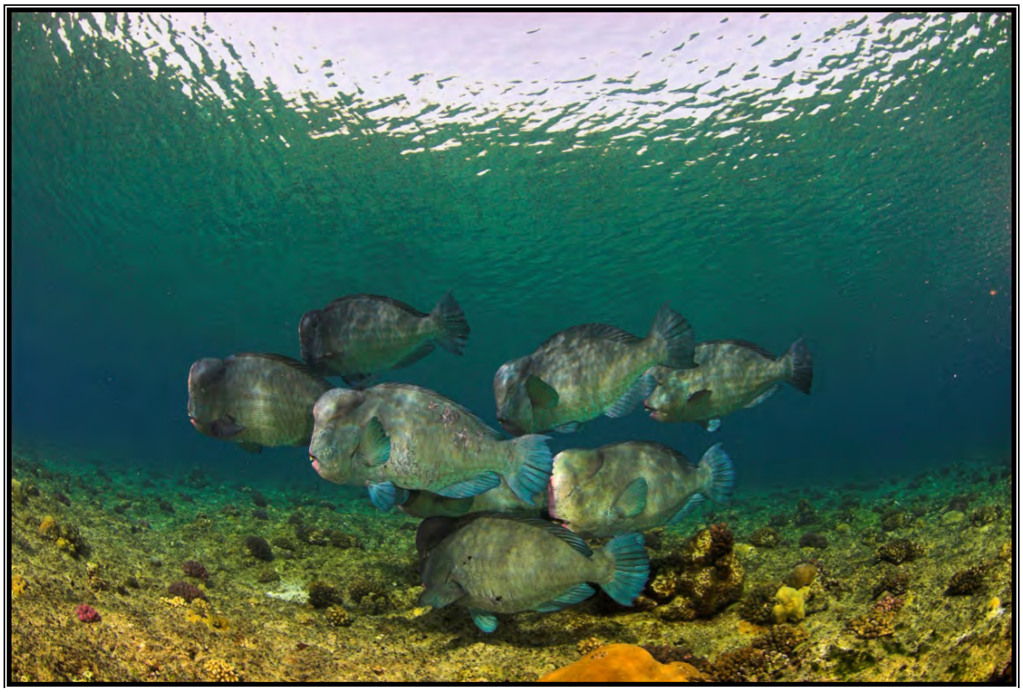
NOAA Technical Memorandum NMFS-PIFSC-26

September 2011

Bumphead Parrotfish (*Bolbometopon muricatum)* Status Review



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National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Bumphead Parrotfish (*Bolbometopon muricatum*) Status Review

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EXECUTIVE SUMMARY

On January 4, 2010, the National Marine Fisheries Service (NMFS) received a petition from WildEarth Guardians requesting that the bumphead parrotfish (*Bolbometopon muricatum*) be listed as endangered or threatened under the U.S. Endangered Species Act (ESA). NMFS reviewed the petition, decided that the petition presented adequate scientific or commercial information indicating that an ESA listing may be warranted, and committed to conducting an ESA status review. NMFS formed a Biological Review Team (BRT; Team) made up of federal scientists to compile the best available scientific and commercial information and assess the status of the species. This document reports the results of this compilation and assessment.

The BRT qualitatively assessed the severity, geographic scope, and level of certainty of potential individual threats to bumphead parrotfish. Because the severity and scope of individual threats may change over time, each threat was evaluated based on its historical impact, its current impact, and its future potential for impact. Additionally, synergistic cumulative impacts were considered. The factors that are believed to have had the greatest potential to contribute to the decline of bumphead parrotfish are overharvesting, loss of juvenile habitat, and recruitment variability. The BRT acknowledged that significant levels of uncertainty are present for all aspects of bumphead parrotfish biology, e.g., reproductive biology, abundance, trends in abundance, and threats.

The Team decided to explicitly treat variation in team member opinions by using a plausibility point system for the extinction risk questions. The Team's objectives in taking this approach were to make the process of arriving at conclusions as transparent as possible, and to assure that the Team was basing decisions on a common understanding of the evidence.

Given the possible threats to the species and all other information assimilated by the Team, the BRT assessed the extinction risk of the bumphead parrotfish species. In the manner of a standard sensitivity analysis, the BRT chose to examine the extinction risk question over multiple frames of reference. For the spatial component, the question was framed with respect to the entire geographic range of the species or the best scientific understanding of SPOIR (significant portion of its range). For the temporal component, the question was framed using 2 values of foreseeable future values. The first value (40 years) was chosen based on the best estimate of the bumphead parrotfish maximum life span. The second value (100 years) was chosen because this is a standard temporal benchmark interval over which to ascertain long-term effects. The Team assessed bumphead parrotfish species extinction risk relative to the Critical Risk Threshold using a tercile approach of certainty with Level 1 reflecting the first tercile of certainty (0-33% certainty), Level 2 reflecting the second tercile of certainty (33-66% certainty), and Level 3 reflecting the third tercile of certainty (66-100% certainty). The BRT made the following conclusions with respect to extinction risk:

- For the entire geographic range over a 40-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 56% of plausibility points to this category, with 40% in the ***Level 2 certainty*** category, and 4% in the ***Level 3 certainty*** category.

- For the entire geographic range over a 100-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 48% of plausibility points to this category, with 46% in the ***Level 2 certainty*** category, and 6% in the ***Level 3 certainty*** category.

- For SPOIR over a 40-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 52% of plausibility points to this category, with 42% in the ***Level 2 certainty*** category, and 6% in the ***Level 3 certainty*** category.

- For SPOIR over a 100-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 2 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 48% of plausibility points to this category, with 46% in the ***Level 1 certainty*** category, and 6% in the ***Level 3 certainty*** category.

The Team finds that, using all available evidence pertaining to the risk of bumphead parrotfish extinction, there is a low plausibility (4-6%) of bumphead parrotfish being at the highest certainty tercile of falling below the "Critical Risk Threshold" in the next 40-100 years over its entire range or over SPOIR. The Team is of the opinion that, while there are geographic areas of concern with low abundance or local extirpation, the species as a whole is unlikely to be driven extinct over the time and space scales examined due to its widespread distribution across the Indo-Pacific, persistent abundance in some geographic areas, high fecundity, flexible ecological requirements, and dispersive capability via adult movement or egg and larval transport.

CONTENTS

1. INTRODUCTION

The bumphead parrotfish (*Bolbometopon muricatum*) is the largest-sized member of the parrotfish family Scaridae. It is widely distributed throughout the Indo-West Pacific Ocean, Indian Ocean, and Red Sea where it is among the largest-sized reef fishes, and is generally uncommon. It is thought to play a key role in structuring and maintaining the coral reef ecosystems where it is abundant (Bellwood et al., 2003). The bumphead parrotfish is a facultative corallivore and has been characterized as a nonselective grazer on benthic reef organisms. As a result, the bumphead parrotfish is thought to be important for maintaining coral reef diversity in the manner of a keystone predator, and it is also thought to be important for sand generation and bioerosion (Hoey and Bellwood, 2008). The bumphead parrotfish is highly sought by fishers in many locations because it is large and is considered a delicacy. Some areas also value this species for ceremonial rites. Unfortunately, it is also quite easy to harvest based on its conspicuousness, coastal habitat, and nighttime sleeping habits on the reef. As a consequence, some areas have experienced serious depletion from overharvesting.

1.1 Purpose and Scope of the Present Document

On January 4, 2010, the NMFS received a petition requesting the bumphead parrotfish (*Bolbometopon* m*uricatum*) be listed as endangered or threatened under the U.S. Endangered Species Act (ESA), in light of overfishing, large size, vulnerability, slow maturation, low reproductive rate, coral bleaching, ocean acidification, and increasing human population size. In addition, the petitioners requested that NMFS designate a critical habitat for bumphead parrotfish.

NMFS found that the petition presented substantial scientific or commercial information indicating that an ESA listing may be warranted (75 *FR* 16713; April 2, 2010). By accepting this petition, NMFS initiated a status review of the bumphead parrotfish to determine if a listing under the ESA was warranted. NMFS formed a team of federal scientists—the Biological Review Team (BRT; Team)[1]—to compile the best available scientific and commercial information and assess the status of the species. The BRT considered a broad and extensive range of scientific and commercial information, including published and unpublished literature, direct communications with researchers working with bumphead parrotfish, public comments as well as technical and scientific information submitted by experts in the field. All information not previously peer-reviewed was formally reviewed by the BRT and was included if it was found to comply with the Team's standard of best-available science (Sullivan et al., 2006). This document reports the results of this compilation and assessment. The basic timeline of the bumphead parrotfish ESA listing petition response process and BRT activities is seen in Figure 1.

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[1] The Biological Review Team included the following members: (1) from the Pacific Islands Fisheries Science Center, Dr. Donald Kobayashi (Team Leader; Connectivity/assessment), Mr. Ryan Nichols (Tropical fish life history), Mr. Brian Zgliczynski (Coral reef fish field survey methodology; since his work on the BRT, Zgliczynski has joined the Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, La Jolla, CA); (2) from the Southwest Fisheries Science Center, Dr. Churchill Grimes (Fish conservation biology and reef fish ecology); (3) from the United States Geological Survey, Hawaii Cooperative Fishery Research Unit, Dr. Alan Friedlander (Coral reef fish ecology).

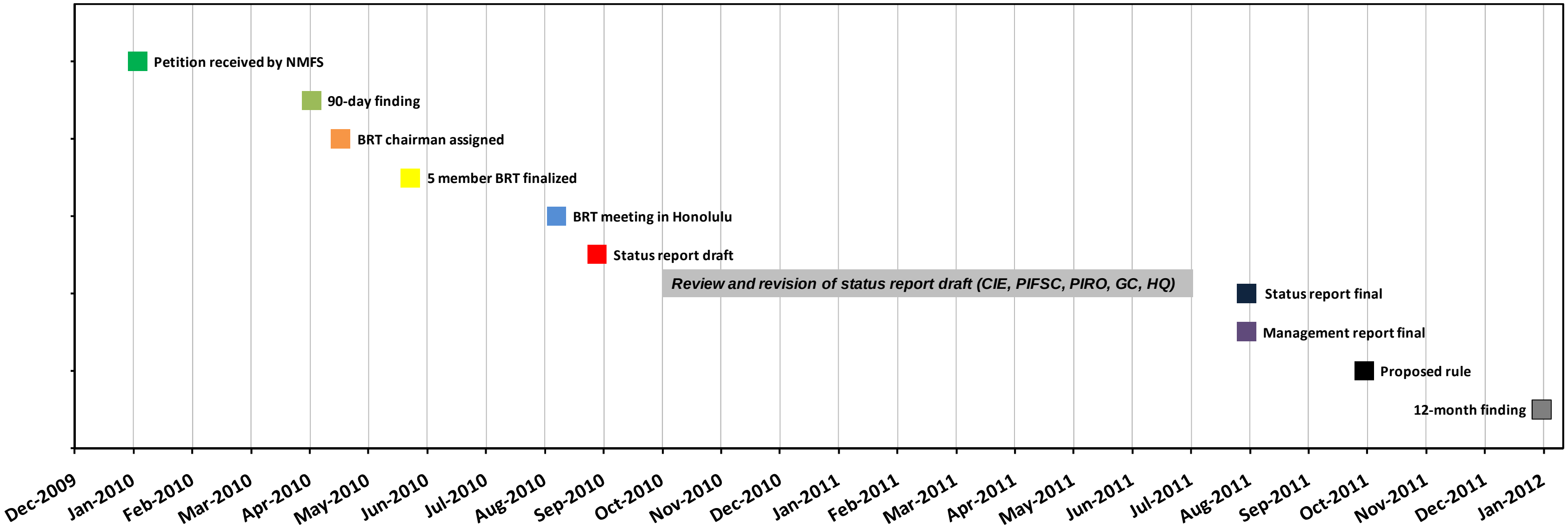

Figure 1.--Timeline of the bumphead parrotfish ESA listing petition response process and BRT activities. Some events still to occur at the time of this writing (July 29, 2011) are estimates only.

