard[7] 1985
Temperature and salinity	20-28^{o}C; 20-40‰	Coral growth	Up to 88% decrease	Hawaii	Coles and Jokiel[4] 1978
Turbidity (from sedimentation)	1.4-6.0 FTU	Live coral cover	Up to 77% decrease	Caribbean	Loya 1976[2]

[7] Calculations with data from Randall and Birkeland (1978)

Methods for the economic valuation of ecosystem goods and services

Goods and services from coral reefs, such as fish products and SCUBA trips, may be purchased in markets. The economic value of changes in these resources can be readily calculated by constructing demand functions and calculating CS (Fig. 2) with the prices and quantities demanded observed in markets. Other sources of economic value, such as aesthetic, cultural, and existence values, which are not usually directly traded in markets, have to be estimated by different methods. These methods for "non-market valuation" may be classified as "direct" and "indirect" (Shechter 2000). Direct, or "stated preference" (also referred to as contingent valuation) methods ask individuals, in an interview format, their willingness to pay for an increase (or their willingness to accept compensation for a decrease) in the quantity and/or quality of an environmental good or service. This approach was used to assess the economic damage caused by the Exxon Valdez grounding in 1989, and to establish restitution charges to compensate for the social costs of the accident. Dixon et al. (1993) used direct valuation to construct a demand curve for users of a marine park in Bonaire, and estimated the average willingness to pay of the respondents for entering the park. This figure could then be used to set an entrance fee, which would provide a funding source for park management.

Indirect, or "revealed preference" methods infer the value of the environment by studying the behavior of individuals toward marketed goods that are related to a particular asset. For example, for individuals visiting a national park, the money spent in gasoline, entrance fees, food, lodging and any sacrifice of income due to lost work hours is an indication of the value to them of the park's recreational services. Shafer et al. (2000) used such travel-cost models and concluded that the value for recreational power boaters of five freshwater resources in Pennsylvania was close to US $400 million annually.

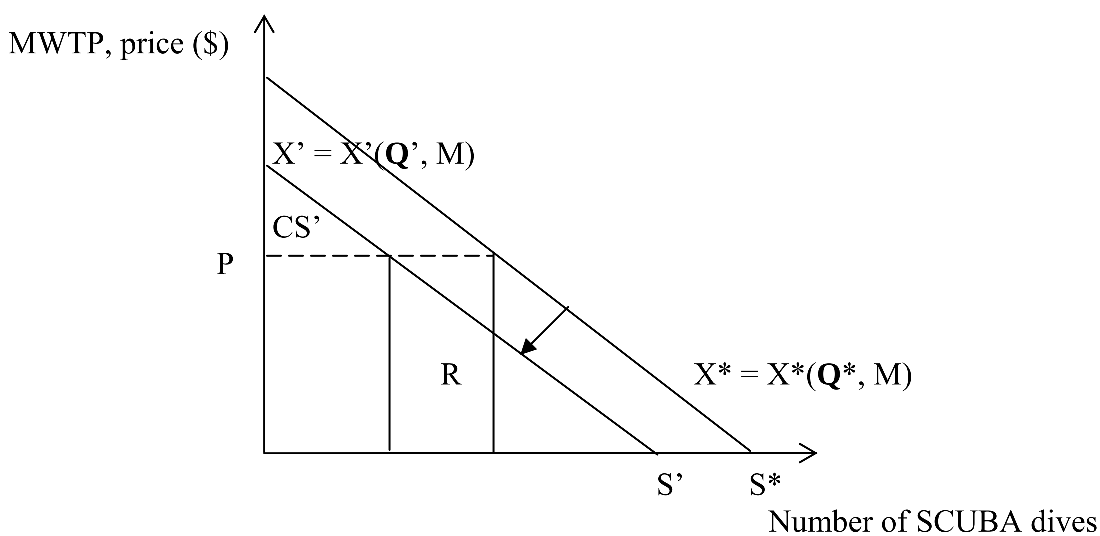
Choice Modeling, a technique relying on both stated and revealed preference, has recently been adopted in the non-market valuation of environmental assets (Hanley et al. 1998; Bennett 1999). By modeling the behavior of recreationists when choosing among sites with varying levels of attributes (including the costs of recreation), or alternatively by presenting hypothetical scenarios to groups of respondents and observing their choices, inferences can be made on changes in welfare associated with attribute decline (Bennett 1999). Choice Modeling has been used, for example, to study attribute preferences of recreational fishermen (Adamowicz et al. 1994) and mountain climbers (Hanley et al. 2001).

Another approach to economic valuation is the "replacement cost" methodology, by which the value of ecosystem goods and services that are lost through damage is measured by the cost of replacing those goods and services by restoration activities. This is an acceptable approximation of economic value only if the following conditions are met (Freeman 2003): (1) the goods and services provided by restoration are of the same quality and quantity as those lost; (2) the restoration project chosen must be the least-costly alternative; and (3) society must be willing to incur the costs of restoration if natural services are lost.

