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P. L. Jokiel and K. S. Rodgers

Surrey Beatty & Sons

43 Rickard Road, Chipping Norton, New South Wales, 2170 Australia
Telephone: (02) 9602 3888 Facsimile: (02) 9821 1253
Email: surreybeatty@iform.com.au

Ranking coral ecosystem "health and value" for the islands of the Hawaiian Archipelago

PAUL L. JOKIEL[1] and KU'ULEI S. RODGERS[1]

An evaluation of the "health" and "value" of the Northwestern Hawaiian Islands (NWHI) in relation to the main eight Hawaiian Islands (MHI) was undertaken as part of the process for evaluating the NWHI for possible designation of this area as a National Marine Sanctuary. Biological information for the NWHI region is very limited due to its extreme isolation, but sufficient data on five important biological indicators were developed for both the NWHI and the MHI. These include: reef fish biomass, reef fish endemics, total living coral cover, population of the endangered Hawaiian Monk Seal *Monachus schauinslandi*, and the number of female Green Sea Turtles *Chelonia mydas* nesting annually on each island. These diverse data sets were used in a simple integrated scoring and ranking scheme for all the islands of the archipelago. The resulting composite scoring is essentially an index of biological integrity. The final result graphically demonstrates the value of the NWHI in a manner easily understood by the public, government decision makers and managers. Further, the contrast of the NWHI to the MHI illustrates the diminished condition of reefs close to human population within the Hawaiian Archipelago. This approach proved to be very useful in the integration of diverse data sets.

Key words: Coral reef, Ecosystem health, Marine protected area, Ranking, Index of biological integrity.

INTRODUCTION

THIS project was developed as a response to an immediate and critical need to describe relative "reef health" or condition and "reef value" for the Hawaiian Islands using available data due to the process of evaluating the Northwestern Hawaiian Islands as a possible marine sanctuary (NOAA 2005). "Reef health" and "reef value" are terms that lack the rigor required for scientific analysis, but are readily understood by the general public and are useful concepts utilized by most managers. Researchers must translate ecological information into a form that is useful to managers, legislators, government administrators and the public. Factors such as coral cover, reef fish biomass, presence of endemic species and presence of threatened or endangered species are universally considered to be important biological indicators of "reef health" or "reef value". Where adequate data exist we can develop a relative ranking scheme to compare different locations. NOAA (2005) set a precedent in using reef fish rank, coral rank and endangered species rank in the analysis of coral reef status within the NWHI. The aim of the current project was to further develop and expand this initial NOAA effort to include the Main Hawaiian Islands (MHI). This project was undertaken to explore the use of a single index of "coral reef health and value" based on the best currently available data to assess coral reefs in the Hawaiian Archipelago.

METHODS

Development of data base

Available data relevant to ranking of the condition and value of coral reef ecosystems were compiled for 18 islands of the Hawaiian Archipelago. In order to produce an integrated ranking and index for the "health" or "value" of these areas it was necessary to use factors with reliable data for all 18 islands. Missing or inconsistent data creates an unworkable situation in the ranking scheme. Further, the factors chosen for the comparison must be accepted as important indicators in the scientific and management communities. There is widespread agreement that factors such as critical habitat of threatened and endangered species must be included. Metrics describing the reef fish and coral communities also rank high as useful diagnostic parameters. A thorough review of existing information was undertaken in order to identify and develop the most meaningful, extensive and complete data sets. Preference was given to previously published data, although some gaps would necessarily need to be filled in with unpublished data provided by experts in the field.

Selection of an index or ranking scale

A number of ranking and scaling schemes have been used in the past. For example, one could rank the 18 Hawaiian Islands from 1 to 18 for each factor or use a percentile score. The need to communicate this information to the public and with non-scientist professionals led to the selection of a simple 0 to 10 scaling of data to produce a composite relative ranking. The public is very familiar with this type of ranking scale because it has been popularized by the media. During the1976 Olympic Summer games in Canada a young Romanian named Nadia Comaneci made Olympic history when she received the first perfect 10 in the history of gymnastics. The 1979 Blake Edward's film "10"

[1]Hawaii Coral Reef Assessment and Monitoring Program (CRAMP), Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, HI 96744 USA. E-mail: jokiel@hawaii.edu, kuuleir@hawaii.edu
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with Bo Derek as Jenny was a box-office hit and did much to popularize the use of the term "perfect 10". For example a "Google™ search" yields hundreds of contemporary references to the term "perfect ten". The general public understands the concept that a number of factors are scaled from 0 to 10 and averaged, and that lower scores will bring down the average. There already is a consciousness in the public that can help to convey the meaning of the combined ranking.

Sensitivity analysis

Use of only five metrics in the ranking of these islands is a cause for concern. A simple sensitivity analysis was conducted by recalculating the index using only four of the factors. In other words the same procedure was run with no turtle data, with no seal data, with no coral data, with no fish biomass data and with no fish endemicity data. The results of this analysis were plotted for comparison to determine whether or not dropping one of the metrics would have a great impact on the ranking.

RESULTS

Five metrics of coral reef biological "health" or "value" were identified that met the requirements presented in the Methods section.