This document is a compilation of the best available scientific and commercial data and a description of past, present, and likely future threats to the bumphead parrotfish. It does not represent a decision by NMFS on whether this species should be proposed for listing as threatened or endangered under the ESA. That decision will be made by NMFS after reviewing this document, other relevant biological and threat information not included herein, efforts being made to protect the species, and all relevant laws, regulations, and policies. The result of the decision will be posted on the NMFS website (http://www.nmfs.noaa.gov/pr/species/) and announced in the *Federal Register*.

The BRT adopted a decision rule for use in assessing risk to the bumphead parrotfish species. To allow individual team members to express uncertainty, the BRT adopted a likelihood point or plausibility point method. The likelihood point method is often referred to as the "FEMAT" method because it is a variation of a method used by scientific teams evaluating options under the Northwest Forest Plan (Forest Ecosystem Management Assessment Team, 1993). Each BRT member was asked to distribute 10 likelihood or plausibility points among the options for a given vote, reflecting their opinion of how likely that option correctly reflected the species status. If a BRT member was certain of a particular option, or felt it was the only plausible scenario, he could assign all 10 points to that option. A BRT member with less certainty about which option best reflected reality or best reflected the status of the species could split the points among 2 or more categories. This method has been used in all status review updates for anadromous Pacific salmonids since 1999, as well as in reviews of Southern Resident killer whales (Krahn et al., 2004; Krahn et al., 2002), West Coast rockfishes (Stout et al., 2001b), Pacific herring (Stout et al., 2001a), Pacific groundfish (Gustafson et al., 2000), North American green sturgeon (Adams et al., 2002; 2005), black abalone (Butler et al., 2009), and the Hawaii insular population of false killer whales (Oleson et al., 2010).

1.2 Summary of the Bumphead Parrotfish Listing Petition

The petition asserts that overfishing is a significant threat to the bumphead parrotfish and that this species is declining across its range and is nearly eliminated from many areas. The petition also asserts that degradation of coral habitat through coral bleaching and ocean acidification is a threat to this species, as coral is its primary food source. The petition further asserts that biological traits (e.g., slow maturation and low reproductive rates), shrinking remnant populations and range reductions, the effects of increasing human populations in the species range, and inadequate regulatory protection are subjecting the bumphead parrotfish to extinction in the foreseeable future. The petition briefly summarizes the description, taxonomy, natural history, distribution, and status for the petitioned species. The bumphead parrotfish is the largest of the parrotfish species and has a wide range. It can be found throughout the Indo-Pacific from the Red Sea and East Africa as far eastward as the Line Islands and Samoa; in the western Pacific it ranges north to Taiwan and the Yaeyama Islands (Japan), south to the Palau, Caroline, Marshall, and Mariana Islands in Micronesia and to the Great Barrier Reef and New Caledonia. Within the Exclusive Economic Zone of the United States it occurs in Guam, American Samoa, the Commonwealth of the Northern Mariana Islands, and the Pacific Remote Island Areas. It is not found in Hawaii or Johnston Atoll. The petition states that this species is classified as vulnerable by the World Conservation Union (IUCN). The IUCN defines vulnerable as a species considered to be facing a high risk of extinction in the wild. The NMFS believes that bumphead parrotfish populations have been declining throughout their range and placed this species on the Species of Concern list in 2004.

1.3 Summary of Public Comments

Eight sets of public comments were received during the 30-day public comment period following the 90-day NMFS finding, and 2 more sets of public comments were received later. All comments were read and considered by the Team. Six sets of comments were primarily informational and of a general nature, covering materials that were already available to the Team. Four sets of comments were very detailed, 2 including arguments in support of listing the species at American Samoa and Guam, with the assertion that these occurrences represent distinct population segments. The other 2 comments were methodical refutations of the listing petition, for Guam and for the entire range, respectively. The Team response to the public comments is presented later in this report.

1.4 Center for Independent Experts Review of Document

Earlier versions of this report were reviewed by individuals at NMFS-PIFSC, NMFS-PIRO, NMFS-GC, and NMFS-HQ. Additionally, PIFSC solicited an external independent peer review by the Center for Independent Experts (CIE) of an earlier version of this document in September 2010. These reviews will be posted on the PIFSC website when the report is released to the public (www.pifsc.noaa.gov). The following are the salient points gleaned from comments provided by the 3 CIE reviewers, followed by the Team responses:

- A reviewer felt that the dietary preference for the species was mischaracterized.
  The Team has reviewed all available evidence and still concludes that, contrary to the review comment, the species is not an obligate corallivore, and respectfully disagrees with this reviewer regarding the importance of living coral for this species to persist.

- A reviewer felt that the extinction risk issue was not handled well.
  The Team is familiar with other means of addressing extinction risk and after careful deliberation decided to use the "Critical Risk Threshold" approach in this data-poor situation. The Team does not agree with this reviewer's notion that mortality of 1/3 of a population would cause localized extinction. The Team also does not agree with this reviewer's characterization of bumphead parrotfish as "low productivity" in terms of its reproductive capability.

- A reviewer felt that there were inadequate citations and that references were not adequately documented.
  The literature coverage was scrutinized by the Team and improved in subsequent versions of the report. It must be reiterated, however, that much of the most valuable scientific information assimilated by the Team

was in the form of seminars and other types of presentations to the Team made by experts, and that these are the bulk of the many "personal communications" found throughout the report. These unpublished references were discussed by the Team and were deemed worthy of use in this status report.

- A reviewer suggested making the bootstrap exercise a comparative approach.

  This was an excellent suggestion and has been incorporated into the analysis. The identical bootstrap approach was simplified to hindcast a pristine, virgin condition by constraining the abundance estimates towards the upper bounds of the distribution.

- There was a typographical error in the text of the reviewed draft leading a reviewer to believe the estimated global population was 3 orders of magnitude lower than is the actual case.

  The methodology has been checked and the inconsistency is that the text initially read: "Operationally, the area in km^2 *is multiplied by the density estimate in number of bumphead parrotfish per m*^{2}*, then the resulting quantity was multiplied by 1000 to accommodate the change in units. This results in an estimate of bumphead parrotfish for the particular stratum" when it should have read, and now reads: "Operationally, the area in km*^{2} *is multiplied by the density estimate in number of bumphead parrotfish per 1000 m*^{2}*; then the resulting quantity is multiplied by 1000 to accommodate the change in units. This results in an estimate of the number of bumphead parrotfish for the particular stratum." As described elsewhere in the report, the survey data were standardized to number per 1000 m*^{2}*, and this was indeed the input unit for the global population calculation. In short, this was a simple typographical error in the sentence which has since been corrected.*

- A reviewer suggested using geographically matched data, where possible, in the global population estimate.

  That was recognized as an excellent idea and the approach is presented as another scenario in the current version of the report.

- A reviewer clarified the sex-change terminology and pointed out some interesting literature to the Team.

  This was corrected in subsequent versions of the report, and the new literature is now cited and further discussed.

- A reviewer had some comments on connectivity and SPOIR.

  The initial connectivity analysis has been replaced with a more exhaustive simulation and analysis of results.

- A reviewer raised a number of points related to distinct population segments.

> *There is no scientific evidence of distinct population segments in this species based on expert opinion, fish behavior, coloration, or morphology. The Team does recognize, however, that some regions such as the Red Sea may be relatively isolated geographically and/or oceanographically.*

1.5 Key Questions in ESA Evaluations

The purposes of the ESA are to provide a means to conserve ecosystems on which endangered species and threatened species depend, to provide a program for the conservation of endangered species and threatened species, and to take appropriate steps to recover a species. The U.S. Fish and Wildlife Service (USFWS) and NOAA's NMFS share responsibility for administering the ESA; NMFS is responsible for determining whether marine, estuarine or anadromous species are threatened or endangered under the ESA. To be considered for listing under the ESA, a group of organisms must constitute a "species" using a definition under the ESA which is different from the conventional evolutionary/taxonomic/genetic definition of a species. The ESA provides the following relevant definitions:

Species **–** The ESA defines the term "species" to include any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature.

Endangered species **–** The ESA defines the term "endangered species" as any species which is in danger of extinction throughout all or a significant portion of its range.

Threatened species **–** The ESA defines the term "threatened species" as any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

The Team evaluated the status of bumphead parrotfish in the context of a single species since it is widely distributed, relatively mobile, and has pelagic propagules (eggs and larvae). Furthermore, there is no indication of genetic differentiation as manifested in morphology, coloration or behavior over the geographic range of the species. The biological characteristics listed above are elaborated on in subsequent sections of this report.

Determination of whether a species should be listed as threatened or endangered is based upon the best available scientific and commercial information. The status is determined based on the definitions of threatened and endangered as analyzed in an extinction risk analysis. Factors specified in Section 4 (a)(1) of the ESA are examined to determine if they may have or may be contributing to decline of a species, including: 1) the present or threatened destruction, modification or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; or 5) other natural or manmade factors affecting the continued existence of the species.

NMFS considers a variety of information in evaluating the level of risk to a species. Important considerations include: 1) absolute numbers of organisms and their spatial and temporal distribution; 2) current abundance in relation to historical abundance and carrying capacity of the habitat; 3) any spatial and temporal trends in abundance; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., artificial rearing); and 6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the species. Additional risk factors, such as disease prevalence or changes in life history traits, may also be considered in evaluating risk to species.

