Ranking Coral Ecosystem "Health and Value" for the Islands of the Hawaiian Archipelago

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Report to:

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October 18, 2005

This research conducted under DOI, NOAA, National Ocean Service MOA 2005-008/6882 Amendment No. 001, "Research in Support of the NWHI Coral Reef Ecosystem Reserve, HIMB, SOEST, UH Manoa" (Dr. Jo-Ann Leong, PI).

Abstract

This report evaluates relative biological "health" and "value" of the coral reefs of the Northwestern Hawaiian Islands (NWHI) in the context of the entire Hawaiian Archipelago. Sufficient data on five vitally important biological indicators have recently been developed for both the NWHI and the Main Hawaiian Islands (MHI). These include: reef fish biomass, reef fish endemicity, 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 data were used to develop a simple integrated scoring and ranking scheme for all the islands of the archipelago. The composite scoring developed using these data shows that the ecological status of the MHI is poor compared to the NWHI. A growing body of information demonstrates that the reefs of the NWHI are an integral component of the Hawaiian Archipelago ecosystem and are an extremely valuable ecological resource. Thus the proper management of the NWHI is important to the ecology of the vitality of the Hawaiian Archipelago as a whole. The NWHI should not be viewed as a separate entity from the MHI because the two areas are clearly interdependent. The migration of turtles from feeding grounds in the MHI to nesting grounds in the NWHI provides an excellent example of the interdependence of the two areas. Movement of large fish and endangered Hawaiian monk seals provide other examples. The fact that the same species of fish, corals and other marine organisms occur along the entire Archipelago with high rates of endemism provides evidence that the NWHI and the MHI represent a single ecosystem with a long evolutionary history.

Introduction

There is an immediate and critical need to develop a preliminary means to describe relative "reef health" or condition and "reef value" for the Hawaiian Islands using available data. "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 management and to 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. This scheme is useful in communicating integrated information to the public and for making management decisions on issues concerning resource use and protection. 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 Northwest Hawaiian Islands (NWHI). The aim of the current project is 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. Development of this preliminary index is a prelude to the development of more refined indices of biotic integrity (IBI) for coral reefs (Rodgers 2005). In the future, the Ecological Gradient Model (EGM) previously described by Rodgers (2005) for the Main Hawaiian Islands will be expanded with inclusion of data from the NWHI.

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” 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 pubic 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.

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 Rodgers (2005) 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 1. 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 Edward DeMartini (personal communication). A summary of all fish biomass data is shown in Fig. 1. DeMartini and Friedlander (2004) reported percent endemism for fish counts in the NWHI. Rodgers (2005) 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 Fig. 2.

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 is comparable (Jokiel et al. manuscript). Average total living coral cover for each of the NWHI (Kenyon and Aeby 2004, Kenyon and Aeby pers. com., and data listed in NOAA 2005 Table 2) as well as comparative data for the MHI (Jokiel et al. 2004, Rodgers 2005) are available. Rodgers (2005) expanded the Coral Reef Assessment and Monitoring data set (Jokiel et al. 2004) to include additional data as shown in Table 1. The mean coral cover values for each island presented by Rodgers (2005) are based on broad sampling of the reefs on Kauai, Oahu, Lanai, Maui and Hawaii. These values were supplemented with additional survey data taken by Kenyon and Aeby (pers. com.) 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 (personal communication) 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. com.) during 2005. These data were combined with the CRAMP data and the Rodgers (2005) 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 9 sites along the south shore and Lehua Island by Kenyon and Aeby during 2005. This entire area is relatively exposed to South Swell and wave wrap from the NE Pacific Swell so is low in cover. A towboard survey during July 2005 revealed low coral cover along the south shore of Niihau (Ben Richards, personal communication), so the value presented for Niihau is realistic. The coral data used in the analysis is presented in Table 2 and Fig. 3, 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 Tables1-2 and Fig. 4.