Fish biomass and endemism

Published data on reef fishes in the Hawaiian Archipelago is available from Friedlander and DeMartini (2002) for the MHI and NWHI (except Midway Island), DeMartini and Friedlander (2004) for the NWHI, and Jokiel *et al.* (2004) and Friedlander *et al.* (2003) for the MHI. All three studies used the same methodology and the same spreadsheets to calculate factors such as total biomass of fishes and rate of endemism. Results are summarized in Table I. Fish biomass is reported in metric tons per hectare (1 metric ton = 2 500 kg). Friedlander and DeMartini (2002) had insufficient data to calculate a value for Midway total fish biomass for the 2002 report. Additional transects have been run since that time and a comparative value has been furnished by E. E. DeMartini (pers. comm.). A summary of all fish biomass data is shown in Figure Ia. DeMartini and Friedlander (2004) reported per cent endemism for fish counts in the NWHI. Jokiel *et al.* (2004) calculated the same values for fish populations in the MHI using the same inter-calibrated fish counting technique and the same spread sheets to process the data. The integrated results are summarized as Figure Ib.

Table I. Data and data sources.

Location	Reef Fish Endemism (% Abundance)	Reef Fish Total Biomass (Tons/hectare)	Coral Cover on Hardbottom (% Live Cover)	Monk Seals (No. Individuals)	Green Sea Turtles (Females Nesting Annually)
NWHI					
Kure Atoll	56 [A]	1.3 [B]	13.8 [E], 12.8 [L]	90 [K]	0 [H]
Midway Atoll	54 [A]	2.5 [C]	9.6 [E], 9.2 [L]	64 [K]	0 [H]
Pearl and Hermes	62 [A]	4.6 [B]	12.8 [E], 11.9 [L]	203 [K]	24 [H]
Lisianski Island	58 [A]	2.6 [B]	59.3 [E], 38.3 [L]	178 [K]	20 [H]
Laysan Island	41 [A]	2.1 [B]	21.7 [E], 16.4 [L]	272 [K]	14 [H]
Maro Reef	50 [A]	1.7 [B]	64.1 [E], 40.7 [L]	0 [K]	0 [H]
Gardner Pinnacles	36 [A]	3.8 [B]	7.3 [E], 12.4 [L]	0 [K]	0 [H]
French Frigate Shoals	46 [A]	2.5 [B]	14.7 [E], 24.0 [L]	290 [K]	630 [H]
Necker Island	35 [A]	1.4 [B]	4.4 [E] 48 [F]	0 [H]	
Nihoa Island	20 [A]	2.8 [B]	11.5 [E] 47 [F]	0 [H]	
MHI					
Niihau	39 [D]	0.7 [D]	4 [D], 0.3 [M]	32 [G]	2 [H]
Kauai	35 [D]	0.4 [B], 0.6 [D]	16 [D], 7.5 [M]	7 [G]	2 [H]
Oahu	38 [D]	0.6 [B], 0.4 [D]	11 [D], 14.4 [M]	1 [G]	2 [H]
Molokai	24 [D]	0.5 [B], 1.0 [D]	41 [D], 8.6 [J], 44 [M]	5 [G]	4 [H]
Lanai	15 [D]	0.6 [D]	15 [D], 34.1 [M]	1 [G]	0 [H]
Maui	33 [D]	0.8 [B], 0.9 [D]	27 [D], 30.4 [M]	3 [G]	2 [H]
Kahoolawe	10 [D]	1.3 [B], 0.6 [D]	54 [D], 32 [I]	2 [G]	0 [H]
Hawaii	22 [D]	0.6 [B], 0.4 [D]	20 [D] 1 [G]	0 [H]	

[A] DeMartini and Friedlander (2004)
[B] Friedlander and DeMartini (2002)
[C] Edward Demartini (pers. comm.)
[D] Jokiel *et al.* (2005)
[E] data listed in NOAA (2005) Table 2. Data from 2002 NOWRAMP survey reports synthesized by Alan Friedlander.
[F] NOAA NMFS (2005)
[G] J. D. Baker and T. C. Johanos (2005).
[H] George Balazs (pers. comm.)
[I] Jokiel *et al.* (1993), 33 sites
[J] Eric K. Brown (pers. comm.)
[K] Stewart (2004) in NOAA (2005)
[L] Jean Kenyon and Greta Aeby (2004)
[M] Jean Kenyon and Greta Aeby (pers. comm.)