An illustration: welfare losses to SCUBA divers due to coral damage

Supposing that the demand for SCUBA diving at a given coral reef site is functionally related to the attributes that compose the "quality" of that dive site, a decrease in attribute levels will impose a cost to society through a reduction in the recreational value of this particular coral reef**.** In Fig. 3, assuming no changes in prices, a reduction in attribute levels would cause a downward shift of the demand curve and a subsequent reduction in consumer surplus (Stevens 1966). One consequence of attribute damage will be that economies dependent on coral reef tourism will experience financial losses accruing from tourists who will seek to satisfy their demand for recreation elsewhere. In areas of Jamaica and Thailand, for example, diving tourism has sharply decreased due to coral reef degradation (Wilkinson 1996).

Figure 3: Changes in CS due to a reduction in environmental quality. If the price of a SCUBA dive is P, and the demand for SCUBA diving is a function of a vector of attributes (**Q**) at a site and the income level of divers (M), a reduction in the level of one or more attributes will decrease coral reef quality from **Q*** to **Q**'. This will shift the demand function for SCUBA diving from X* to X' (see arrow), and reduce consumer surplus to CS'. The new level of demand will be S'. Gross financial losses to SCUBA operators accruing from reductions in diving activity will be equal to the rectangle R, which is the difference between the money spent in diving before and after the decrease in the level(s) of the attribute(s).



A single attribute may contribute to the value of a number of coral reef goods and services. For example, biodiversity clearly contributes to the value of the first 7 categories in Table 1, and could possibly be linked to more. Social costs of anthropogenic activities that reduce coral reef biodiversity include the decrease in the value of all goods and services to which this attribute contributes.

Some economic costs of attribute loss can be readily estimated for reductions in levels of recreationally significant attributes, since markets are usually present where recreational services are exchanged for money. For example, Cesar et al. (2000) estimated the current and future financial losses to coral reef tourism due to destruction of one square kilometer of reef in Indonesia to be between US $27,900 and $100,800. Berg et al. (1998) valued attribute loss to represent a cost of between $5,500 and $368,000 per square kilometer for coral reefs in Sri Lanka. Correspondingly, Hodgson and Dixon (1988) predicted financial losses in the order of US $40 million over a ten-year period due to tourism and fishery declines in a coastal area of Palawan, the Philippines, resulting from increased sedimentation produced by logging.

Economic costs to recreationists that are not apparent from market transactions can be estimated with the use of economic valuation methods. These methods provide a means of estimating the demand curves for individual attributes and services such as shoreline protection and climate regulation, which are not traded in the marketplace. Impacts on human welfare due to demand shifts caused by attribute changes can be readily explored once the demand for attributes is known. For example, McConnell (1986) used a combination of travel-cost and contingent valuation models and estimated that the damages to beach users accruing from PCB pollution in New Bedford, Massachusetts were in the order of $3 - $4 per person annually.

2. THE ECONOMIC VALUATION OF CORAL REEF ATTRIBUTE DAMAGE AT EILAT

Wielgus et al. (2003) used the Choice Modeling technique to estimate reductions in SCUBA diver welfare arising from coral reef degradation at Eilat. Choice Modeling has its foundations in random utility theory (Hensher and Johnson 1981; Louviere, Hensher, and Swait 2000; Bennett and Adamowicz 2001). In this framework, a consumer will choose one type of good or service over another, whenever consumption of the first results in higher utility (satisfaction) than consumption of the second. Utility is represented by an indirect utility function (U) consisting of an observed (conditional) component (V) and a random, unobserved component (E). The conditional component of indirect utility is assumed to be a linear function of a good's attributes. For an individual i, the utility of consuming good j that has a vector of attributes **X** can be expressed as:

$$Uij = Vij\ (\mathbf{X}) + Eij \qquad (1)$$

In a utility maximizing framework, the probability that individual i will choose good j over all other choices in a bundle with m choices, is the probability that $Uij > Uik$ for all k different than j. The utility of goods having the same *types* of attributes may differ if the *levels* of the attributes are not equal for each good. Assuming that the unobserved component (E) of utility is identically and independently distributed with an Extreme Value Type I (Gumbel) distribution, this probability can be expressed as:

$$P_{ij} = e^{V_{ij}} \left(\sum_{k=1}^{m} e^{V_{ik}}\right)^{-1} \qquad (2)$$

The parameters of the conditional indirect utility function can be estimated with maximum likelihood methods (Freeman 2003) and the marginal rate of substitution (MRS) between two attributes X1 and X2, that is the willingness with which people will trade one unit of one attribute for the other, can be calculated as:

$$MRS = ß_{X1}/ß_{X2} \qquad (3)$$

where $ß_{X1}$ and $ß_{X2}$ are the attribute coefficients. If price is included in the model as a "negative attribute", and its coefficient is represented by $ß_P$, the marginal or implicit price (IP) of any other attribute A, or the quantity of A that a person is willing to trade for one unit of money, will be given by:

$$IP_A = -(ß_A/ß_P) \qquad (4)$$

In the economic valuation of changes in environmental quality, respondents are presented with choice sets consisting of alternatives, where each alternative is a unique combination of attributes of an environmental good, such as a coral reef diving site. By modeling the choices made by respondents, the implicit prices of the different attributes (e.g., biodiversity, visibility) can be calculated as shown above. The influence of the socioeconomic characteristics of respondents on their choices can also be studied.