Table 1. 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 Turtles (Females Nesting Annually)
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]
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 (personal communication)

[D] Rodgers 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 (personal communication)

[I] Jokiel et al.(1993), 33 sites

[J] Eric K. Brown (personal communication)

[K] Stewart (2004) in NOAA (2005) Table 2

[L] Jean Kenyon and Greta Aeby (2004)

[M] Jean Kenyon and Greta Aeby pers. com

Table 2. Mean values 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 Turtles (Females Nesting Annually)
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
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 Turtles (Females Nesting Annually)	**AVERAGE SCORE**
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**
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**

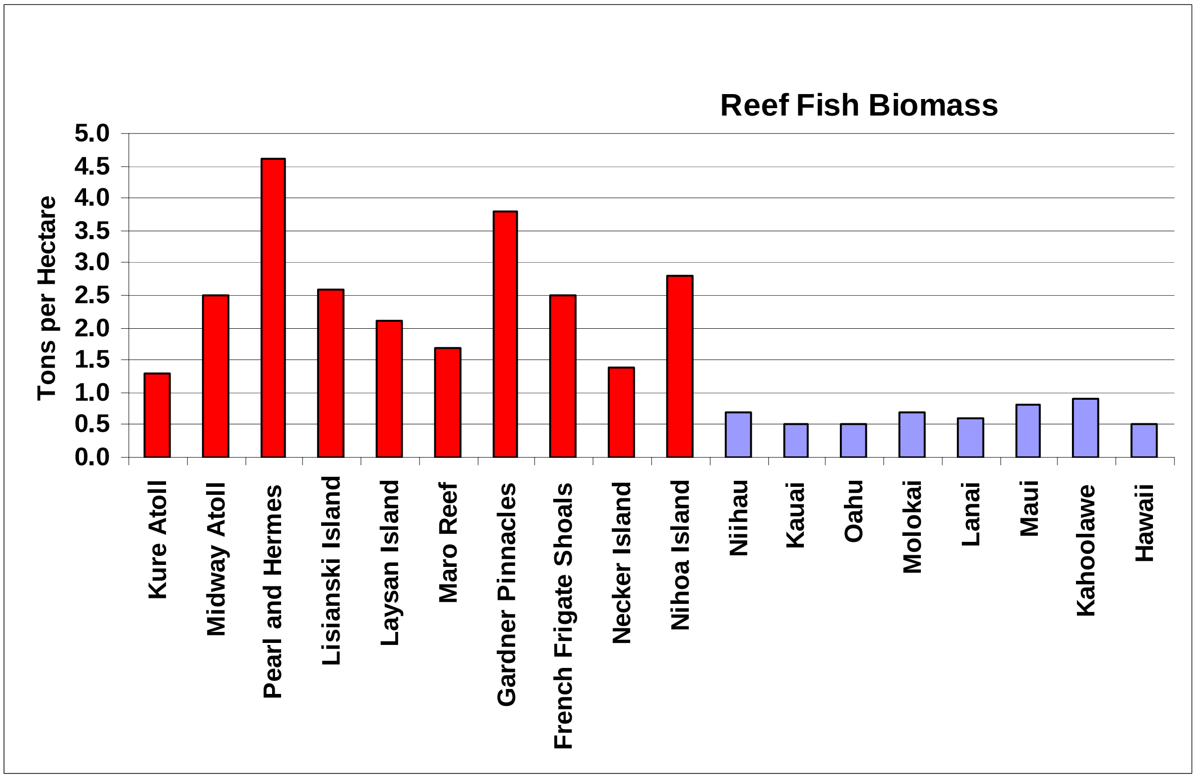

Fig. 1. Reef fish biomass (metric tons per hectare) for islands of the Hawaiian Archipelago.