1.5.1 The “SPOIR” Question

The ESA definitions above use the important phrase “significant portion of its range”, or SPOIR. “Significant” as used in this context is defined in the Webster’s dictionary as “of a noticeably or measurably large amount”. While this may imply that SPOIR could be fixed at a particular percentage, fraction or ratio of a total amount of range, recent technical guidance (Vucetich et al., 2005; Waples et al., 2007) suggests undertaking a case-by-case examination of the ecological setting rather than choosing any particular cutoff value of percentage of range (e.g., 33%). Considering that a unit of range is not necessarily ecologically equal to any other unit of range, it is important to examine critical geographic components in tailoring SPOIR for a particular species. An attempt to delineate bumphead parrotfish ecological SPOIR is presented in a subsequent section of this report.

1.5.2 The “Extinction Risk” Question

The information considered in evaluating status can generally be grouped into two categories: 1) demographic information reflecting the past and present conditions (e.g., data on population abundance or density, population trends and growth rates, the number and distribution of populations, exchange rates of individuals among populations, and the ecological, life-history, or genetic diversity among populations); and 2) information on previous factors for decline as well as species threats (e.g., habitat loss and degradation, overutilization, disease, and climate change). The demographic risk data and threats reviewed by the BRT are summarized in this document.

Evaluating extinction risk of a species includes considering the available information concerning the abundance, growth rate/productivity, spatial structure/connectivity, and diversity of a species and assessing whether these demographic criteria indicate that it is at high risk of extinction, at moderate risk or neither. A species at very low levels of abundance and with few populations will be less tolerant to environmental variation, catastrophic events, genetic processes, demographic stochasticity, ecological interactions, and other processes (Gilpin and Soule, 1986). A rate of productivity that is unstable or declining over a long period of time may reflect a variety of causes but indicate poor resiliency to future environmental variability or change (Foley, 1997; Lande, 1993; Middleton and Nisbet, 1997). For species at low levels of abundance, in particular, declining or highly variable productivity confers a high level of extinction risk. A species that is not widely distributed across a variety of well-connected habitats will have a diminished capacity for recolonizing locally extirpated populations and is at increased risk of extinction as a result of environmental perturbations and catastrophic events (Cooper and Mangel, 1999; Schlosser and Angermeier, 1995). A species that has lost locally adapted genetic and life-history diversity may lack the characteristics necessary to endure short- and long-term environmental changes (Hilborn et al., 2003; Wood et al., 2008).

The demographic risk criteria described above are evaluated based on the present species status in the context of historical information, if available. However, there may be threats, or other relevant biological factors, that might alter the determination of the species’ overall level of extinction risk. These threats or other risk factors are not yet reflected in the available demographic data because of the time lags involved, but are nonetheless critical considerations in evaluating a species’ extinction risk (Wainwright and Kope, 1999). Forecasting the effects of threats and other risk factors into the foreseeable future is rarely straightforward and usually necessitates qualitative evaluations and the application of informed professional judgment. This evaluation highlights those factors that may exacerbate or ameliorate demographic risks so that all relevant information may be integrated into the determination of overall extinction risk for the species. Examples of such threats or other relevant factors may include: climatic regime shifts or other phenomena that portend changing temperature and marine productivity conditions, e.g., El Niño, La Niña, and the Pacific Decadal Oscillation that are anticipated to result in reduced food quantity or quality or recent or anticipated increases in the range and/or abundance of predator populations.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific and commercial information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. In this review, we do not evaluate likely or possible effects of conservation measures. Therefore, we do not make recommendations as to whether the species should be listed as threatened or endangered. Rather, we have drawn scientific conclusions about the risk of extinction faced under the assumption that present conditions and/or trends will continue (recognizing, of course, that natural demographic and environmental variability is an inherent feature of "present conditions and/or trends"). Conservation measures will be taken into account by the NMFS Regional Office in drafting a management report and making listing recommendations.

Working definitions of key words and phrases are needed to be absolutely clear what the BRT recommends. Most such definitions are standard or assumed, but several key terms will be discussed here.

Extinction − "Extinction" as used in this context is defined as biological extinction meaning no living individuals of the species in existence.

Likely – “Likely” is defined in the Webster’s dictionary as “having a better chance of existing or occurring than not”. The Team considers this terminology to generally reflect situations in which an event has a greater than 50% chance of occurring.

Foreseeable future – It is appropriate to interpret “foreseeable future” in the statutory context as the timeframe over which identified threats are likely to impact the biological status of the species and can be reasonably predicted. The appropriate period of time corresponding to the foreseeable future depends on the particular kinds of threats, the life-history characteristics, and the specific habitat requirements for the species under consideration. The bumphead parrotfish BRT selected 40 years as a working definition which is the approximate maximum age of individuals of this species (keeping in mind that age at which most females spawn is approximately 10 years, so that this reference point spans approximately 4 generations). As a means of evaluating the sensitivity of this definition, an independent vote was taken examining the effect of extending the definition of foreseeable future to 100 years (approximately 10 generations elapsed).

2. BUMPHEAD PARROTIFSH LIFE HISTORY AND ECOLOGY

2.1 Taxonomy, Phylogeny, and Genetics

Bolbometopon muricatum (Valenciennes 1840) is a member of a conspicuous group of shallow-water fishes (parrotfishes in the family Scaridae) that are closely associated with coral reefs (Bellwood, 1994; Randall et al., 1997). Parrotfishes are distributed circumtropically and originated during the Miocene-Oligocene (14-35 million years ago) in the tropical Tethys Sea (Bellwood and Schultz, 1991). Differentiation occurred prior to and after the closure of the Tethys Sea and was promoted by an increasing number of habitat associations and feeding modes. Early parrotfishes were browsers inhabiting seagrass beds and shifted to feeding as scrapers and excavators inhabiting rocky and coral reef habitats (Bellwood, 1994; Streelman et al., 2002).

Parrotfishes are considered a monophyletic group but are sometimes classified as a subfamily (Scarinae) of the wrasse family (Labridae); however, the Team follows the notion that the parrotfishes are a distinct family called the Scaridae. Currently, 90 species in 10 genera are recognized in the parrotfish family Scaridae (Bellwood, 1994; Parenti and Randall, 2000). Parrotfishes are distinguished from other labroid fishes based on their unique dentition (dental plates derived from fusion of teeth), loss of predorsal bones, lack of a true stomach, and extended length of intestine (Randall, 2005).

The bumphead parrotfish is the largest member of the parrotfishes, growing to a maximum total length of 130 cm and weighing up to 46 kg (Donaldson and Dulvy, 2004; Randall, 2005). Adults are primarily olive to blue green or grey in color with the anterior region near the head being yellow to pink in coloration (Randall, 2005). A prominent bulbous bump on the forehead, from whence the generic name is derived, is also a common feature observed in adults. Juveniles are greenish brown in color with 2-3 vertical rows of white spots along the flank (Bellwood and Choat, 1989; Randall, 2005). Bumphead parrotfishes are distinguished from other parrotfish species by possessing 2 to 4 median predorsal scales; 3 rows of cheek-scales 1(4-6), 2(3-6), 3(1-2); 16-17 pectoral-fin rays; 16-18 gill rakers; and 12 precaudal vertebrae.

The taxonomic classification of the bumphead parrotfish is as follows:

- Class: Actinopterygii
  - Order: Perciformes
    - Family: Scaridae
      - Subfamily: Scarinae

Genus: *Bolbometopon*

Species: *muricatum*

Junior synonyms: *Scarus muricatus* (Valenciennes, 1840), *Bolbometopon muricatus* (Valenciennes, 1840), *Callyodon muricatus* (Valenciennes, 1840), *Pseudoscarus muricatus* (Bleeker 1859)

Common Names: Buffalo Parrotfish, Bumphead Parrotfish, Double-headed Parrotfish, Giant Humphead Parrotfish, Green Humphead Parrotfish, and Humphead Parrotfish.

In addition to the above-mentioned common names, there are numerous variations of market and regional names. The names are primarily based on the geographic location and the associated indigenous vernacular. The most common name, based notably on its most distinctive feature, is "bumphead/humphead parrotfish" and it is used throughout the United States, Australia, Christmas Island (Australia), Guam and American Samoa (Choat and Randall, 1986; Dulvy and Polunin, 2004). Several anthropological and ethnographic studies of sea tenure[2] have increased the vernacular associated with this species. These regional names include: Lendeke, Kitkita, Topa, Topa kakara, Perroquet bossu vert, Togoba, Uloto'i, Gala Uloto'i, Laea Uloto'i, Loro cototo verde, Berdebed, Kalia, Kemedukl, Kemeik, Tanguisson, as well as the English vernacular "green humphead parrotfish". Several of these names are a reflection of the different size ranges of the fish used within a society (Adams and Dalzell, 1994; ASFIS, 2010; Aswani and Hamilton, 2004; Hamilton, 2004; Hamilton, et al., 2007; Helfman and Randall, 1973; Johannes, 1981).

Currently there is no genetic information on bumphead parrotfish (Robert Toonen, Hawaii Institute of Marine Biology, pers. comm.). Regional variation in morphology, meristics, coloration, or behavior has not been observed.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish taxonomy, phylogeny, and genetics", the bumphead parrotfish is a single, well-described species.

2.2 Habitat and Range

2.2.1 Description of Habitat

Adult bumphead parrotfish are found primarily on shallow (1-15 m) barrier and fringing reefs during the day, and they rest in caves and shallow sandy lagoon habitats at night (Donaldson and Dulvy, 2004). Choat (unpubl. data) found that bumphead parrotfish were more abundant on the reef crest compared with the channels on the outer Great Barrier Reef (Figure 2). Comparisons between Papua New Guinea, Helene Atoll, Palau and the Great Barrier Reef showed much higher densities on the Great Barrier Reef compared with these other locations. Either fishing pressure or preferred habitat differences may account for the observed patterns.

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[2] Sea tenure is defined as "a situation in which particular groups of people have riparian entitlement to nearshore areas, and in which their entitlements to use and access resources are excludable, transferable, and enforceable, either conditionally or permanently." Aswani, S. 2002. Assessing the effects of changing demographic and consumption patterns on sea tenure regimes in the Roviana Lagoon, Solomon Islands. Ambio 31:272-284.

The extensive reef structure on the Great Barrier Reef with adjacent lagoons appears to provide optimal habitat for bumphead parrotfish (Choat, unpubl. data). By comparison, Lihou and Herald are two isolated islands in the Coral Sea approximately 1000 km from the Great Barrier Reef with little fishing pressure. Densities of bumphead parrotfish are over an order of magnitude higher on the Great Barrier Reef compared with these two locations (Figure 3). Thus, the differences in abundance among locations appear to be related to habitat and biogeographic preference for the outer Great Barrier Reef. This highlights the habitat importance of exposed outer reef front with high structural complexity, along a continuous reef system with an adjacent lagoon.