By providing implicit prices for environmental attributes, Choice Modeling can also be used to calculate economic welfare changes. If V_0 represents the conditional indirect utility before attribute damage occurs and V_1 is the conditional indirect utility after the damage (after the attribute change), compensating variation (CV), a measurement related to consumer surplus, is given by:

$$CV = (-1/ ß_P)(V_0 - V_1) \qquad (5)$$

When multiple recreation sites are considered, CV for a change in the attribute levels in one or more of "n" sites can be calculated as (Louviere et al. 2000):

$$CV = (-1/ ß_P)\left(\ln\sum_{s=1}^{n} e^{V_0} - \ln\sum_{s=1}^{n} e^{V_1}\right) \qquad (6)$$

CV measurements for individuals can then be aggregated to the level of a studied population, for example the total number of people benefiting from recreation, in order to explore the social consequences of changes to the environmental good in question.

In the Wielgus et al. (2003) study, 189 SCUBA divers (out of which 181 completely answered the ensuing questionnaire) were shown three short video samples, each representing a dive site with a particular combination of a biological index and visibility. The biological index was created by adding the abundance/m^2 (number of specimens of corals and fish/m^2) and the number of taxonomic categories of corals and fish at each site. Taxonomic categories were mostly at the species level, but if the same species of fish or coral exhibited different morphotypes, they were counted as separate categories. The results of the choice analysis showed that SCUBA divers that dive in the Coral Nature Reserve are willing to pay 11.86 NIS (New Israeli Shekels; one U.S. dollar equals approximately 4.5 NIS) per dive for an additional unit of the biological index, and 5.46 NIS per dive for an additional meter of visibility. The observed willingness to pay for quality improvements in diving sites by SCUBA divers at Eilat implies that activities causing attribute degradation have a negative impact on the economic welfare of divers.

Economic welfare changes were calculated for different scenarios, taking as a base an annual dive rate of 250,000 dives at Eilat (Zakai and Chadwick-Furman 2002), and assuming no changes in the current price of SCUBA diving. The first scenario assumed a 25% increase in the biodiversity index and in visibility. A second scenario considered a 25% increase in the biodiversity index and a 50% increase in visibility. The third scenario evaluated attribute increases to the "pre-damage" levels of 1963, assuming that the average visibility at the time was 20 m and that coral and fish abundance and species richness resembled the present-day reefs at nearby sites in Sinai (biodiversity index = 32.25). (Visibility in Eilat's reefs in 1963 was probably lower than the current average levels at Sinai (30 m.), due to the location of the former at the northern tip of the Gulf of Eilat (Aqaba), making them subject to higher levels of land-borne particulate matter that increase turbidity). Welfare changes for these scenarios ranged between 2,778,000 and 13,214,000 NIS per year. These values may be viewed as the costs imposed on SCUBA divers by economic activities that prevent the improvement of coral reef attributes.

3. CHARGES FOR DAMAGES TO CORAL REEF RESOURCES

Damage by Vessel Groundings and Restoration of Coral Reefs

A vessel is defined in this protocol as any vehicle operated in the water and capable of causing damage to the structure of the coral reef.

Damage to coral reefs by vessel groundings can range from relatively minor injuries, consisting of the damage or death of a small number of coral colonies, to catastrophic events in which the structural complexity of the reef framework is degraded (Precht et al. 2001a). While reefs have the ability to recover from minor and moderate injuries naturally, human intervention is required to rehabilitate them after a catastrophic event (Hudson and Goodwin 2001; Riegl 2001), after which reductions in the abundance and species richness of fish, corals, and other invertebrates are evident (Hatcher 1984; Hudson and Díaz 1988; Ebersole 2001; Miller and Barimo 2001; Riegl 2001). Effects of catastrophic groundings may be visible for centuries as scars on the coral substrate (Ebersole 2001; Riegl 2001) and alterations in the richness and abundance of fish species (Ebersole 2001).

With an estimated natural recovery time for coral and fish communities of 100-150 years in shallow reef slopes, the regeneration of sites impacted by ship groundings in the northern Red Sea appears to be slower than in other areas (Riegl 2001).

A typical restoration process includes the following (Precht 1998):

- Initial damage assessment and remedial actions (see Appendices 1 and 2). Initial remedial actions aim at rescuing the damaged resources, and include the salvaging of broken coral colonies or fragments, and removal or stabilization of loose debris and sediments to prevent further damages (Jaap 2000). Antifouling paint may be released by a vessel's hull into the marine environment and contaminate the sediment; antifouling paints with TBT (tributyltin) as their main active ingredient are known to be toxic to many marine organisms including mollusks, corals and anemones. Sediments contaminated by these substances should be removed (GBRMPA 2004).