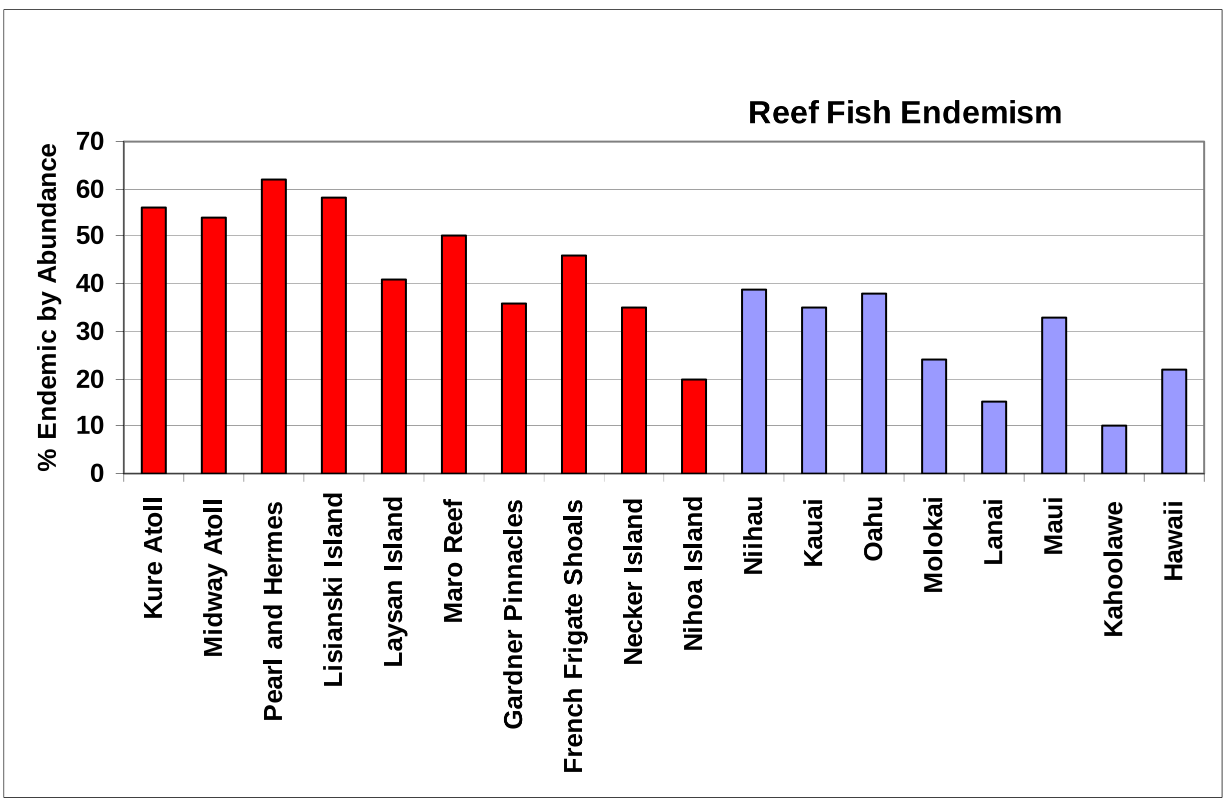

Fig. 2. Endemism of reef fishes (% of abundance) for islands in the Hawaiian Archipelago.