The likely limiting factors for bumphead parrotfish are sheltered lagoons for recruitment, high energy forereef foraging habitat for adults, and nighttime shelter (caves) for sleeping (Choat, pers. comm.). These and others factors are discussed further in a subsequent section pertaining to carrying capacity.

Juvenile bumphead parrotfish in the Solomon Islands were restricted to the shallow inner lagoon while larger individuals occurred predominately in passes (Aswani and Hamilton, 2004; Hamilton, 2004). Choat (unpubl. data) found densities of juveniles (< 50 mm FL) an order of magnitude higher in the inner lagoon around Cocos-Keeling in the Indian Ocean than in the central lagoon; lower numbers of juveniles occurred on the forereef (Figure 4). The inner lagoon consisted of a sheltered, shallow habitat dominated by *Turbinaria* and *Acropora* coral species mixed with *Dictyota* and *Sargassum* macroalgae (Figure 5).

Size distributions of bumphead parrotfish at Cocos-Keeling show a dominance of small individuals in the inner lagoon with the mode at 18 mm FL. The mid-lagoon shows a bimodal distribution with a mode of 24 mm FL and another mode at 72 mm FL. The forereef size distribution consists of larger juveniles with a mode at 66 mm FL (Figure 6).

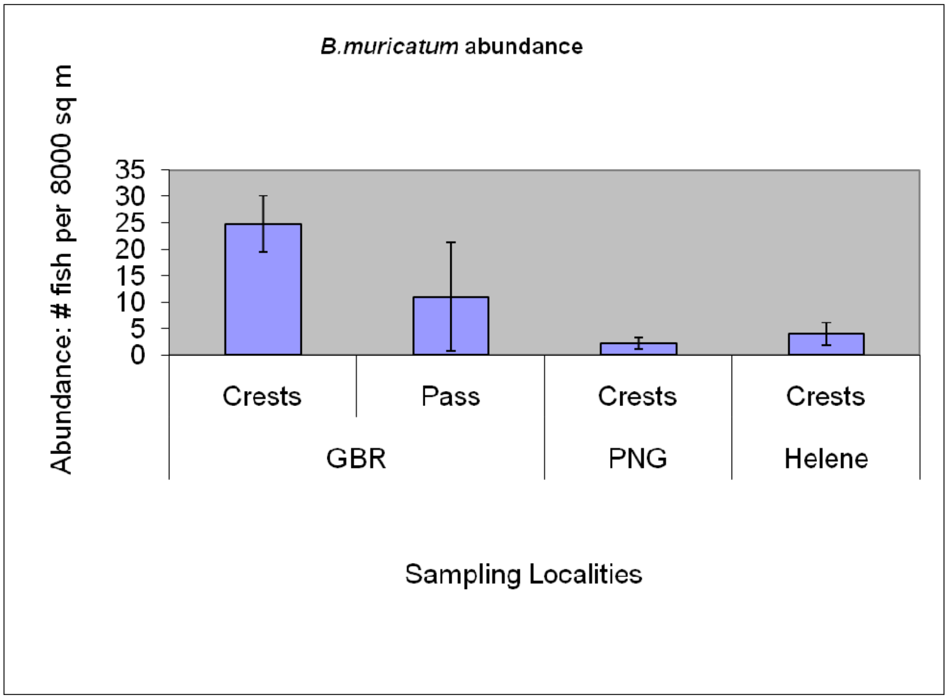

Figure 2.--Abundance data – 500 × 20 m visual surveys. West Pacific—Great Barrier Reef (1995), Papua New Guinea (2000), Helene Atoll, Palau (2000). Densities are higher on Great Barrier Reef with the reef crest habitat preferred (Choat, unpubl. data). GBR and PNG abbreviate Great Barrier Reef and Papua New Guinea, respectively. Bars: mean abundance; Intervals: mean ± 1 SE.

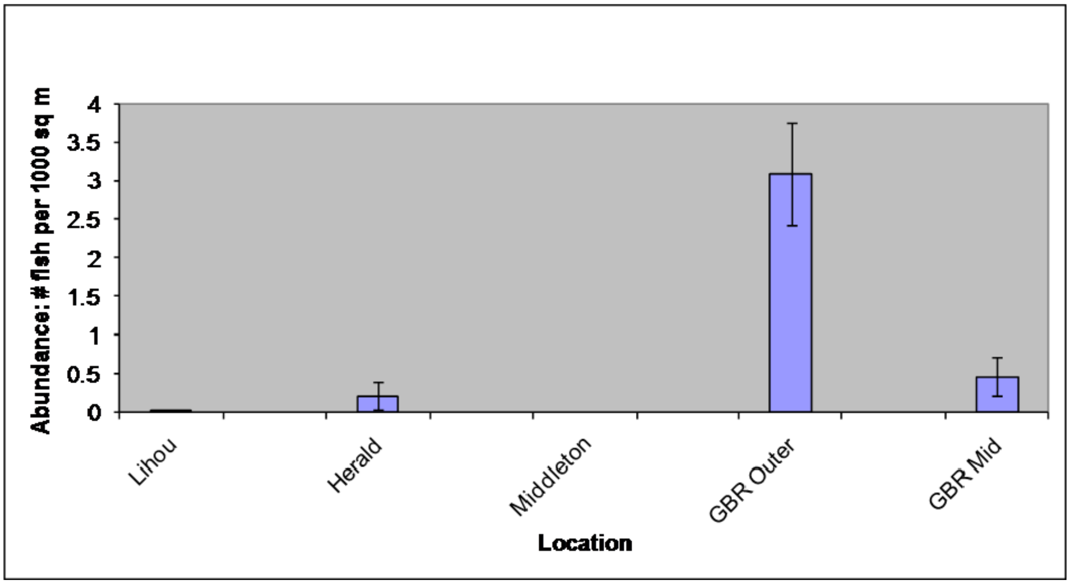

Figure 3.--Abundance of bumphead parrotfish in the western Pacific from 500 × 20 m swims. (Choat, unpubl. data). GBR abbreviates Great Barrier Reef. Various survey dates. Bars: mean abundance; Intervals: mean ± 1 SE.

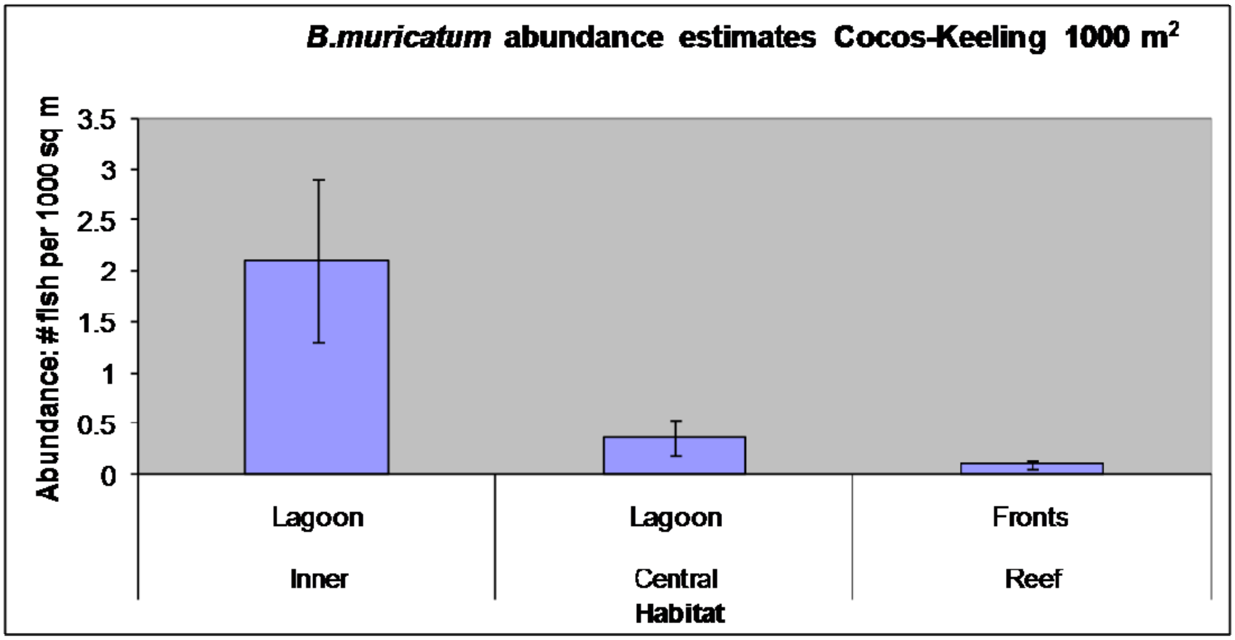

Figure 4.--Density of bumphead recruits (< 50 mm FL) at Cocos-Keeling, Indian Ocean (Choat, unpubl. data). Bars: mean abundance; Intervals: mean ± 1 SE.