- Detailed damage assessment and preparation of a restoration plan

- Implementation of the restoration plan

- Monitoring of coral reef recovery

- Adaptive management of the restoration plan

A variety of coral reef restoration methods has been employed, varying greatly in complexity and costs (see Jaap 2000; Miller and Barimo 2001). Common restoration activities include (Jaap 2000):

- Structural reconstruction of the damaged coral reef substrate. If possible, large coral formations are reattached to their original location with the use of winches. If this is not possible, coral formations are replaced with artificial structures having a similar structure. For the restoration of coral (Miller and Barimo 2001) and fish (Ebersole 2001) assemblages to be effective, it is important that the original three-dimensional structure of the reef is replicated. Cement, limestone boulders, and a combination of the two have been used for this purpose. Steel reinforcements have been applied for strengthening fractured reef structures.

    - Transplantation of corals and other organisms

Approaches to Charging for Coral Reef Damage

1. The United States

The United States legislation for the protection of natural resources is unique in that it addresses both the restoration of lost ecological services and the lost economic value of natural resources in the assessment of charges for damages (Boyd, forthcoming). There are two legal statutes that cover physical injuries caused to marine resources: The Marine Protection, Research, and Sanctuaries Act (MPRSA), and the National Parks System Resources Protection Act (NPSRPA). Three other bodies of law: the Comprehensive Environmental Response, Compensation, and Liability Act; the Oil Pollution Act, and the Clean Water Act, contemplate injuries to natural resources resulting from the release of oil and hazardous substances.

The MPRSA was enacted in 1972 in response to a growing concern about the increasing degradation of marine habitats in the United States. There are currently 13 areas protected as National Marine Sanctuaries, including coral reefs located in the Florida Keys (Table 3), the Flower Garden Banks in the Gulf of Mexico, and Fagatele Bay in American Samoa. The Secretary of Commerce of the United States, whose office has jurisdiction over the National Oceanic and Atmospheric Administration (NOAA), acts as trustee for the resources in the National Marine Sanctuaries, and may bring a legal action on his/her behalf. Those responsible for injuring or destroying a sanctuary resource are liable for the costs of damage assessment, any necessary enforcement activities, restoration expenses, the value of the lost use of the resource while restoration is taking place, and the monitoring of damages and restoration activities. If the resource is not recoverable or an equivalent resource cannot be acquired, liability is for the value of the lost resource (Lee et al. 2002).

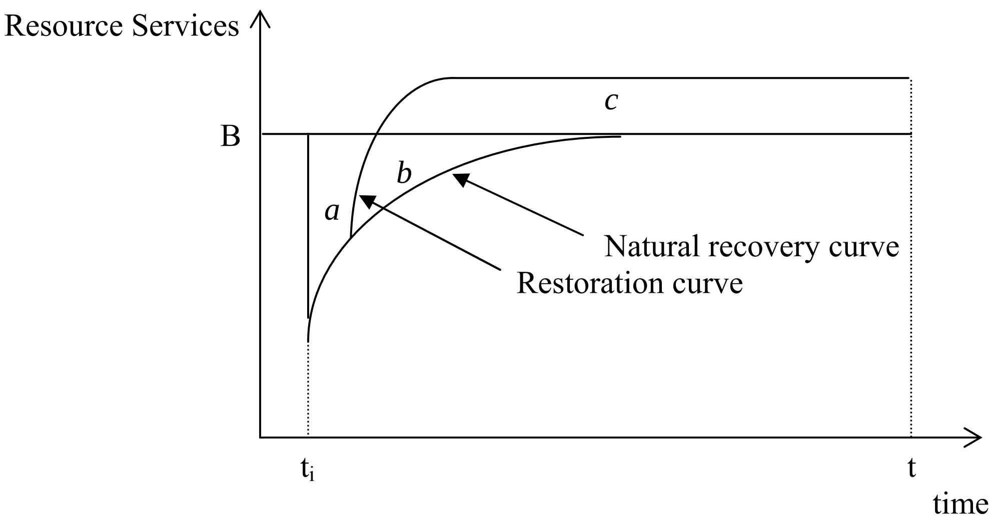
Table 3: Vessel grounding cases in the Florida Keys in which legal suits for damages to coral reefs have been based on the Marine Protection, Research, and Sanctuaries Act (MPRSA). Total coral reef destruction refers to the death of all coral colonies in an area; partial destruction refers to the occurrence of colony deaths and damages. The funds recovered as compensation for damages arising from court decisions or out of court settlements are shown (Sources: NOAA, 2003; USCRTF 2004).