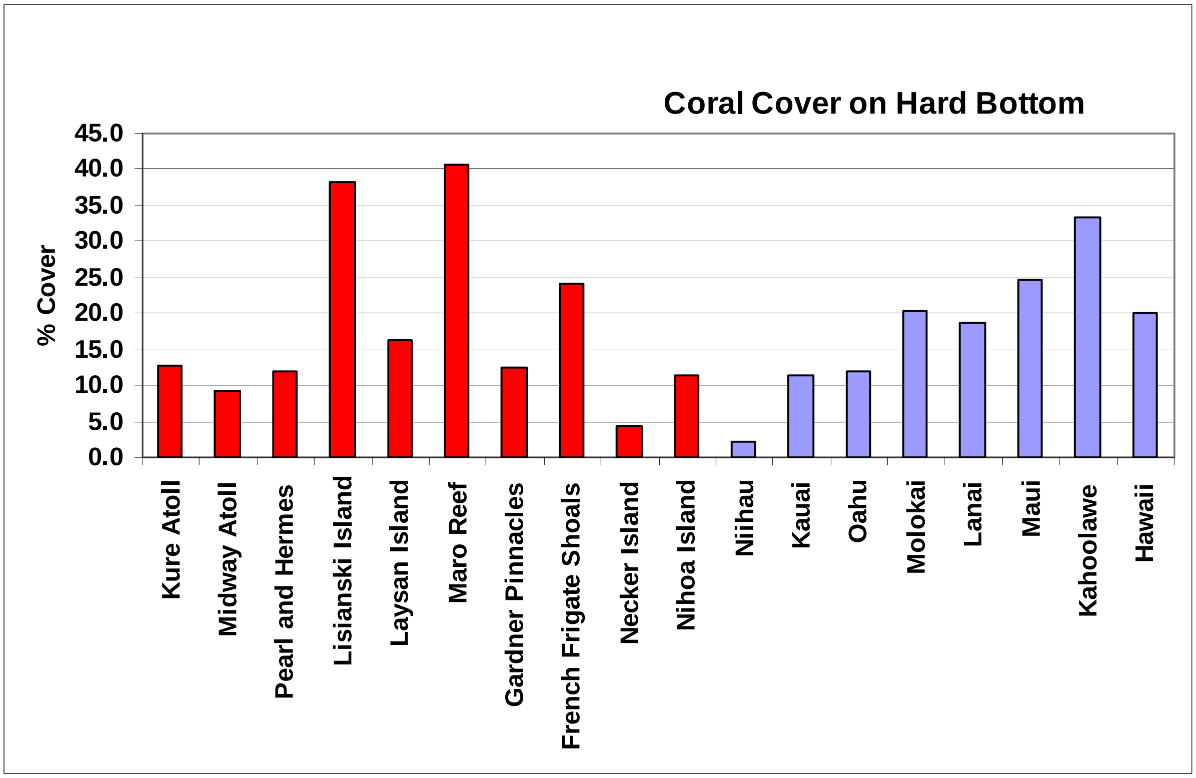

Fig. 3. Coral cover (% live coral on hard bottom) for islands of the Hawaiian Archipelago.