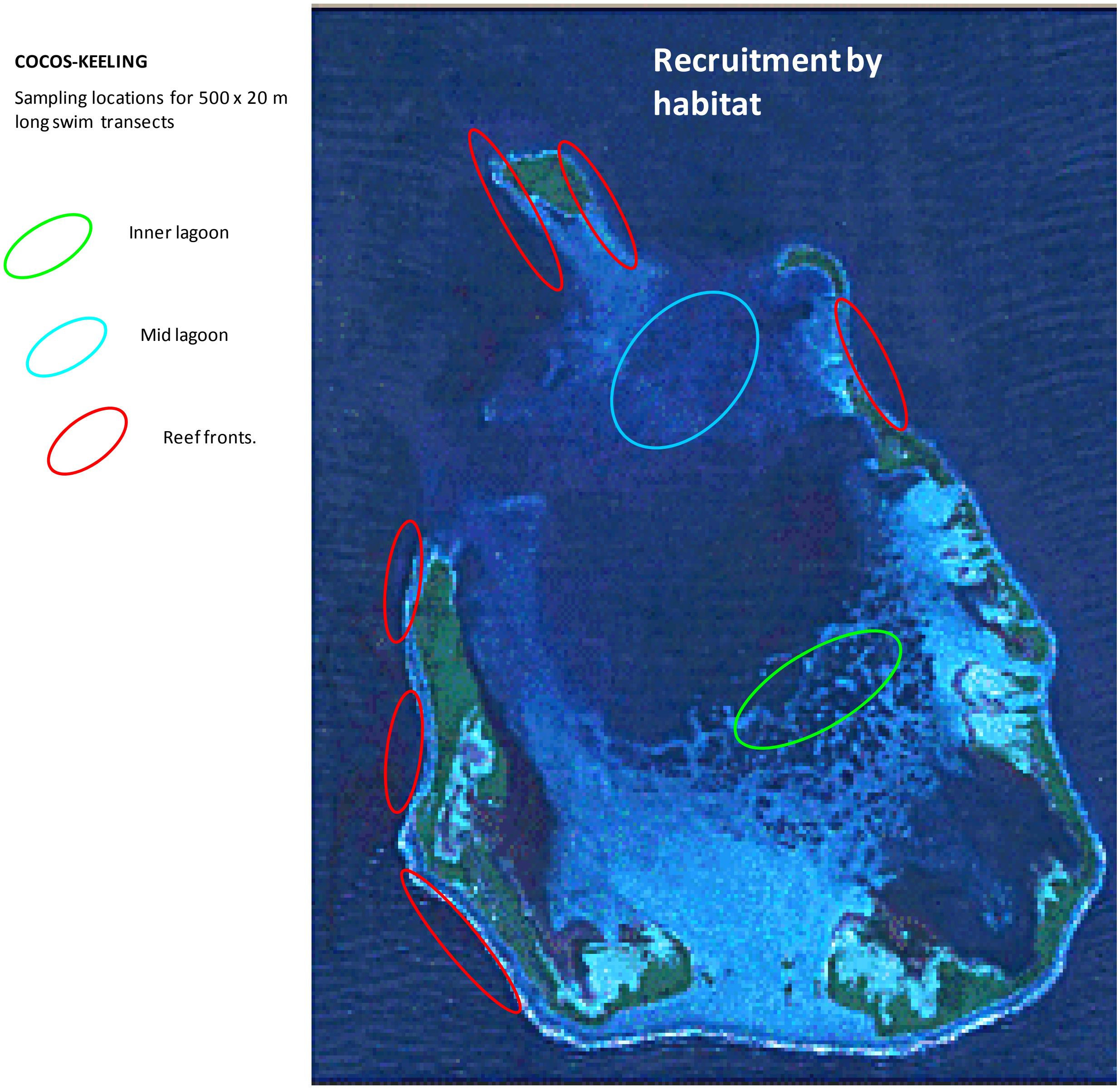

Figure 5.--Aerial view of Cocos-Keeling showing location of juvenile survey sites (Choat, unpubl. data).

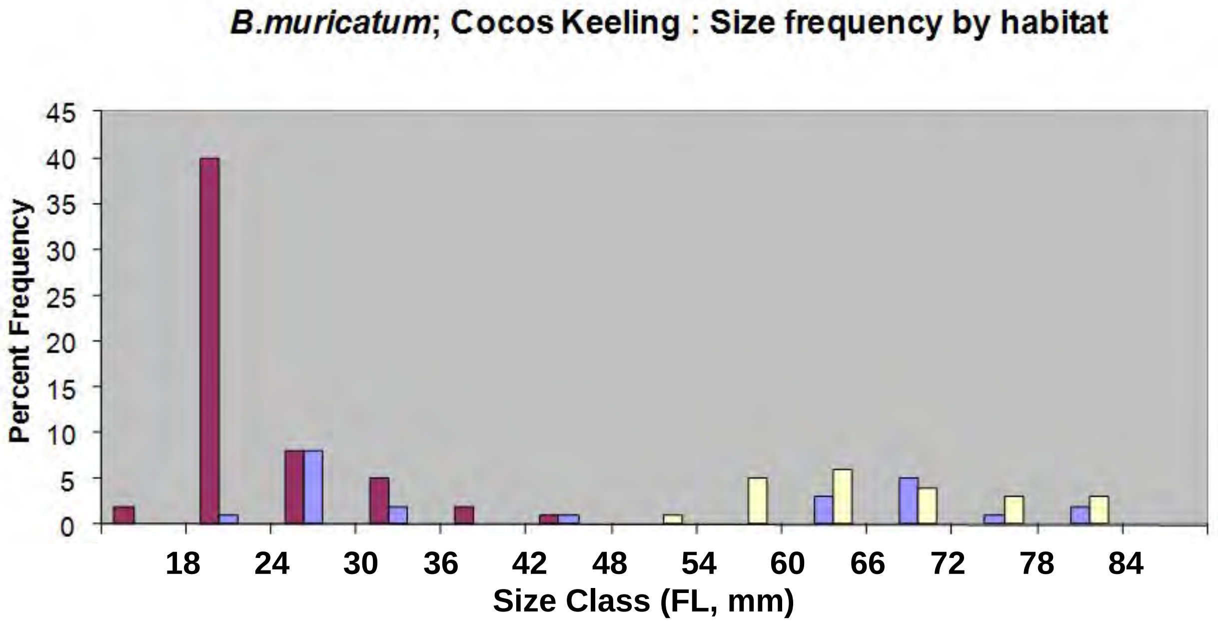

Figure 6.--Size frequency distribution of bumphead parrotfish among inner lagoon (purple), mid-lagoon (blue), and forereef (yellow) habitats at Cocos-Keeling (Choat, unpubl. data).

2.2.2 Range and Quantification of Habitat

Bumphead parrotfish are recorded from many areas across the Indo-Pacific: the Red Sea; East Africa; Asia; Australia; the Line Islands;, Tonga and other island nations in the western and South Pacific. Their range also extends through some U.S. territories, including American Samoa, Guam, Northern Mariana Islands, and Pacific Remote Island Areas.in the Central Pacific (Mundy et al., 2011). Geographic range resolved along geopolitical boundaries or island groups was gleaned from published and unpublished references with specific mention of the geographic range of bumphead parrotfish. This was supplemented by verbal interviews of experts in Pacific, Indian Ocean, and Red Sea fish biogeography (refer to specific listing in Acknowledgements). A range map showing these geographic strata was constructed (Figure 7). In all, 62 strata were identified which were primarily country specific. It should be noted that certain geographic strata are in or near the overall range polygon but are not known to have bumphead parrotfish (e.g., Hawaii, Johnston Atoll, Cook Islands, Tokelau, Nauru, British Indian Ocean Territory, etc.). This pattern appears to be a natural characteristic of the species range, suggesting that the current range is equivalent to the historical range (Jack Randall, pers. comm.). No documentation was found to suggest that the bumphead parrotfish range (as opposed to abundance) was larger than that observed in contemporary times. ReefCheck data (1997-2009, *n* = 4990 transects) supported the absence of bumphead parrotfish in the Cook Islands but recorded bumphead parrotfish in parts of French Polynesia, Reunion, Israel (Eilat), and Iran (Persian Gulf), range areas which were not initially apparent from the literature search and expert interviews. These occurrences involved repeated instances per location and the data forms clearly distinguish the tabulation of this species from other similar large labroid fish (e.g., humphead wrasse). Therefore, these data for French Polynesia, Reunion, Israel, and Iran are assumed to be valid for the time being. Of these 4 sites, the Iran occurrences are probably the most suspect and these occurrences need further investigation (Shokri, pers. comm.). Since a separate Red Sea Exclusive Economic Zone (EEZ) polygon for Israel was not available from the Flanders Marine Institute (http://www.vliz.be/vmdcdata/marbound/index.php), the Eilat survey data were assumed to originate from the Sinai portion of the Gulf of Aqaba and combined with survey data from Egypt, which shares jurisdiction of the Gulf of Aqaba with Saudi Arabia, Jordan, and Israel (this accounts for the occasional reference to either 62 or 63 geographic strata).

Of the 3 types of habitat areas important to bumphead parrotfish, the high-energy forereef area used by adults could be estimated from existing information and is presented in this report. Details of this habitat tabulation are presented in the Appendix (Appendix: Global Estimation of Population). Lagoonal area is difficult but not impossible to quantify from existing sources (although see the mangrove index used in the SPOIR section later in this report), and nighttime sleeping shelters also pose a challenge to quantify. For adult habitat, nominal coral reef area was estimated directly from a 4-km global grid. An aggregate correction was applied to scale the area to actual coral reef based on survey studies. An additional scaling adjusted the coral reef area to the amount of preferred forereef area, also based on survey studies. This forereef value was further adjusted to account for the estimated pattern of habitat utilization by bumphead parrotfish (Table 1). The areal breakdown of likely bumphead parrotfish habitat is presented graphically in Figure 8. These habitat values are used in a subsequent section pertaining to the estimation of bumphead parrotfish global population size.

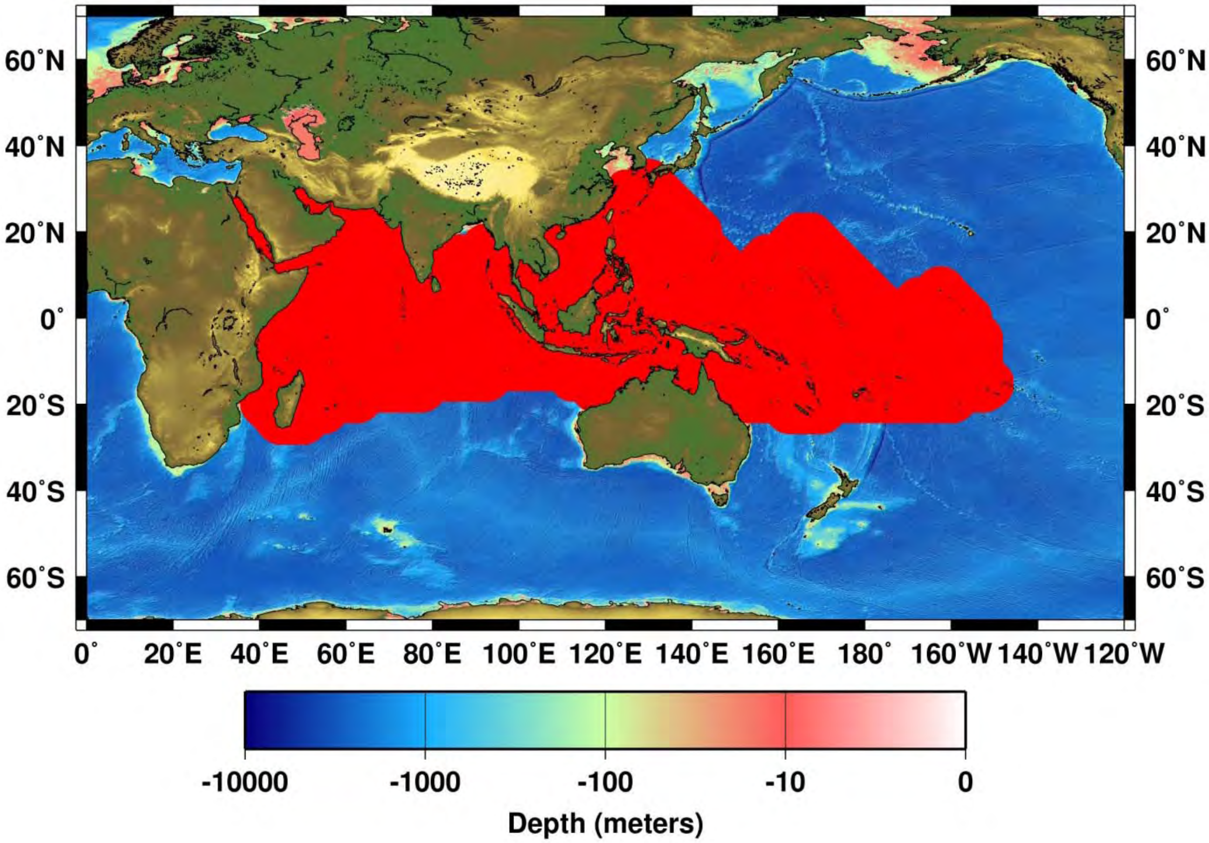

Figure 7.--Overall range of bumphead parrotfish (delineated in red) using published and unpublished records, including expert interviews and survey data.