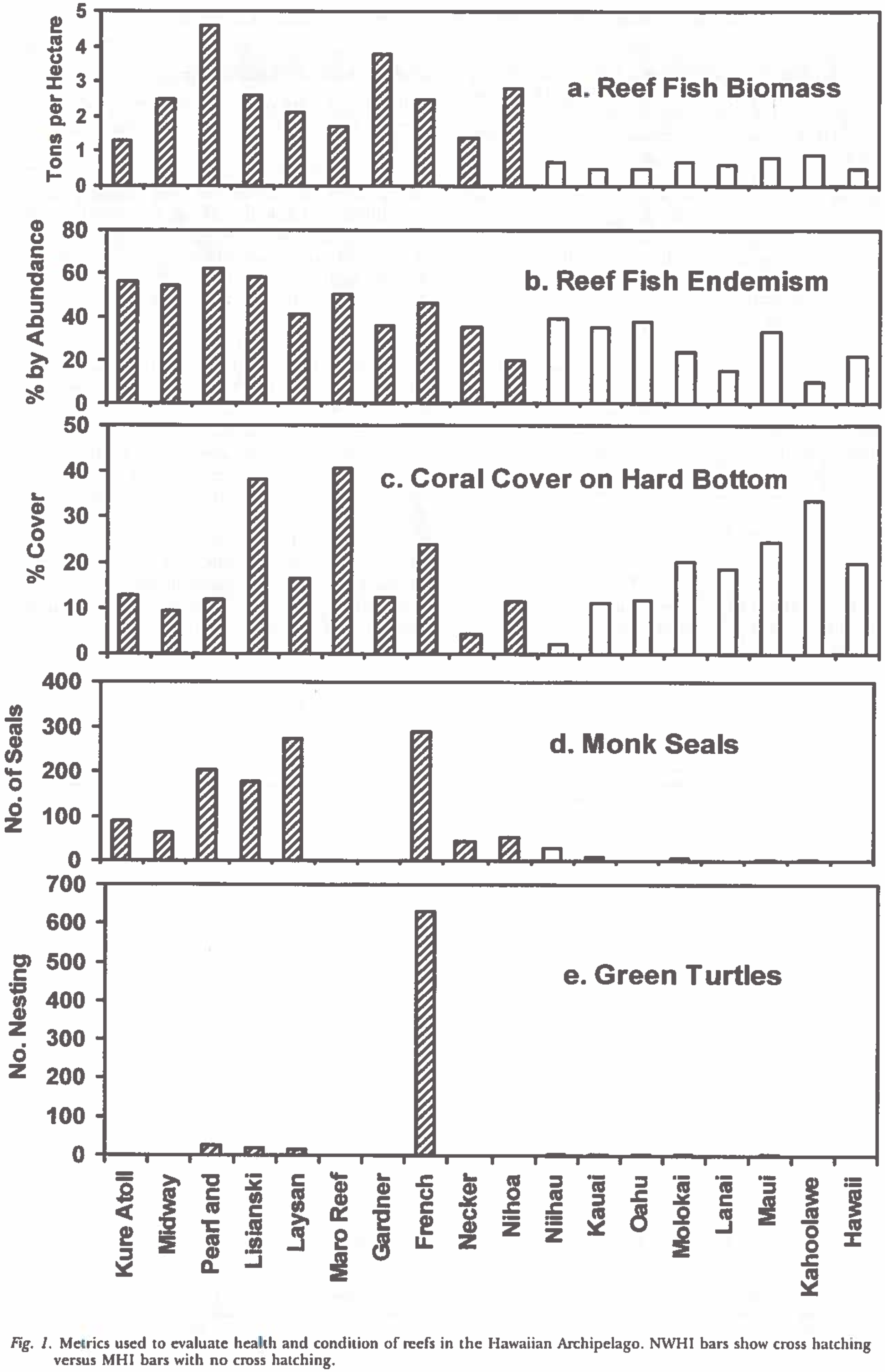

Fig. 1. Metrics used to evaluate health and condition of reefs in the Hawaiian Archipelago. NWHI bars show cross hatching versus MHI bars with no cross hatching.

Coral cover on hard substrate

Estimates for average coral cover on each island were made using the best internally consistent data sets with a large number of samples from around each island in various habitats. A recent comparison of methodology demonstrated that data from the different sources used in this analysis are comparable (Jokiel *et al.* 2005). Average total living coral cover for each of the NWHI (Kenyon and Aeby 2004; Kenyon and Aeby, pers. comm. and data listed in NOAA 2005) as well as comparative data for the MHI (Jokiel *et al.* 2004) are available (Table 1). These values were supplemented with additional survey data taken by Kenyon and Aeby (pers. comm.) during 2005 and listed as means of all data in Table 1. Coral cover measurements made by CRAMP (n = 25) on Molokai were previously restricted to the sheltered south shore, where coral cover is very high. Fortunately, Eric K. Brown (pers. comm.) has recently completed a series of additional transects (n = 48) along the north shore. Additional transects (n = 4) were run by Kenyon and Aeby (pers. comm.) during 2005. These data were combined with the CRAMP data in order to calculate a more realistic average for the entire island. Likewise, Kahoolawe has not been adequately sampled (n = 2) by CRAMP. However, coral cover data from transects (n = 33) taken along the shoreline of the entire island shoreline are available (Jokiel *et al.* 1993). These data are comparable to the CRAMP data and were combined in order to calculate a mean coverage for Kahoolawe. The data for Niihau consists of stations taken along the north shore by CRAMP with an additional series of nine sites along the south shore and Lehua Island by Kenyon and Aeby during 2005. This entire island is exposed to South Swell and wave wrap from the NE Pacific Swell so coral cover is low. A tow-board survey during July 2005 revealed low coral cover along the entire south shore of Niihau (Ben Richards, pers. comm.), so the value presented for Niihau is realistic. The coral data used in the analysis are presented in Table 2 and Figure 1c, with the scores shown in Table 3.

Monk seal population

The Hawaiian Monk Seal *Monachus schauinslandi* is an endemic endangered species. In other parts of the world similar species of tropical seals have been extirpated or greatly reduced in numbers. The NWHI remains one of the last major populations and is considered to be an extremely valuable resource from the standpoint of biodiversity, conservation and the ecology of the Hawaiian Archipelago. Estimates of Hawaiian Monk Seal population in the NWHI used in this investigation were developed using data of B. S. Stewart as reported in Table 2 of NOAA (2005). The NWHI data were updated using information from NOAA NMFS (2005). Population estimates of the Hawaiian Monk Seal in the MHI are from Baker and Johanos (2005). Results are shown in Tables 1–2 and Figure 1d.

Number of female Green Sea Turtles nesting annually

The Green Sea Turtle *Chelonia mydas* in the Hawaiian Archipelago is a single spatially distinct

Table 2. Data used in the analysis.