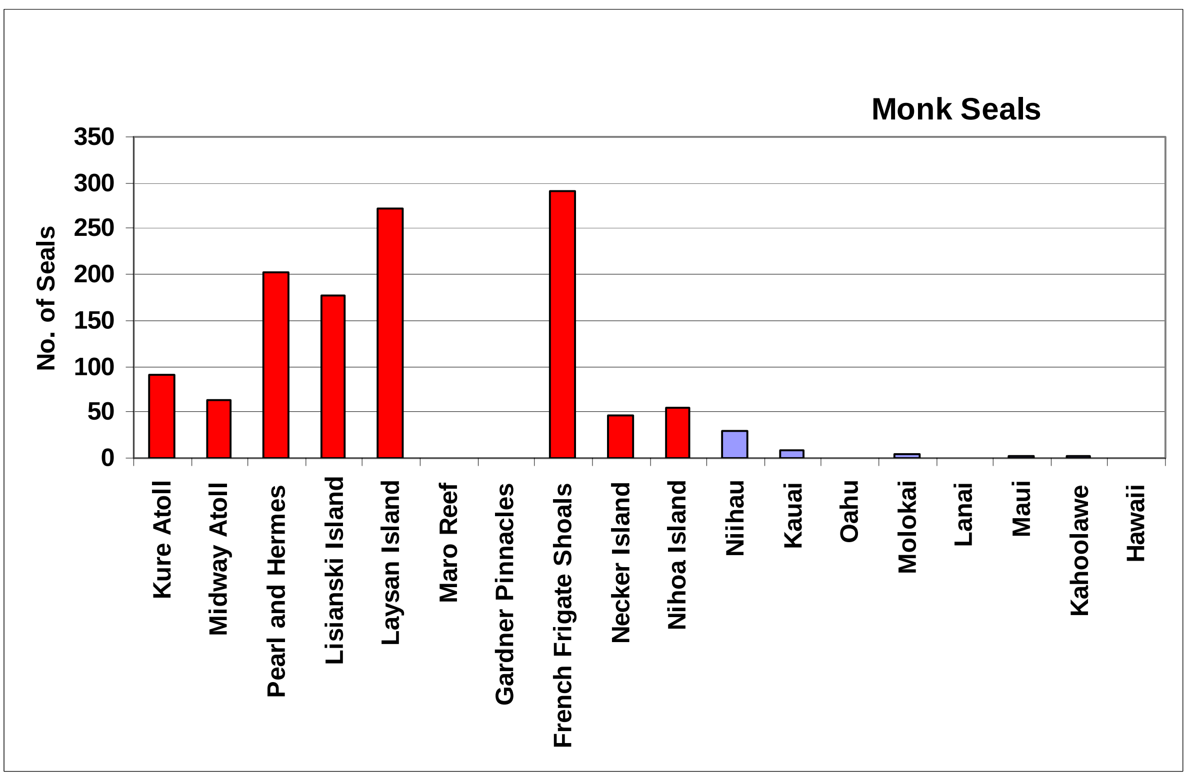

Fig. 4. Numbers of Hawaiian monk seals inhabiting each island of the Hawaiian Archipelago.