Case	**Year of grounding**	**Vessel length (meters)**	**Reported scope of damage**	**Funds recovered ($)**
Wellwood	1984	122	extensive biological and structural injury	5,654,228
Mini Laurel	1986	65	biological and structural injury	30,000
Alec Owen Maitland	1989	47	partial destruction of 930 m^2 of reef; total destruction of 680.5 m^2	1,450,000
Elpis	1989	143	partial destruction of 482 m^2; total destruction of 2604.7 m^2	2,275,000
Jacquelyn L.	1991	54	total destruction of 123.1 m^2	251,554
Miss Beholden	1993	45	partial destruction of 1025.6 m^2	1,873,741
Columbus Iselin	1994	52	total destruction of 345 m^2	3,760,488
Petty Cache	1994	15	total destruction of 17.25 m^2	25,000
Contship Houston	1997	187	2333 m^2 of crushed coral reef substrate; over 3000 broken pieces of coral	5,738,000
Golden Lady	1997	22	total destruction of 42 m^2; additional sanctuary resources injured	54,716
Flyway	1998	14.6; sailing vessel	partial destruction of 9.3 m^2	Responsible party has undertaken restoration

The NPSRPA was enacted by the Congress of the United States in 1990 partly in response to a catastrophic ship grounding on a coral reef in a national park in Florida (Lee et al. 2002). Its purpose is to enable the United States government to initiate legal action against individuals who damage or destroy marine resources within the National Park System, and to allow for the recovery of funds for the prompt restoration or replacement of the affected resources. Prior to this Act, the government could recover damages to national park resources only under a legal action for damages to public property. The government had to meet a high burden of proof, and there was no assurance that any recovered funds would be used in restoring the affected resource (Lee et al. 2002). The recoverable costs and damages in the NPSRPA are similar to those of the MPRSA, but also include the costs of activities necessary to prevent or minimize further destruction, loss, or injuries to national park resources.

NOAA's Damage Assessment and Restoration Program (DARP) is responsible for generating guidelines for natural resource damage assessments. DARP has developed a method called Habitat Equivalency Analysis (HEA), by which the amount of compensatory restoration of damaged natural resources is calculated (NOAA 2003). HEA is consistent with the "replacement cost" method of economic valuation; its goal is to estimate the quantity of restored resources that will compensate for the loss of services from the time of injury until the damaged resources recover to baseline levels (interim losses) (Fig. 4). Natural resource damage assessment rules in the United States (contained in the Oil Pollution Act) specify that the trustees of the damaged natural resource should give the party responsible for the damage the opportunity to implement or fund the chosen restoration alternative (see the Flyway grounding case in Table 3). If the responsible party declines, the natural resource trustees are authorized to bring a civil action in a federal court (NOAA 1997).

Figure 4: The Habitat Equivalency Analysis (HEA) method calculates the quantity of natural resources that will compensate for the services lost from time t_i, when an injury occurs, until the baseline level (B) is reached. If there is no restoration (only natural recovery of the resources), the loss in services (interim losses) will be the area $a + b$. With restoration, interim losses will only be area a. Area c represents the additional resources that are supplied by the restoration project to compensate for interim losses; its discounted value should equal the discounted value of a. The period for the analysis is t. (Modified from Deis and French 1998).



Once the scale of a restoration project has been calculated that will return damaged resources to baseline levels and compensate for interim losses, the suitability of different restoration alternatives is examined according to criteria that include (NOAA 1997):

- Cost of the alternative. This must be a consideration for achieving economic efficiency (NOAA 1995; Freeman 2003).

- Likelihood of success

- Extent to which the implementation of the alternative avoids causing additional damages to natural resources

- Extent to which the alternative may benefit more than one natural resource or service

A recent application of HEA in damage assessment (Banks et al. 1998) generated a claim of $2.4 million against the United States government for injury to a coral reef caused by the grounding of the submarine USS Memphis off southeastern Florida. A detailed assessment of damages was conducted by the use of transects and aerial photographs. The grounding completely destroyed an area of 1,205 m^2 (all stony corals were killed). Impacts of the grounding on the abundance/m^2, live coral cover and species richness of stony corals were studied by comparing the values in the injured site with adjacent sites, since no previous data for these parameters were available. A conservative figure for reef recovery of 35 years was used, and only the area that was completely destroyed was included in the model. It was estimated that in addition to restoring the area that was destroyed, the restoration project would have to create 37 m^2 of new reef (with artificial reefs) to compensate for interim losses. The costs of assessment, removal of loose rubble, substrate stabilization, transplantation of corals, construction and deployment of artificial reefs, and implementation of a 20-year monitoring program were the base of the $2.4 million legal claim.

2. Experiences in Other Countries

In Australia, the Great Barrier Reef Marine Park Act of 1975 orders any damage to the Park arising from a vessel grounding to be repaired, mitigated or remedied by the responsible party, or the costs are paid by the responsible party. The costs of removing TBT and stabilizing a vessel-grounding site vary from A$1 to A$3 million (James Aston, Great Barrier Reef Marine Park Authority, personal communication). Additionally, fines of up to A$1.1 may be charged for long-term damages to the Great Barrier Reef, and fines are charged for entering areas that are prohibited to navigation. Australia currently does not have legislative provisions for the recovery of interim losses (James Aston, Great Barrier Reef Marine Park Authority, personal communication).