Location	Reef Fish Endemism (% Abundance)	Reef Fish Total Biomass (Tons/hectare)	Coral Cover on Hardbottom (% Live Cover)	Monk Seals (No. Individuals)	Green Sea Turtles (Females Nesting Annually)
NWHI					
Kure Atoll	56	1.3	12.8	90	0
Midway Atoll	54	2.5	9.2	64	0
Pearl and Hermes	62	4.6	11.9	203	24
Lisianski Island	58	2.6	38.3	178	20
Laysan Island	41	2.1	16.4	272	14
Maro Reef	50	1.7	40.7	0	0
Gardner Pinnacles	36	3.8	12.4	0	0
French Frigate Shoals	46	2.5	24.0	290	630
Necker Island	35	1.4	4.4	48	0
Nihoa Island	20	2.8	11.5	47	0
MHI					
Niihau	39	0.7	2.1	29	2
Kauai	35	0.5	11.3	9	2
Oahu	38	0.5	11.8	1	2
Molokai	24	0.7	21.6	5	4
Lanai	15	0.6	18.7	1	0
Maui	33	0.8	24.6	3	2
Kahoolawe	10	0.9	33.4	2	0
Hawaii	22	0.5	20.0	1	0

Table 3. Scoring of values from Table 2 on a scale of 0–10.

Location	Reef Fish Endemism (% Abundance)	Reef Fish Total Biomass (Tons/hectare)	Coral Cover on Hardbottom (% Live Cover)	Monk Seals (No. Individuals)	Green Sea Turtles (Females Nesting Annually)	AVERAGE SCORE
NWHI						
Kure Atoll	8.85	1.95	2.77	3.10	0.00	3.33
Midway Atoll	8.46	4.88	1.84	2.21	0.00	3.48
Pearl and Hermes	10.00	10.00	2.54	7.00	0.38	5.98
Lisianski Island	9.23	5.12	9.38	6.14	0.32	6.04
Laysan Island	5.96	3.90	3.70	9.38	0.22	4.63
Maro Reef	7.69	2.93	10.00	0.00	0.00	4.12
Gardner Pinnacles	5.00	8.05	2.67	0.00	0.00	3.14
French Frigate Shoals	6.92	4.88	5.67	10.00	10.00	7.49
Necker Island	4.81	2.20	0.60	1.66	0.00	1.85
Nihoa Island	1.92	5.61	2.44	1.62	0.00	2.32
MHI						
Niihau	5.58	0.49	0.00	1.00	0.03	1.42
Kauai	4.81	0.00	2.38	0.31	0.03	1.51
Oahu	5.38	0.00	2.52	0.03	0.03	1.59
Molokai	2.69	0.49	5.05	0.17	0.06	1.69
Lanai	0.96	0.24	4.30	0.03	0.00	1.11
Maui	4.42	0.73	5.83	0.10	0.03	2.22
Kahoolawe	0.00	0.98	8.11	0.07	0.00	1.83
Hawaii	2.31	0.00	4.64	0.03	0.00	1.40

genetic population with numerous feeding grounds and nesting grounds (Balazs and Chaloupka 2004a). Successful reproduction is a critical aspect of the population biology of this protected species. The turtles occur throughout the archipelago, but nesting takes place in the NWHI. Over 90% of the nesting activity takes place at French Frigate Shoals (Balazs and Chaloupka 2004b). George Balazs (pers. comm.) provided estimates of the average numbers of female turtles nesting annually off each of the Hawaiian Islands (Table 1). This estimate is based on his extensive work over the past 30 years (e.g., Balazs and Chaloupka 2004b). The number of females nesting on a given island is highly variable from year-to-year. For example, there is a distinct 3–4 year periodicity in annual nesting abundance. Further, there has been a substantial long-term increase in abundance of turtles following cessation of harvesting in the 1970s, so the population is not in equilibrium. Results are shown in Tables 1–3 and Figure 1e.

Calculation of 0–10 scores for each factor

Mean values calculated from Table 1 were used in the analysis and presented as Table 2 and Figure 1. Examination of the data (Tables 1–2, Fig. 1) reveals that higher values generally occur in the NWHI compared to the MHI, but with a great deal of variation. Thus, it is difficult for anyone to cognitively integrate these patterns into a coherent overall picture. Each factor is on a different scale and there is variability between the different islands. This difficulty was overcome by scoring each island on a scale from 0 to 10 for each of the five factors. In this way a meaningful average score can be calculated. The score on a scale of 0 to 10 is calculated by the formula:

$$\text{Score} = (10)(X - X_{min}) / X_{max} - X_{min}$$

Where X is the value of the variable to be ranked, X_{max} is the maximum value for that variable in the data set and X_{min} is the minimum value for that variable in the data set. This calculation will produce a 0 to 10 score for each value.

This formula will give the lowest value for each parameter (X_{min}) a score of 0 and the highest value (X_{max}) a score of 10. The other islands will have intermediate scores (Table 3). A mean score for each island was calculated as the average of the five scores (Table 3 and Fig. 2). No island received a "perfect 10", which would require one island to have the top score in each of the five categories. Note that the five categories were each given an equal weight in this analysis — each accounted for 20% of the average score. Different weights could be assigned to each factor depending on perceived relative value, management questions and management criteria, but for purposes of this analysis each was given the same weight.

Sensitivity analysis

Results of the sensitivity analysis are shown in Figure 3. Eliminating any one of the five metrics had little impact on the general pattern between the MHI and NWHI, suggesting that each factor is equally important and should be given the same weight. Further, the result suggests that relatively few metrics are needed, probably because the differences between major biological parameters between the MHI and NWHI are so great.