Table 1.--Estimated bumphead parrotfish habitat (km^2) in each of the 62 geographic strata of range. 'Nominal' refers to coral reef area estimated directly from a 4-km global coral grid from Reefs At Risk Project. 'Corrected' refers to an average correction (56.85%) based on survey data. 'Forereef' refers to a forereef adjustment (15.97%). 'Scaled forereef' refers to a reduction (50%) based on conservative estimate of bumphead parrotfish occupancy patterns. Details in Appendix.

Geographic strata	***Nominal***	***Corrected***	***Forereef***	***Scaled forereef***
Indonesia	110366.27	47625.22	7603.65	3801.82
Australia	77892.57	33612.18	5366.38	2683.19
Papua New Guinea	36372.92	15695.63	2505.90	1252.95
Philippines	32919.29	14205.32	2267.96	1133.98
Fiji	20925.51	9029.77	1441.66	720.83
French Polynesia	16086.34	6941.57	1108.26	554.13
New Caledonia	15002.12	6473.71	1033.57	516.78
Solomon Islands	13944.28	6017.23	960.69	480.34
Maldives	13882.36	5990.51	956.42	478.21
Marshall Islands	12306.13	5310.34	847.83	423.91
Saudi Arabia	11413.73	4925.25	786.35	393.17
Eritrea	11354.08	4899.51	782.24	391.12
Andaman and Nicobar	10297.36	4443.51	709.43	354.72
Micronesia	9106.34	3929.57	627.38	313.69
Egypt	7583.40	3272.39	522.46	261.23
Tanzania	7503.74	3238.01	516.97	258.48
Madagascar	7223.02	3116.87	497.63	248.81
Malaysia	6679.68	2882.41	460.19	230.10
Mozambique	5980.05	2580.51	411.99	206.00
Myanmar	4735.21	2043.34	326.23	163.12
Vanuatu	4621.91	1994.44	318.42	159.21
Sudan	4481.68	1933.93	308.76	154.38
India	4185.66	1806.20	288.37	144.18
Spratly Islands	4115.64	1775.98	283.55	141.77
Gilbert Group	4102.63	1770.36	282.65	141.32
Yemen	3786.88	1634.11	260.90	130.45
Tonga	3750.41	1618.38	258.38	129.19
Japan	3525.79	1521.45	242.91	121.45
Seychelles	3489.46	1505.77	240.41	120.20
Thailand	3295.44	1422.05	227.04	113.52
China	2662.12	1148.76	183.41	91.70
Somalia	2267.35	978.41	156.21	78.10
Palau	2212.93	954.92	152.46	76.23
Tuvalu	2033.48	877.49	140.10	70.05
Kenya	2023.49	873.17	139.41	69.70
Mauritius	1750.48	755.37	120.60	60.30
Viet Nam	1599.73	690.32	110.21	55.11
Samoa	1552.54	669.95	106.96	53.48
Sri Lanka	1537.90	663.63	105.95	52.98
Iran	1394.01	601.54	96.04	48.02
Paracel Islands	1373.95	592.89	94.66	47.33
Line Group	1238.52	534.44	85.33	42.66
Wallis and Futuna	1178.37	508.49	81.18	40.59
Djibouti	1172.80	506.08	80.80	40.40
Mayotte	1039.38	448.51	71.61	35.80
Phoenix Group	895.70	386.51	61.71	30.85
Taiwan	823.28	355.26	56.72	28.36
East Timor	745.77	321.81	51.38	25.69
American Samoa	645.86	278.70	44.50	22.25
Comoro Islands	499.55	215.57	34.42	17.21
Howland and Baker Islands	442.40	190.90	30.48	15.24
Christmas Island	403.73	174.22	27.81	13.91
Glorioso Islands	314.85	135.86	21.69	10.85
Niue	303.09	130.79	20.88	10.44
Northern Mariana Islands and Guam	279.84	120.76	19.28	9.64
Palmyra Atoll	264.51	114.14	18.22	9.11
Cocos Keeling	217.08	93.67	14.96	7.48
Reunion	145.04	62.59	9.99	5.00
Wake Island	31.45	13.57	2.17	1.08
Ile Tromeline	21.36	9.22	1.47	0.74
Jarvis Island	18.91	8.16	1.30	0.65
Cambodia	10.92	4.71	0.75	0.38
Total km^2	***502030.25***	***216635.94***	***34587.21***	***17293.61***
Thousand km^2	***502.03***	***216.64***	***34.59***	***17.29***

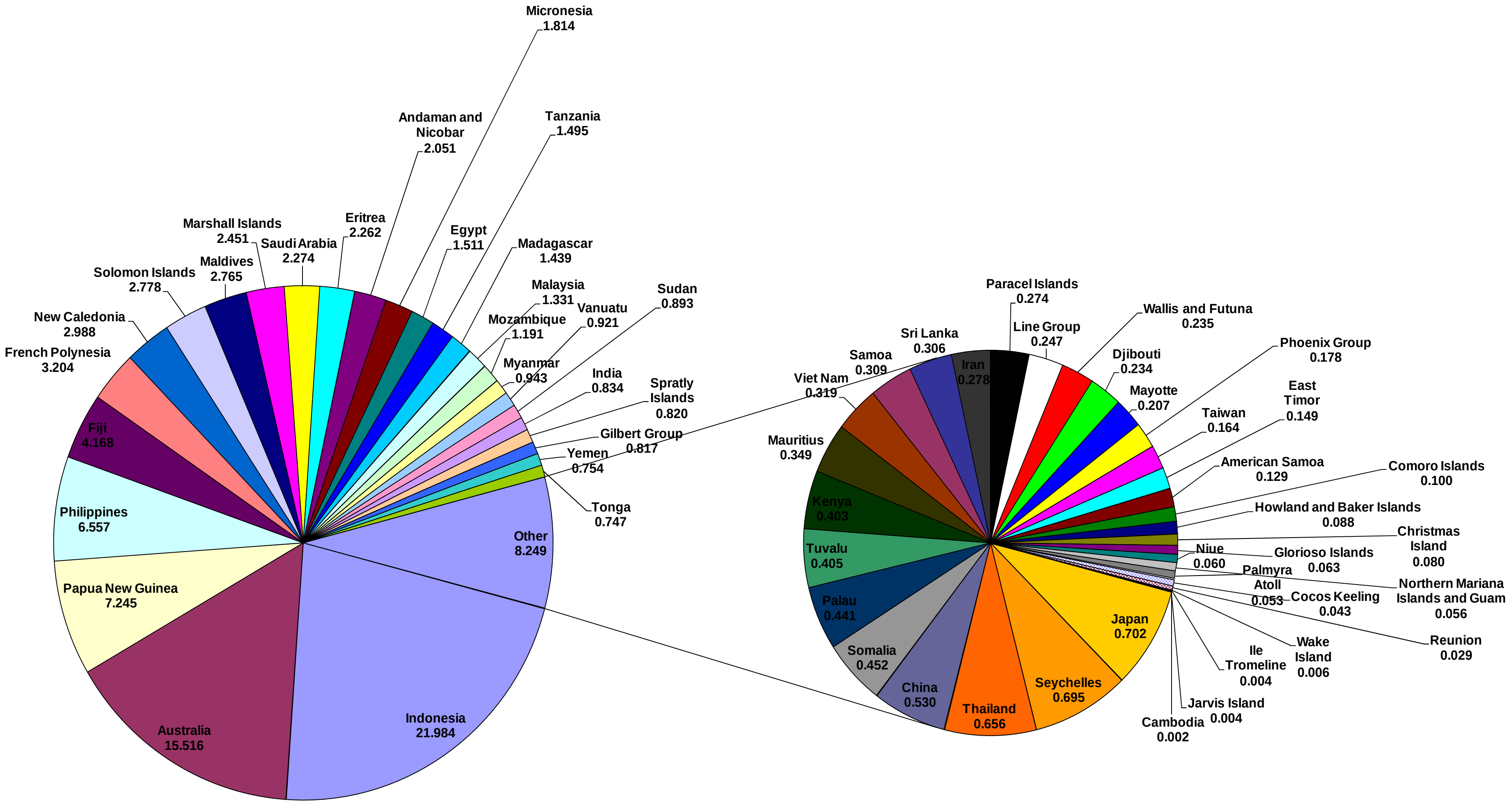

Figure 8.--Areal breakdown by percentage of bumphead parrotfish adult habitat across 62 geographic strata of range. The list was gleaned from the literature and from other sources such as expert interviews and diver surveys.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish habitat and range", the bumphead parrotfish appears to have specific habitat requirements for different stages of its life-history ranging from shallow lagoonal areas for the young, to high-energy forereef areas for the adults, that there is a critical need for nighttime sleeping shelters; that the species is broadly distributed across the Pacific Ocean, Indian Ocean, and Red Sea, with relatively large amounts of adult habitat in Indonesia, Australia, Papua New Guinea, and the Philippines; and that the current range is equivalent to the historical range.

2.3 Abundance and Density

The bumphead parrotfish is thought to have been abundant throughout its range historically (Dulvy and Polunin, 2004). Numerous reports suggest that fisheries exploitation has reduced local densities to a small fraction of their historical values in populated or fished areas (Bellwood et al., 2003; Dulvy and Polunin, 2004; Hamilton, 2004; Hoey and Bellwood, 2008).

Current and accurate estimates of abundance throughout the entire geographic range of bumphead parrotfish are unavailable in the published literature. However, efforts have been made to document the abundance of reef fishes, including the bumphead parrotfish, at specific locations within the geographic range of the species (Dulvy and Polunin, 2004; Jennings and Polunin, 1995; 1996). These studies use fisheries independent survey methods (Underwater Visual Census) such as strip transect, stationary point count, timed swims, or towed-diver surveys to estimate abundances of fishes over a predefined area. Additionally, these studies span a gradient of human population densities and associated levels of fisheries exploitation. Abundance of large-bodied species, including the bumphead parrotfish, is lower at sites where human population density and fisheries exploitation are higher than at sites that are remote, uninhabited or protected from fishing (e.g., no-take marine reserves). A number of studies have constructed indices of abundance using different survey methodologies or qualitative approaches; these are primarily for adult bumphead parrotfish and will be summarized in the following paragraphs.