The Egyptian government made a $30,000,000 compensation claim in 1991, based on lost diving revenues, against the owners of the cargo ship M/V Mayflower, which damaged 340 m^2 of coral reef in the Strait of Tiran. An out of court settlement for $600,000 was finally reached (Spurgeon 1992).

4. WORKING HYPOTHESES

Based on the work of Wielgus et al. (2003) and the theoretical background provided above on coral reef damage and recovery, a protocol for the recovery of economic losses arising from coral reef damage can be formulated under the following working hypotheses (supporting evidence for the hypotheses from previous studies is given in parentheses):

1. Economic valuation methods provide a means to calculate interim losses (NOAA 1997; Milon and Dodge 2001; Freeman 2003). The Choice Modeling method is used in the present protocol to quantify interim losses. The "replacement cost" approach is used to estimate the costs of restoring a damaged coral reef site to baseline levels.

2. SCUBA diving is a major source of value for coral reefs in the Nature Reserve in Eilat, and the economic damages to the coral reef will be based on the economic losses in diver welfare. Because the coral reef of Eilat may be the source of other types of value, this will be a conservative estimate of economic losses.

3. The expenditures of SCUBA divers in Eilat (i.e., the number of dives they make) will not be affected by vessel groundings.

4. Currently, SCUBA divers in Eilat dive mainly in the following sites: Closed Reserve, Japanese Gardens, Caves, Migdalor/University, Princess Hotel North, Princess Hotel South, and Taba Terminal. These sites are located at the Nature Reserve. They have shallow areas susceptible to damage by vessel groundings.

5. Approximately 250,000 dives per year take place in the sites above (Zakai and Chadwick-Furman 2002).

6. Divers in Eilat usually rent diving equipment for two dives (they receive a large discount for renting equipment for half a day), which makes the costs of renting equipment per dive approximately 50 NIS. Divers will pay 75 NIS to a diving operator for a single dive to the Japanese Gardens (Aquasport, personal communication), but most will use their own transportation to dive at the other sites (personal observation). Although there is an entry fee of 20 NIS to dive in the Closed Reserve, most people diving there avoid paying it by entering the site from an adjacent area. For this reason, no entry fee is assigned for the Closed Reserve. The total cost of diving in a site will be the equipment rental plus any applicable fee charged by a diving operator. This is summarized in the following table:

Site	**Diving costs (NIS)**
Closed Reserve	50
Japanese Gardens	125
Migdalor/University	50
Caves	50
Princess Hotel North	50
Princess Hotel South	50
Taba Terminal	50

7. SCUBA divers in Eilat value coral abundance, fish abundance, coral species richness, and fish species richness equally (Wielgus et al. 2003). Divers have a good perception of the total number of coral and fish species in a dive site, but their impression of "abundance" is based on the average number of coral and fish per unit area, not the total number observed during a dive (Wielgus et al. 2003).

Divers can recognize between live and dead corals, and damage reduces the value of corals.

8. Visibility is another attribute valued by SCUBA divers (Wielgus et al. 2003), but it will not be affected by grounding events. Even though groundings may generate sediment by the pulverization of coral substrate (Jaap 2000), it is assumed that the restoration project will include the stabilization of substrate and the removal of excess sediments. Additionally, it is assumed that the average visibility at sites in the Nature Reserve is 20 meters (Wielgus et al. 2003).

9. A vessel-grounding event will affect the abundance of coral and fish in the impacted area of a site, but the site is large enough so that impacts will not reduce its number of coral and fish species.

10. Coral and fish abundance are correlated with reef size (Jennings et al. 1996; Acosta and Robertson 2002; Holbrook et al. 2002). At each site, linear relationships are assumed between coral abundance and reef area, and fish abundance and reef area (Holbrook et al. 2002).

11. A damaged area may consist of sections in which corals are killed and sections in which corals are injured (e.g., branches will be broken).

12. Due to the long time required for natural restoration, and the possibility that not conducting active restoration will lead to further deterioration of the reef resources, artificial methods will be used to enhance the damaged site. Two options are currently possible: (1) transplantation of juvenile corals from the Underwater Observatory (Mitzpeh Tat-Iami), and (2) transplantation of adult corals from donor sites in the North Beach. These sites may be sources of coral recruits for the Nature Reserve (Glassom et al. 2004), and may have recreational value in the future. For these reasons, the use of corals from donor sites for restoring damaged areas is not recommended.

13. The chosen restoration project will restore coral abundance to baseline levels. Fish abundance is correlated with live coral cover (Bell and Galtzin 1984; Bouchon-Navarro and Bouchon 1989), and will recover with improvements in coral abundance (Ebersole 2001). In addition, the recreational value of the restored site will be equivalent to the value of the site before the damage occurred.