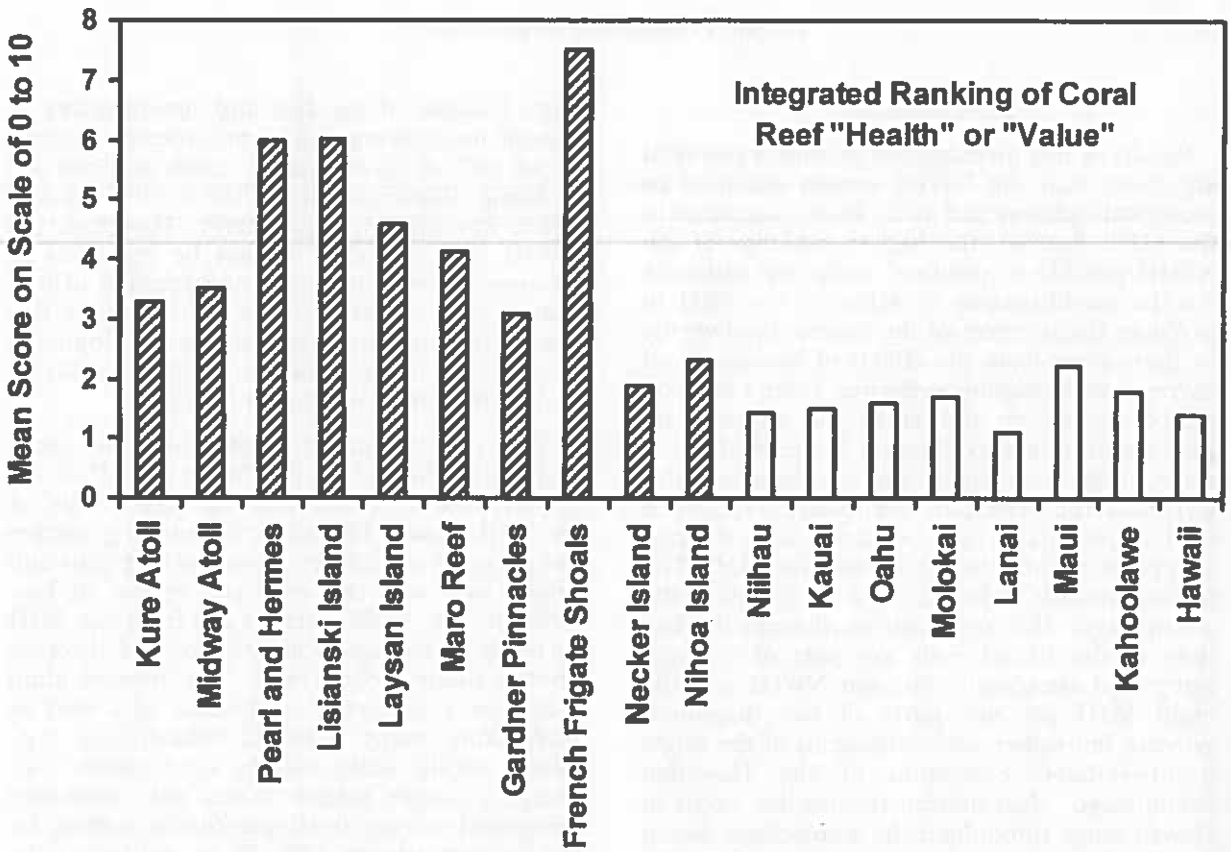

Fig. 2. Mean score (based on scale of 0–10) for each island of the Hawaiian Archipelago using five metrics (See Table 3). NWHI bars show cross hatching versus MHI bars with no cross hatching.