Dulvy and Polunin (2004) collated all currently available information related to local-scale density estimates of bumphead parrotfish for 39 locations within the range of the bumphead parrotfish. This information was used to make a qualitative assessment of the presence/absence, abundance, and exploitation status of the bumphead parrotfish (see Table 2 and Table 3 from Dulvy and Polunin, 2004). In addition to the qualitative assessment, Dulvy and Polunin obtained quantitative abundance data for 6 locations within the range of the species. Locations included the following: Great Barrier Reef; Solomon Islands; Fiji (Lau Islands); Fiji (Mamanuca Islands); Tanzania; and select sites in the Philippine Islands.

Based on Dulvy and Polunin's paper, the Great Barrier Reef had the highest observed densities of bumphead parrotfish with an estimate of 3.05 fish per km^2, citing Choat data. (The Team has concerns about a possible typographical error in that report; the correct units probably were fish per 1000 m^2, as shown in Figure 3 extracted from a Choat presentation). Both units are used in the literature; conversion from numbers per km^2 to numbers per 1000 m^2 involves dividing the former by 1000.

Bumphead parrotfish were also observed in the Solomon Islands. However, density estimates were about half (1.40 fish per km^2) those reported for the Great Barrier Reef. In Fiji, bumphead parrotfish were infrequently observed, with densities ranging between 0.03 and 0.02 fish per km^2 at both Fiji island groups. No bumphead parrotfish were observed in Tanzania or the Philippine Islands. Heavy subsistence, artisanal, and commercial fisheries were reported at all locations where bumphead parrotfish densities were less that 1 fish per km^2.

Densities of bumphead parrotfish in the Indian Ocean show a biogeographic distributional gradient with the highest densities adjacent to the western Australian coast and densities decreasing to the west (Choat, unpubl. data, Figure 9). Densities at Rowley Shoals off western Australia are similar to the high densities observed on the outer Great Barrier Reef and highlight the importance of exposed outer reef habitats with adjacent lagoons. Densities of bumphead parrotfish in the western Indian Ocean (East Africa, Seychelles) are generally lower than those observed in Australia and the western Pacific (Choat, pers. comm.), although some areas of the Seychelles such as Farquhar Atoll (Friedlander, pers. obs.) and Cousin Island (Jennings, 1998) support large numbers of bumphead parrotfish. Also, large numbers of bumphead parrotfish are found in some areas of Borneo and Malaysia (e.g., Sipadan; Randall, pers. comm.).

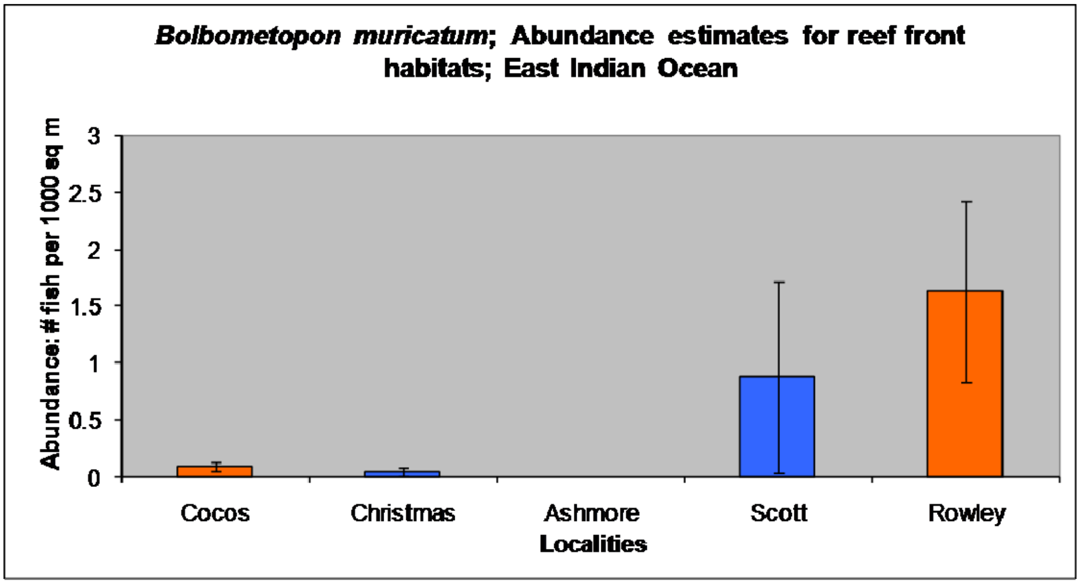

Figure 9.--Abundance estimates of bumphead parrotfish across the East Indian Ocean (Choat, unpubl. data). Bars: mean abundance; Intervals: mean ± 1 SE.

In the U. S. Pacific Islands, the abundance of bumphead parrotfish has been assessed as part of the NOAA/Pacific Islands Fisheries Science Center's Reef Assessment and Monitoring Program. Since 2000, under the leadership of the Center's Coral Reef Ecosystem Division (CRED), researchers have conducted quantitative assessments of reef fishes on a biennial or annual basis. Regions visited that are within the range of the bumphead parrotfish include: Guam and the Mariana Archipelago, the islands of American Samoa, and the Pacific Remote Island Areas. Towboard[3] data showed that bumphead parrotfish are rare in the U.S. Pacific islands and only reported in notable numbers with towed-diver surveys (Richards et al., 2011). Bumphead parrotfish were most abundant at Wake Atoll with lesser numbers at Palmyra Atoll and Pagan Island in the Commonwealth of the Northern Mariana Islands (Figure 10, Table 2). The highest densities of bumphead parrotfish were observed at Wake Atoll with an estimate of ~300 fish observed per km^2. The second highest densities were observed at Palmyra Atoll with 5.22 fish per km^2. Density at the Pagan site in the Mariana Archipelago was 1.62 fish per km^2. In American Samoa, bumphead parrotfish were observed at Tau (1.08 fish per km^2) and at Tutuila (0.41 fish per km^2). Bumphead parrotfish were also observed at Jarvis Island (1.26 fish per km^2).

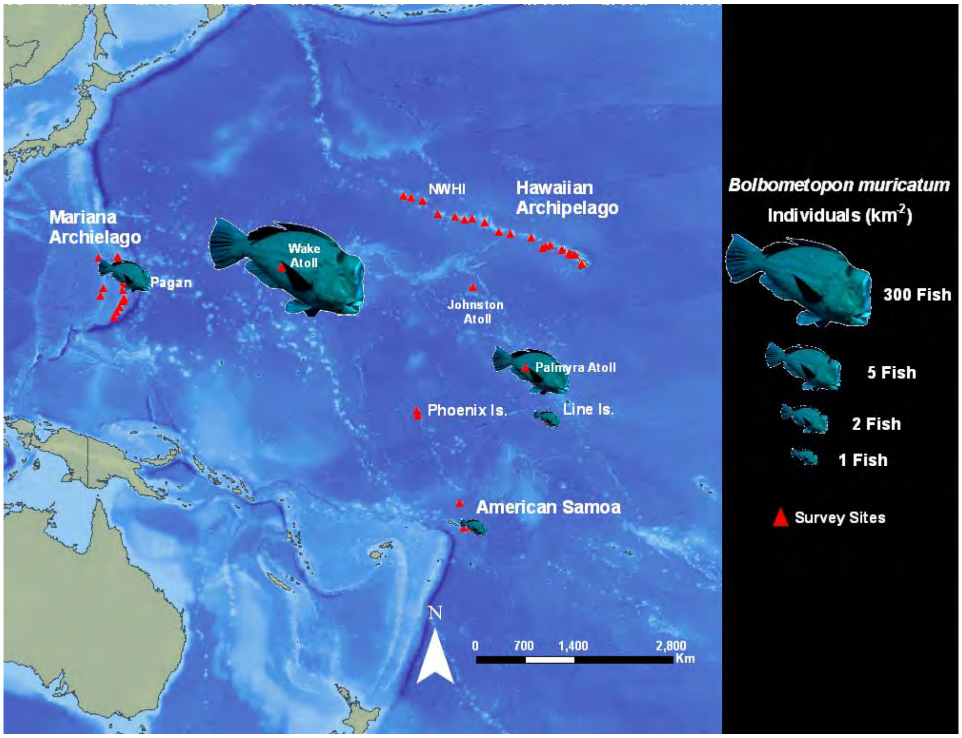

Figure 10.--Standardized abundance of bumphead parrotfish observed on towed-diver surveys at the U. S. Pacific Islands. Standardized abundance (number of fish per km^2) was obtained by dividing the number of fish observed by the area of the towed-diver transect (PIFSC/CRED data).

Surveys conducted by the Secretariat of the Pacific Community (SPC) in their Pacific Regional Oceanic and Coastal Fisheries (PROCFish) project in 2001-2008 revealed relatively high numbers of bumphead parrotfish in Palau with slightly more than 1.5 individuals per station (Table 3). Numbers in New Caledonia were approximately half of those observed in Palau. Sites

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[3] A field survey method whereby scuba diver(s) are towed behind a small boat for a distance of ~2 km, using a board-like planing device for depth control, while recording or relaying visual sighting information.

in Papua New Guinea and the Federated States of Micronesia also recorded modest numbers of individuals. Low numbers in Tonga, Fiji, and the Solomon Islands may reflect fishing pressure (e.g., Dulvey and Polunin, 2004; Hamilton, 2004), while their absence from a number of locations are likely the result of these locations being outside of the range for the species (i.e., French Polynesia, Cook Islands, and Marshall Islands) or the lack of suitable lagoonal habitats for recruitment (i.e., Niue, Nauru).

Table 2.--Abundance of bumphead parrotfish in the U. S. Pacific Islands 2000-2009. Results are based from towed-diver surveys and abundance values are in number of individuals per km^2. PRIAs abbreviates Pacific Remote Island Areas. CNMI abbreviates Commonwealth of the Northern Mariana Islands (PIFSC/CRED data).

Region	Islands	Effort (number of transects)	Abundance (number per km^2)	Standard deviation	Standard error
PRIAs	Jarvis	43	1.26	8.25	1.26
CNMI	Pagan	69	1.62	13.45	1.62
PRIAs	Palmyra	64	5.22	33.24	4.15
Samoa	Tau	50	1.08	7.63	1.08
Samoa	Tutuila	122	0.41	4.50	0.41
PRIAs	Wake	51	296.64	687.24	96.23

Based on the Secretariat of the Pacific Community data, the maximum number of individuals per school was 120 individuals in Palau and 100 individuals in New Caledonia (Table 4). Overall, the average number of indivuals observed per school was 8.17 (SD = 17.9).