14. A 3% real annual discount rate is used. This figure is commonly used in the economic valuation of natural resources (NOAA 1995; 1997).

5. PROCEDURE FOR THE ESTIMATION OF THE ECONOMIC DAMAGES CAUSED BY VESSEL GROUNDINGS

The following procedure can be used to estimate the implications of vessel groundings on the economic welfare of SCUBA divers:

1. Conduct a baseline survey of each of the dive sites in the Nature Reserve (Closed Reserve, Japanese Gardens, Migdalor/University, Caves, Princess Hotel North, Princess Hotel South, and Taba Terminal) to estimate: (1) the size of the area used by SCUBA divers; and (2) the Biological Index (BI) (Wielgus et al. 2003), which is given by:

   $$BI = c + f + C + F \qquad (7)$$

   where c= number of corals per m^2; f = number of fish per m^2; C = number of coral species in the site; and F = number of fish species in the site. BI can be estimated by sampling representative quadrats or transects (see for example English et al, 1997) Areas which lack live coral (e.g., patches of dead coral or sand) should not be surveyed, since they are assumed not to be valuable for divers. Coral and fish species that look similar should be aggregated into a single taxonomic category, since divers will probably consider them as a single species (Wielgus et al. 2003). Species of fish that are highly mobile and do not establish territories in single sites should not be counted, since their presence in a specific site is a random occurrence from a diver's perspective. Cryptic species of corals and fish, which are usually not seen by divers, should also not be counted. Baseline surveys should be repeated every few years, due to the decreasing trend in live coral cover and abundance at Eilat (Fishelson 1995).

2. Evaluate the physical and ecological damage immediately after a grounding event, following for example the protocol of Hudson and Goodwin (2001). Initiate restoration actions, as discussed above.

3. Estimate the size of the area damaged by the grounding, and the proportion of the total site that this area represents.

4. Estimate the costs of restoring the damaged site to baseline levels, and the time of recovery, for several restoration alternatives. Analyze the probability of success of the alternatives. A highly cost-efficient, technically feasible alternative with a good probability of success should be selected.

5. Estimate interim losses. Following equation (6), calculate the Compensating Variation (CV) for changes in the level of BI in the damaged site, taking into account the discounting of losses occurring in different time periods. Analysis should include the time elapsed from the moment of damage to the expected return of resources to baseline levels.

6 Calculate the total value of damages by adding the assessment costs to the expected restoration, interim, monitoring, and any other applicable costs.

6. A HYPOTHETICAL CASE STUDY

The following hypothetical example illustrates the calculation of a legal claim for damages caused by a vessel grounding to the coral reef of Eilat.

A vessel grounding damages the Caves site. The area commonly visited by divers at this site has been previously calculated at 400 m^2. The hypothetical BI of the sites in the Nature Reserve is given in the following table.

Site	BI
Closed Reserve	26
Japanese Gardens	29
Migdalor/University	22
Caves	23
Princess Hotel North	22
Princess Hotel South	23
Taba Terminal	20

The cost of a diver per hour (diver-hours) is assumed to be 80 NIS. Initial assessment of the damages requires 6 diver-hours. The divers estimate the damage at 20 m^2; this includes areas in which corals were killed, and areas were branching corals were broken. It is decided that loose sediments should be removed from the injured area to prevent additional damage to corals, and that the live loose fragments of corals will be reattached. These tasks will take an additional 80 diver-hours and 800 NIS in materials.

To restore the sections where corals were killed, it is decided to transplant juvenile corals brought from the Underwater Observatory (Mitzpeh Tat-Iami). This will take 120 diver-hours (including the time to transport the corals from the Observatory) and 1,200 NIS in equipment costs. The damaged area will take an estimated 6 years to recover to baseline levels of corals and fish/m^2. After 6 years the transplanted coral colonies in the site are expected to have grown to levels in which they have recreational value, and fish abundance is expected to have recovered (Epstein et al. (1999) found that 6 years after a site in the Nature Reserve was closed to the public, branching corals had significantly recovered from breakage. Although a 6-year period will probably not be enough time for natural recovery in coral abundance to take place in a site injured by a vessel grounding, coral transplantation will be used to artificially restore abundance in the site). To examine the survival of the broken corals, re-attached coral fragments, and transplanted corals, a monitoring program will be implemented consisting of 4 diver-hours every 3 months during a 2 year period (a total of 32 diver-hours).