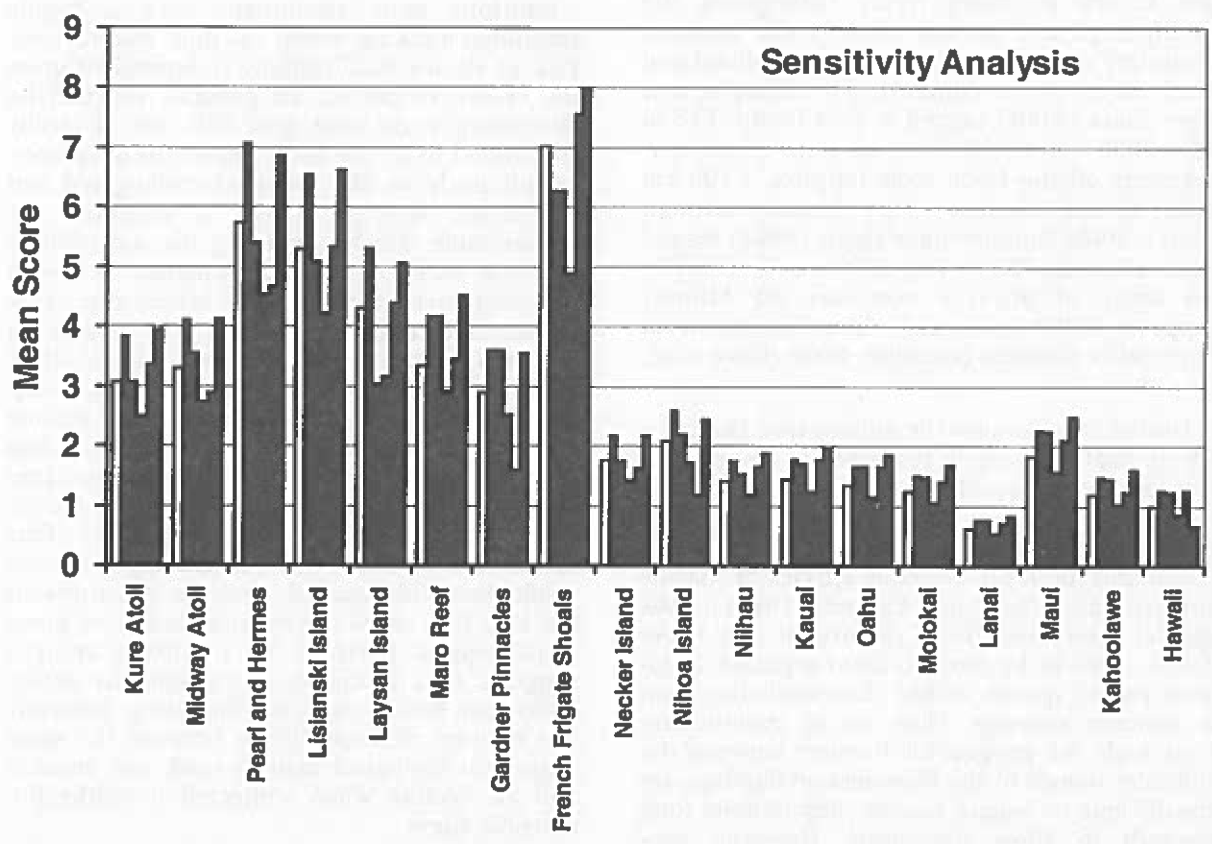

Fig. 3. Results of sensitivity analysis with ranking recalculated using only four of the five metrics. From left to right in the figure the first bar (open) is the index calculated with all five metrics for use as a reference. The second bar was calculated with no turtle data, the third bar no seal data, the fourth bar no fish biomass data and the fifth bar no fish endemism data.

DISCUSSION

Results of this investigation provide a powerful argument that the NWHI retains much of its biological richness and value when compared to the MHI. Further, the higher rankings of the NWHI provide a "positive" ecological rationale for the establishment of MPAs in the MHI to promote the recovery of the marine biodiversity in these areas from the effects of historical and current anthropogenic pressures. Over 1 200 000 people reside on the MHI, but there is no permanent human population in the NWHI. For various political, administrative and biogeographic purposes the Hawaiian Archipelago has been split conceptually into two artificially defined groups of islands: the NWHI and the MHI. The present analysis included all of the islands of the archipelago. This approach emphasizes the fact that all the island reefs are part of a single integrated ecosystem. The ten NWHI and the eight MHI are not parts of two disjointed systems, but rather are components of the single highly-isolated ecosystem of the Hawaiian Archipelago. Most marine species that occur in Hawaii range throughout the archipelago. Green Sea Turtles are a single genetic population with individuals that migrate from forage areas in the MHI to nest in the NWHI (Balazs and Chaloupka 2004a,b). Sharks and other large fish are known to move freely throughout the archipelago and do not observe the artificial boundary created by humans (Kim Holland and Carl Meyer (pers. comm.)). For example, one tiger shark (#005) tagged at East Island, FFS in July 2000 was detected by an array of acoustic receivers off the Kona coast (approx. 1 190 km straight line distance) from January through March 2003. Another tiger shark (#008) tagged at East Island, FFS in July 2000 was detected by an array of acoustic receivers off Midway (approx. 1 280 km straight line distance) from September through December 2002 (Lowe *et al.*, in press).

During past decades the endangered Hawaiian Monk Seal was largely restricted to the NWHI, but has not respected this arbitrary division and recently has begun to re-colonize the MHI (Baker and Johanos 2005). In Hawaii, genera containing multiple endemic species of marine invertebrates (Kay and Palumbi 1987) corals (Jokiel 1987) and fishes (Hourigan and Reese 1987) seem to be derived from separate Indo-west Pacific species rather than radiating from a common ancestor. Thus, on an evolutionary time scale the geographic barriers between the different islands of the Hawaiian archipelago are insufficient to isolate marine populations long enough to allow speciation. However, sub-populations of some species can be detected at the genetic level. The Archipelago is severely isolated from other islands of the Pacific so a large fraction of the fish and invertebrates in Hawaii have diverged endemic species. Overall about 30% of invertebrates, corals and fish are endemic (Hourigan and Reese 1987; Jokiel 1987; Kay and Palumbi 1987). Therefore the NWHI and the MHI cannot be regarded as separate systems in regard to formation of new species, but act as a single unit. Perhaps this generalization should include nearby Johnston Atoll which has a coral fauna very similar to Hawaii (Maragos and Jokiel 1986).

Results of the analysis conducted in this study (Table 2) indicate that the "worst island" of the NWHI (Necker) ranks with the "best island" of the MHI (Maui). The numerical ranking mirrors the personal experience of marine biologists and others who visit the area and marvel at how different the NWHI islands are from the MHI in terms of biological abundance and diversity on the shallow coral reefs. The human mind produces a subjective evaluation of a reef by integrating many types of information (i.e., fishes, corals, seals, turtles, etc.) rather than using a single metric. Thus the combined integrated average 0–10 quantitative scoring for the various islands (Fig. 2) is similar to the subjective impressions reported by many observers in the Hawaiian Archipelago when comparing the MHI with the NWHI.