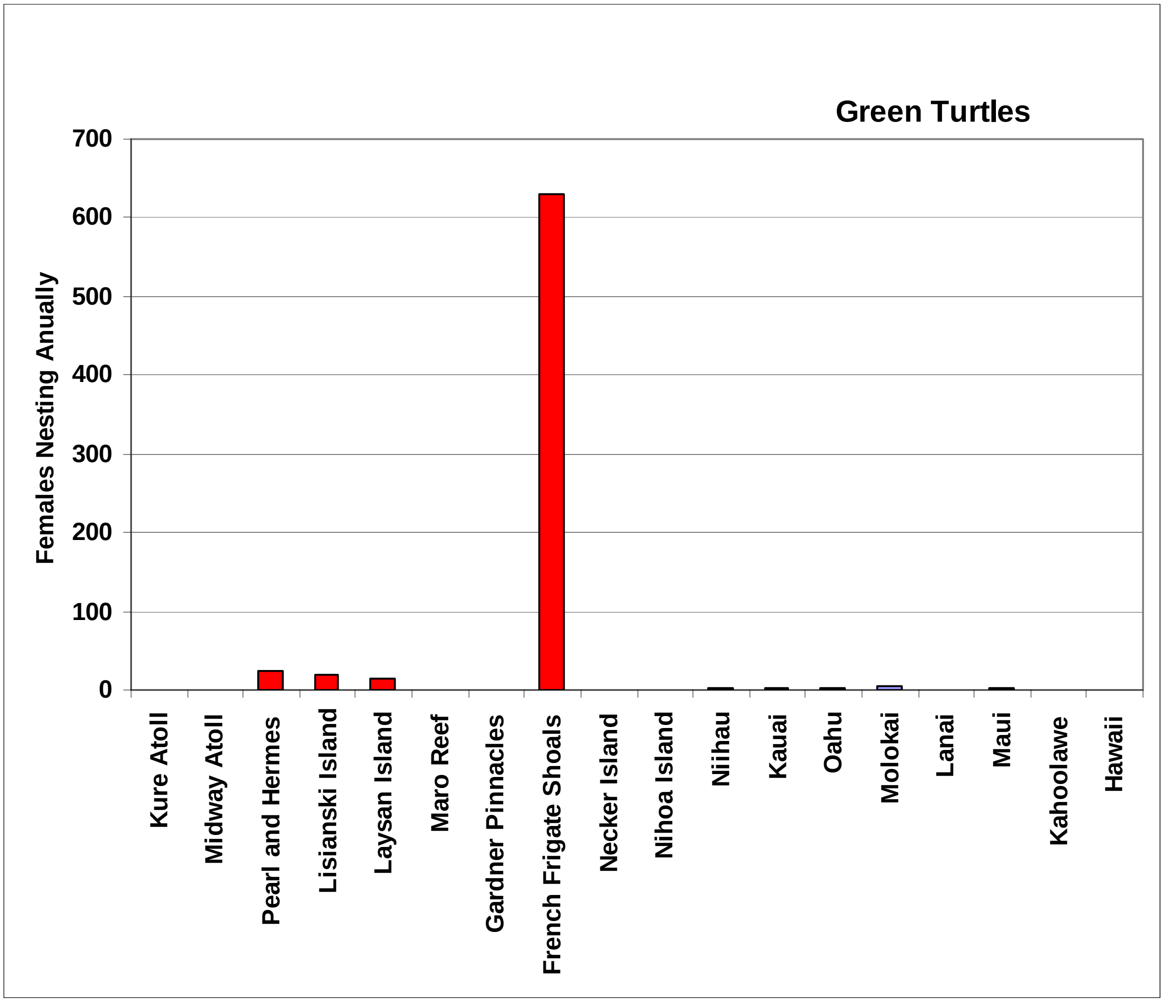

Fig. 5. Numbers of green turtle females nesting annually on each island of the Hawaiian Archipelago.

Number of female green turtles nesting annually.

The green turtle (*Chelonia mydas*) in the Hawaiian Archipelago is a single spatially distinct 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 (personal communication) 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 numbers 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 Fig. 5.

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 Figs. 1-5. Examination of the data (Tables 1-2, Figs. 1-5) 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:

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

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. 6). 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.