To calculate interim losses, V_0 and V_1 are computed for each site using values for the average visibility and diving costs given in the Working Hypotheses, and the following coefficients from Wielgus et al. (2003):

Parameter	Coefficient
BI	0.1227
Visibility	0.0565
Price	-0.0103

$V_{0(\text{Closed Reserve})} = (0.1227)(26) + (0.0565)(20) + (-0.0103)(50) = 3.805$
$V_{0(\text{Japanese Gardens})} = (0.1227)(29) + (0.0565)(20) + (-0.0103)(125) = 3.401$
$V_{0(\text{Migdalor/University})} = (0.1227)(22) + (0.0565)(20) + (-0.0103)(50) = 3.314$
$V_{0(\text{Caves})} = (0.1227)(23) + (0.0565)(20) + (-0.0103)(50) = 3.437$
$V_{0(\text{Princess Hotel) North}} = (0.1227)(22) + (0.0565)(20) + (-0.0103)(50) = 3.314$
$V_{0(\text{Princess Hotel South})} = (0.1227)(23) + (0.0565)(20) + (-0.0103)(50) = 3.437$
$V_{0(\text{Taba Terminal})} = (0.1227)(20) + (0.0565)(20) + (-0.0103)(50) = 3.069$

V_1 is identical to V_0 for all sites except for the damaged site (Caves), for which it is assumed for this example that the initial BI (23) was composed of 15 species of coral and fish, and 8 specimens of coral and fish per m^2. Since 5% of the site has been damaged, it is assumed (see Working Hypothesis 10) that the same proportion in the numbers of coral and fish/m^2 are eliminated. Hence the new value for $BI_{(\text{Caves})}$ is (15 + 7.6) = 22.6.

If recovery is linear (an assumption used in NOAA 1995) throughout the 6-year period, at the end of each year BI will be:

Year	BI
1	22.67
2	22.73
3	22.80
4	22.87
5	22.93
6	23.00

Using the average level of BI for each period, the corresponding $V_{1(\text{Caves})}$ will be:

$V_{1(\text{Caves})\,1} = (0.1227)(22.64) + (0.0565)(20) + (-0.0103)(50) = 3.393$
$V_{1(\text{Caves})\,2} = (0.1227)(22.70) + (0.0565)(20) + (-0.0103)(50) = 3.400$
$V_{1(\text{Caves})\,3} = (0.1227)(22.77) + (0.0565)(20) + (-0.0103)(50) = 3.409$
$V_{1(\text{Caves})\,4} = (0.1227)(22.84) + (0.0565)(20) + (-0.0103)(50) = 3.417$
$V_{1(\text{Caves})\,5} = (0.1227)(22.90) + (0.0565)(20) + (-0.0103)(50) = 3.425$
$V_{1(\text{Caves})\,6} = (0.1227)(22.97) + (0.0565)(20) + (-0.0103)(50) = 3.433$

Using equation (6), interim damages (per dive) are calculated for each period:

$CV_1 = -0.6125$
$CV_2 = -0.5121$
$CV_3 = -0.3940$
$CV_4 = -0.2751$
$CV_5 = -0.1725$
$CV_6 = -0.0519$

The negative values indicate a negative willingness to pay by divers for decreases in BI; the absolute values are the required levels of compensation, per dive, for causing a decrease in the recreational value of the area. Aggregating for 250,000 dives per year and discounting with a 3% rate gives a net present value of 468,654 NIS:

Year	**CV (Absolute value)**	**Aggregate CV**	**Present Value (NIS)**
1	0.6125	153,125	148,665
2	0.5121	128,025	120,676
3	0.3940	98,500	90,141
4	0.2751	68,775	61,106
5	0.1725	43,125	37,200
6	0.0519	12,975	10,866
Total			**468,654**

The basis for a legal claim would be the following:

Source of costs	**Costs (NIS)**
Damage assessment	480
Damage control (sediment removal, fragment re-attachment)	7,200
Coral transplantation	10,800
Interim losses	468,654
Monitoring program	2,560
TOTAL	**489,694**

7. FINAL COMMENTS

- Economic valuation methods have been endorsed by economists and by the United States legal system as a basis for claims against those responsible for natural resource damages. Previous economic and ecological studies and a set of working hypotheses can be used as a basis for estimating the required compensation for damages to the coral reef of Eilat.

- A current survey of each of the sites used by SCUBA divers to estimate baseline (pre-damage) levels would facilitate the application of this protocol, but would have to be updated periodically due to the trend of decreasing biodiversity in Eilat. Alternatively, the undamaged areas of a site injured by a grounding event could be surveyed as part of the damage assessment activities to estimate baseline levels of the site.

- To estimate the required compensation for damages, each grounding event should be analyzed separately, since the impact on economic welfare depends on the attribute levels of the damaged site, the extent of the damage, the required restoration activities, and the estimated time required to achieve baseline levels.

- With the implementation of legal claims for reef damage, it can be contemplated to begin requiring vessel operators to purchase insurance policies that will provide coverage against damages caused by groundings. This would ensure that vessel owners have the ability to pay for the damages they cause to reef resources (Boyd, forthcoming).

- Other types of physical impact to the reef, like trampling by swimmers/snorkelers and coral breakage by SCUBA divers, can be analyzed similarly to vessel groundings to estimate compensating payments for the damages they cause to reef resources.

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