Cautions must accompany such a highly simplified ranking based on only five metrics. First of all, the final ranking is dependent upon the choice of metric. In general, key metrics describing coral and reef fish are generally considered to be the most important indicators. In this study we also included endangered and threatened species. There is potential for considerable debate regarding the inclusion of different variables and also whether to weight different metrics more than others (i.e., is it appropriate to give equal emphasis to data on the total biomass of all reef fish species versus population estimates for a single seal species?). The initial strategy for this study was to include all five of the metrics for which reliable data exist for all 18 of the islands. We had no pre-existing rationale to weigh any of these metrics. When the index was recalculated using any four of the five metrics we get essentially the same result shown in Figure 3. This analysis supports the idea that all of the metrics chosen be given equal weight. Further, the sensitivity analysis suggests that it might be possible to define ecosystem health or condition using relatively few metrics. Perhaps this is because the most important biological metrics track one another and all decline when subjected to anthropomorphic stress.

The sampling methods, habitats, sampling intensity and level of training of persons taking the data must be consistent for each island. As noted in the methods section the data for this study were taken by the same methodology on each island. George Balazs devoted the past 30 years studying the Green Sea Turtle and has produced an internally consistent data set for the various islands of the Hawaiian Archipelago. The data on the Hawaiian Monk Seals throughout the Hawaiian Archipelago is the result of a team effort at the National Marine Fisheries Service and likewise is internally consistent. The fish data were taken by the same group of individuals (Friedlander and DeMartini 2002; Friedlander *et al.* 2003; Demartini and Friedlander 2004; Jokiel *et al.* 2004) using the same methodology. Likewise coral data taken by different investigators was shown to be comparable (Jokiel *et al.* 2005). The direct comparisons between the NWHI and MHI appear valid because the sheer volume of data is likely to compensate for inherent biases in the individual datasets. Finally, an implicit assumption of this investigation is that low scores can be directly attributed to anthropogenic stress caused by large populations of humans on the MHI. We were unable to identify alternate and perhaps natural explanations for observed patterns. Human activity and animals introduced by humans have historically interfered with Green Sea Turtle nesting and Hawaiian Monk Seals in the MHI even though beaches and other resources are extensive in the MHI. Conditions in the MHI are much better for coral growth due to warmer sea water temperatures and higher light intensity (Grigg 1983). Further, the NWHI receive much higher wave impact due to proximity to storm centers in the North Pacific and a lack of wave shelter from large high islands. Over fishing is a major issue in the MHI (Friedlander and DeMartini 2002; Friedlander *et al.* 2003). For example, fishing pressure has greatly reduced stocks of bottom fish in the MHI in recent years in relation to bottom fish stocks in the NWHI (Heineman *et al.* 2005). Presumably the pristine MHI during the pre-human contact period would have scored higher than the NWHI. An important use for the dataset presented in this paper during future years will be to compare changes in the health scores over time to see if trajectories for MHI reflect increasing anthropogenic stresses.

The MHI are valuable in certain respects that are not reflected in the scoring developed for this study. For example, if total reef area were included as an index of reef value, then many of the MHI would rank above some islands in the NWHI. A major foraging area for the Green Sea Turtle is in the MHI. However, the point of this project was to rank the islands in terms of "reef health" or condition in addition to total "value". Is a large area of reef in poor condition more valuable than a small reef area in good condition? On the other hand, the NWHI contain many unique species not found in the MHI (e.g., *Acropora* corals), but this factor was not included due to the lack of data from many of the islands. Another caveat is that data used in the analysis integrate all habitats on each island. Thus islands with lagoons (Pearl and Hermes for example) will have higher integrated coral cover. Future analyses will be based on a larger data set and must compare ecological condition within each of several main habitats. Other analytical questions might arise concerning randomness of the sampling and variability of the data, but the trends are so strong that it is doubtful if future analyses based on more data will change the basic conclusions. Larger data sets in the future will allow more refined analysis, but we expect the general conclusions to remain the same.

An integrated index or score such as that developed in this investigation can be of great value in the assessment of relative reef condition or reef value. This approach can be used to communicate findings based on complex scientific data to a broad audience in a straightforward and understandable manner. The conclusions of this study are based on the best and most complete data sets available for the NWHI and the MHI at the present time. In the future, the work will be expanded to include other factors as the NWHI research programme develops. This report is a prelude to more detailed analyses using the concepts of the Hydrogeomorphic (HGM) models (Brinson 1993) and the Index of Biotic Integrity (IBI) models (Jameson *et al.* 1998) used widely in other ecosystems and incorporated into the CRAMP Ecological Gradient Model (EGM) currently being developed for the MHI using 61 variables measured at 184 stations within 52 sites. This more extensive data base does not yet exist for the NWHI.

The EGM allows more detailed comparisons to be made within given habitats, but must be based on considerably more data than is presently available from the NWHI. In the meantime, this preliminary result of the present study drives home three important points. The first is that the NWHI are an extremely valuable biological resource that is pristine in comparison to the MHI. The second is that the NWHI are integral components of the Archipelago ecosystem and must be properly managed for the good of the entire Hawaiian marine ecosystem. Finally, the data indicate that it might be possible in some cases to describe reef ecosystem health and value using relatively few metrics.