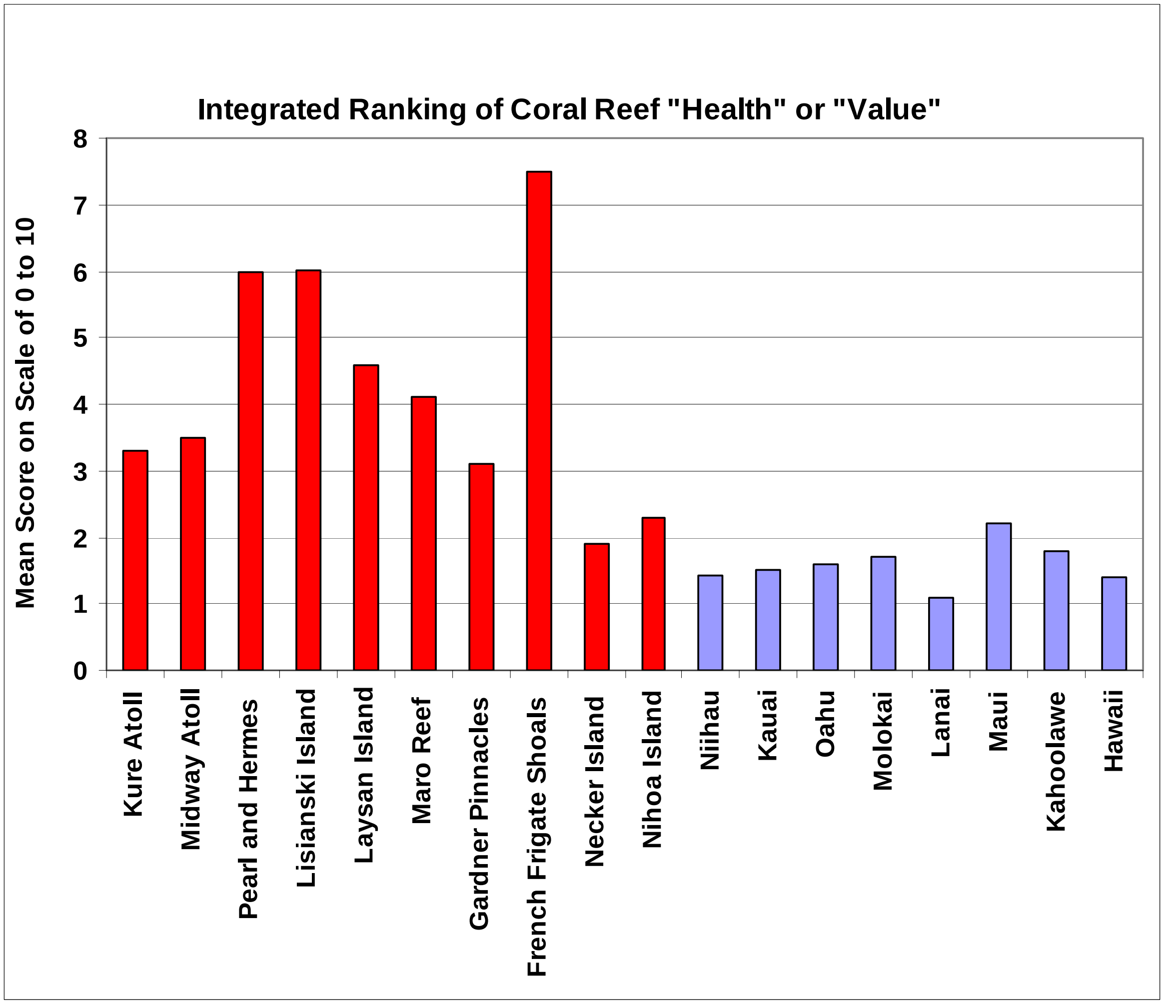

Fig. 6. Mean score (based on scale of 0-10) for each island of the Hawaiian Archipelago (See Table 3).

Discussion

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. Results of this investigation (Fig. 6) indicate that the NWHI retains much of its biological richness and value. 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. Such artificial divisions obscure the fact that all the island reefs are part of a single integrated ecosystem. 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 personal communication). 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. 1190 km straight line distance) from January through March 2003. Another tiger shark (#008) tagged at East Island, FFS in July 2000 was detected by our array of acoustic receivers off Midway (approx.

1280 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 fish and invertebrates diverge into true Hawaiian endemic species. Overall about 30% of invertebrates, corals and fish are endemic (Kay and Palumbi 1987, Jokiel 1987, Hourigan and Reese 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 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. 6) is similar to the subjective impressions reported by many observers in the Hawaiian Archipelago when comparing the MHI with the NWHI.

The MHI are valuable in certain respects that are not reflected in the scoring developed in 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 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.

The results of this investigation demonstrate that an integrated index or score can be of 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.

The work will be expanded to include other factors as the research program develops. This report is a prelude to more detailed analyses using the concepts of the Hydrogeomorphic Models (HGM) and the Index of Biotic Integrity (IBI) models used widely in other ecosystems and incorporated into the CRAMP Ecological Gradient Model (EGM) currently being developed (Rodgers 2005). The EGM allows more detailed comparisons to be made within given habitats, but must be based on considerably more data from the NWHI. In the meantime, this preliminary result drives home two 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.

Acknowledgments

We are indebted to George Balazs for providing the data on numbers of female green sea turtles nesting annually on each island. Eric K. Brown and Edward DeMartini provided vital unpublished data that enabled us to complete the data tables for coral and fish. Jean Kenyon and Greta Aeby provided data on coral cover in the NWHI. Alan Friedlander verified sources of data reported in NOAA (2005).

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