This synthesis of the biological data was undertaken to evaluate the value of the NWHI as part of the effort to include the NWHI in the National Marine Sanctuary Program (NOAA 2005). On June 15, 2006 President George W. Bush used his authority under the *Antiquities Act* to designate the Northwestern Hawaiian Islands as a national monument. Establishment of the Northwestern Hawaiian Islands National Monument rather than a National Marine Sanctuary means the area is now under full legal protection. No extraction of resources will be allowed and visitation will be strictly regulated. This area encompasses nearly 363 000 km² (140 000 miles²) of U.S. waters, including 11 700 km² (4 500 miles²) of relatively undisturbed coral reef habitat. This Marine National Monument is the largest single area dedicated to conservation in the history of the United States. It is more than 100 times larger than Yosemite National Park, larger than 46 of the 50 United States, and more than seven times larger than all U.S. National Marine Sanctuaries combined (http://www.hawaiireef.noaa.gov/).

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REFERENCES

Baker, J. D. and Johanos, T. C., 2005. Distribution and abundance of Hawaiian Monk Seals in the main Hawaiian Islands. Values are from 2001 survey reported in (http://www.mmc.gov/reports/workshop/pdf/baker.pdf).

Balazs, G. H. and Chaloupka, M., 2004a. Thirty-year recovery trend in the once depleted Hawaiian Green Sea Turtle stock. *Biol. Cons.* **117**: 491–98.

Balazs, G. H. and Chaloupka, M., 2004b. Spatial and temporal variability in somatic growth of Green Sea Turtles (*Chelonia mydas*) resident in the Hawaiian Archipelago. *Mar. Biol.* **145**: 1043–059.

Brinson, M. M., 1993. A hydrogeomorphic classification for wetlands, Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. NTIS No. AD A270 053.

DeMartini, E. E. and Friedlander, A. M., 2004. Spatial patterns of endemism in shallow-water reef fish populations of the Northwestern Hawaiian Islands. *Mar. Ecol. Prog. Ser.* **271**: 281–96.

Friedlander, A. M. and DeMartini, E. E., 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. *Mar. Ecol. Prog. Ser.* **230**: 253–64.

Friedlander, A. M., Brown, E. K., Jokiel, P. L., Smith, W. R. and Rodgers, K. S., 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. *Coral Reefs* **22**: 291–305.

Grigg, R. W., 1983. Community structure, succession and development of coral reefs in Hawai'i. Marine Ecology Progress Series **11**: 1–14.

Heinemann, D., Gillelan, H. and Morgan, L., 2005. Bottomfish fishing in the Northwestern Hawaiian Islands. Is it ecologically sustainable? Report to the Ocean Conservancy, 40 Pp. (Available on line at http://www.oceanconservancy.org).

Hourigan, T. F. and Reese, R. S., 1987. Mid-ocean isolation and the evolution of Hawaiian reef fishes. *Trends in Ecol. and Evol.* **2**: 187–91.

Jameson, S. C., Erdmann, M. V., Gibson, G. R. and Potts, K. W., 1998. Development of biological criteria for coral reef ecosystem assessment. Atoll Research Bulletin, September 1998, No. 450, Smithsonian Institution, Washington, DC. 102 Pp.

Jokiel, P. L., 1987. Ecology, biogeography and evolution of corals in Hawaii. *Trends in Ecol. and Evol.* **2**: 179–82.

Jokiel, P. L., Cox, E. F. and Crosby, M. P., 1993. An evaluation of the nearshore coral reef resources of Kahoolawe, Hawaii. Final Report for Co-operative Agreement NA27OM0327. Hawaii Institute of Marine Biology. 185 Pp.

Jokiel, P. L., Brown, E. K., Friedlander, A. M., Rodgers, S. K. and Smith, W. R., 2004. Hawaii Coral Reef Assessment and Monitoring Program: Spatial patterns and temporal dynamics in reef coral communities. *Pac. Sci.* 58(2): 145–58.

Jokiel, P. L., Rodgers, K. S., Brown, E. K., Kenyon, J. C., Aeby, G., Smith, W. R. and Farrell, F., 2005. Comparison of methods used to estimate coral cover in the Hawaiian Islands. Report to the Northwest Hawaiian Islands Coral Reef Ecosystem Reserve, Honolulu. 22 Pp.

Kay, E. A. and Palumbi, S. R., 1987. Endemism and evolution in Hawaiian marine invertebrates. *Trends in Ecol. and Evol.* **2**: 183–86.

Kenyon, J. and Aeby, G., 2004. National Marine Fisheries Service. NOAA ship/Hi,ialakai/. Cruise Report No. CR-04-01HI. Pacific Islands Fisheries Science Center, 2570 Dole St., Honolulu, HI, 96822. 108 p. 2 December 2004.

Lowe, C. G., Wetherbee, B. M. and Meyer, C. G. In Press. Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and Giant Trevally around French Frigate Shoals and Midway Atoll. *Atoll Res. Bull.*

Maragos, J. E. and Jokiel, P. L., 1986. Reef corals of Johnston Atoll: one of the world's most isolated reefs. *Coral Reefs* 4:141–50.

NOAA, 2005. Proposed Northwestern Hawaiian Islands Sanctuary. Advice and Recommendations Developed Under the National Marine Sanctuary Act Section 304(a)(5). September 20, 2005.

NOAA NMFS, 2005. Stock Assessment Report, Hawaiian Monk Seal (*Monachus schauinslandi*) On-line address: http://www.nmfs.noaa.gov/pr/PR2/Stock_Assessment_Program/Pinnipeds/Hawaiian_Monk_Seal/po04hawaiianmonkseal.pdf revised 3/15/2005.