The Team was unable to find any published quantitative information on the abundance of bumphead parrotfish in the Red Sea. Qualitatively, the species is observed to be relatively abundant in some parts of Sudan, Egypt, Eritrea, and Yemen (Bogorodsky, pers. comm.). The ReefCheck database, mentioned earlier with regard to bumphead parrotfish range, also contains information on bumphead parrotfish density in the Red Sea, which is briefly summarized here. The ReefCheck project (http://www.reefcheck.org/) of trained volunteer divers has amassed a large standardized survey database across the Pacific Ocean, Indian Ocean, Red Sea, and Persian Gulf (1997-2009, n = 4990 transects). Abundance of bumphead parrotfish and number of transects from the ReefCheck surveys are shown in Table 5.

The merged database (using a common standardization to number per 1000 m^2) of SPC PROCFish and ReefCheck observations resulted in 49 geographic strata having a standardized bumphead parrotfish density estimate. These results are shown in Table 6 and Figure 11. The total number of transects from the merged database is shown in Figure 18.

Two other analyses pertaining to bumphead parrotfish abundance are presented later in this report in the section on extinction risk assessment. First, a synthesis of abundance data—converting the survey data into a simple index of abundance—is presented in in GIS format. Second, an estimate of the contemporary global population size of bumphead parrotfish is presented. These analyses were thought to be more relevant to the extinction risk question, hence their placement in that section of the report.

Table 3.--Bumphead parrotfish abundance data from the Secretariat of the Pacific Community PROCFish diver surveys. N refers to the number of diver survey stations (250 m^2 each) in each island area, and 'bhp' and 'bhp_station' refer to the number of bumphead parrotfish observed and the average abundance (number of fish per 250 m^2), respectively. It should be noted that some of the surveyed areas (e.g., Cook Islands, Nauru) are outside of the known range of bumphead parrotfish.

Country	N	bhp	bhp_station
Palau	188	294	1.56
New Caledonia	248	188	0.76
Papua New Guinea	168	109	0.65
FSM	164	87	0.53
Vanuatu	192	52	0.27
Fiji	288	58	0.20
Solomon Islands	191	14	0.07
Tonga	486	6	0.01
Wallis And Futuna	186	1	0.01
Cook Islands	132	0	0.00
French Polynesia	288	0	0.00
Kiribati	194	0	0.00
Marshall Islands	149	0	0.00
Nauru	100	0	0.00
Niue	100	0	0.00
Samoa	202	0	0.00
Tuvalu	288	0	0.00

Table 4.--Secretariat of the Pacific Community data on bumphead parrotfish school size (number of fish per school) from PROCFish diver surveys.

Country	Average	SD	Minimum	Maximum
Fiji	14.50	13.40	1	27
Federated States of Micronesia	4.58	8.55	1	35
New Caledonia	15.67	28.79	1	100
Palau	11.76	25.55	1	120
Papua New Guinea	8.38	9.47	1	26
Solomon Islands	1.00	0.00	1	1
Tonga	1.50	0.58	1	2
Vanuatu	7.43	14.48	1	40
Wallis And Futuna	1.00	-	1	1
Grand Total	8.17	17.88	1	120

Table 5.--Summary of ReefCheck survey data for bumphead parrotfish standardized abundance.

Geographic strata	Number per 1000 m^2	Number of transects
Seychelles	2.50	14
Indonesia	1.82	794
Papua New Guinea	1.41	112
Sudan	1.35	13
Palau	1.25	26
Solomon Islands	0.91	26
Christmas Island	0.88	20
Vanuatu	0.75	50
Reunion	0.67	41
Egypt	0.67	195
Cocos Keeling	0.63	50
Iran	0.58	15
Madagascar	0.57	35
Northern Mariana Islands	0.45	33
Fiji	0.44	435
Malaysia	0.42	349
Australia	0.42	171
French Polynesia	0.34	232
Mauritius	0.29	13
East Timor	0.25	10
Saudi Arabia	0.25	20
Micronesia	0.22	96
Yemen	0.21	6
Japan	0.19	212
Philippines	0.17	667
Myanmar	0.16	23
Cambodia	0.10	50
Maldives	0.07	117
Mayotte	0.07	18
Viet Nam	0.06	455
New Caledonia	0.04	195
Thailand	0.04	175
Tanzania	0.03	38
American Samoa	0.00	2
China	0.00	175
Djibouti	0.00	19
Eritrea	0.00	4
India	0.00	2
Kenya	0.00	7
Marshall Islands	0.00	6
Mozambique	0.00	23
Sri Lanka	0.00	5
Taiwan	0.00	37
Tonga	0.00	4

Table 6.--Summary of merged SPC PROCFish and ReefCheck survey data for bumphead parrotfish abundance.

Region	Number per 1000 square meters
Palau	5.17
Seychelles	2.50
Papua New Guinea	1.92
Indonesia	1.82
Sudan	1.35
New Caledonia	1.21
Micronesia	1.10
Vanuatu	0.97
Christmas Island	0.88
Reunion	0.67
Egypt	0.67
Cocos Keeling	0.63
Iran	0.58
Madagascar	0.57
Fiji	0.53
Northern Mariana Islands and Guam	0.45
Solomon Islands	0.42
Malaysia	0.42
Australia	0.42
French Polynesia	0.34
Mauritius	0.29
East Timor	0.25
Saudi Arabia	0.25
Yemen	0.21
Japan	0.19
Philippines	0.17
Myanmar	0.16
Cambodia	0.10
Maldives	0.07
Mayotte	0.07
Viet Nam	0.06
Tonga	0.05
Thailand	0.04
Tanzania	0.03
Wallis and Futuna	0.02
American Samoa	0.00
China	0.00
Djibouti	0.00
Eritrea	0.00
Gilbert Group	0.00
India	0.00
Kenya	0.00
Marshall Islands	0.00
Mozambique	0.00
Niue	0.00
Samoa	0.00
Sri Lanka	0.00
Taiwan	0.00
Tuvalu	0.00

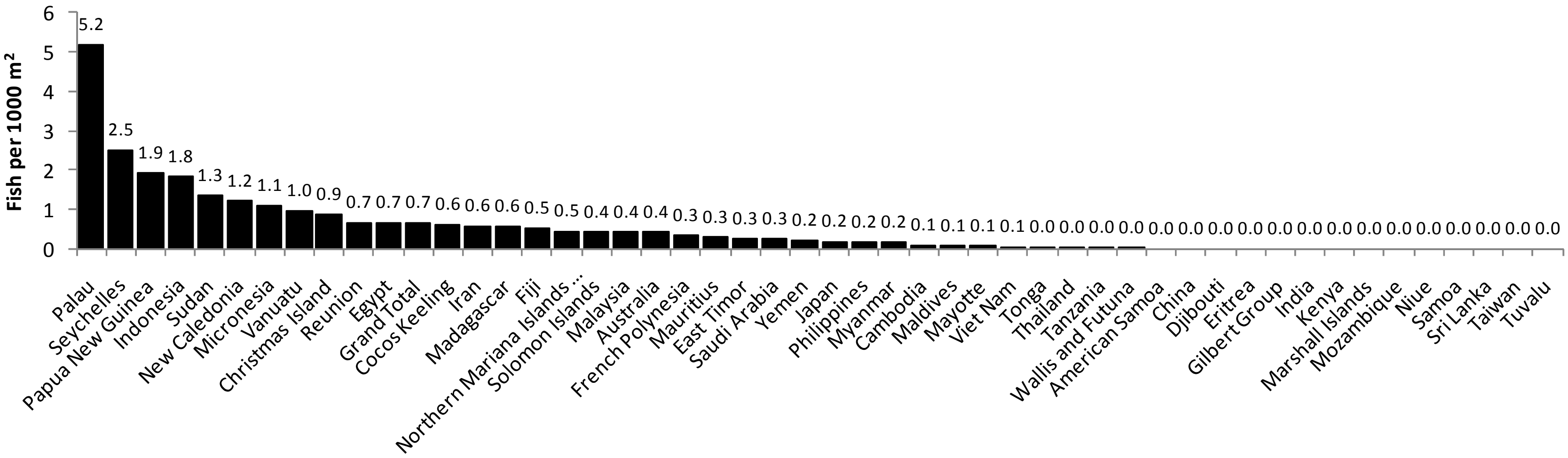


Figure 11.--Graphical summary of merged SPC PROCFish and ReefCheck survey data for bumphead parrotfish abundance.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish abundance", the bumphead parrotfish appears to have a wide range of abundance from being relatively uncommon in parts of Fiji, Samoa, Guam, Mariana Islands, Tonga, and Solomon Islands to being relatively abundant in parts of the Great Barrier Reef, Indian Ocean, Palau, Malaysia, Wake Atoll, Red Sea, and Seychelles with many other areas at intermediate levels of abundance and some at unknown levels of abundance.

2.4 Age and Growth

The growth characteristics of adult parrotfishes (family Scaridae) are well known; they tend to possess indeterminate growth and achieve moderate longevities. Most scarids have maximum ages of ~20 years (Choat and Robertson, 2002). The scarids have typical growth curves in which size increases gradually throughout life, and there is a tendency for higher maximum ages in larger species. In some instances, sex-specific growth differences result in males being larger than females at most ages (Choat et al., 1996). Bumphead parrotfish has a longevity consistent with that of its confamilials, i.e., being the largest scarid, it has the greatest longevity of all the scarids (Choat, pers. comm.).

Age and growth estimates have been developed for the species throughout much of its range. There are five age and growth studies: two from northeast Australia (Choat et al., 2006; Choat and Robertson, 2002), one from the western Solomon Islands (Hamilton, 2004), one from New Caledonia (Couture and Chauvet, 1994), and the last from the Indo-Pacific region (Brothers and Thresher, 1985). With the exception of the study from New Caledonia, which used scales, all ages were determined using otolith sections and some concern has been expressed that the two age determination methods are not equally valid. Based on limited sample size, lack of validation and/or disagreement among scale or otolith techniques, the potential exists to misestimate longevity, growth, and natural mortality for the species (Choat et al., 2006).

The species has been estimated to reach 40 years of age assuming that checks on otoliths are deposited annually (Figure 12) (Choat and Robertson, 2002), although others have estimated maximum age for bumphead parrotfish to range from the upper 20s to mid 30s (Hamilton, 2004). However, these estimates may be overly conservative as the largest and potentially oldest individuals observed may not have been included in the analysis (Choat and Robertson, 2002; Hamilton, 2004). There is a length-frequency based estimate of growth parameters using ELEFAN I, and although these values are comparable to other estimates, concern has been expressed regarding the potential underestimation of ages (Kitalong and Dalzell, 1994). Von Bertalanffy growth parameters have been derived from otolith-based age data. Growth coefficient (K) values for this species range from 0.10 to 0.136, with associated maximum length (L_∞) values ranging from 121.5 cm to 94.5 cm TL (Hamilton, 2004; Choat, pers. comm.).

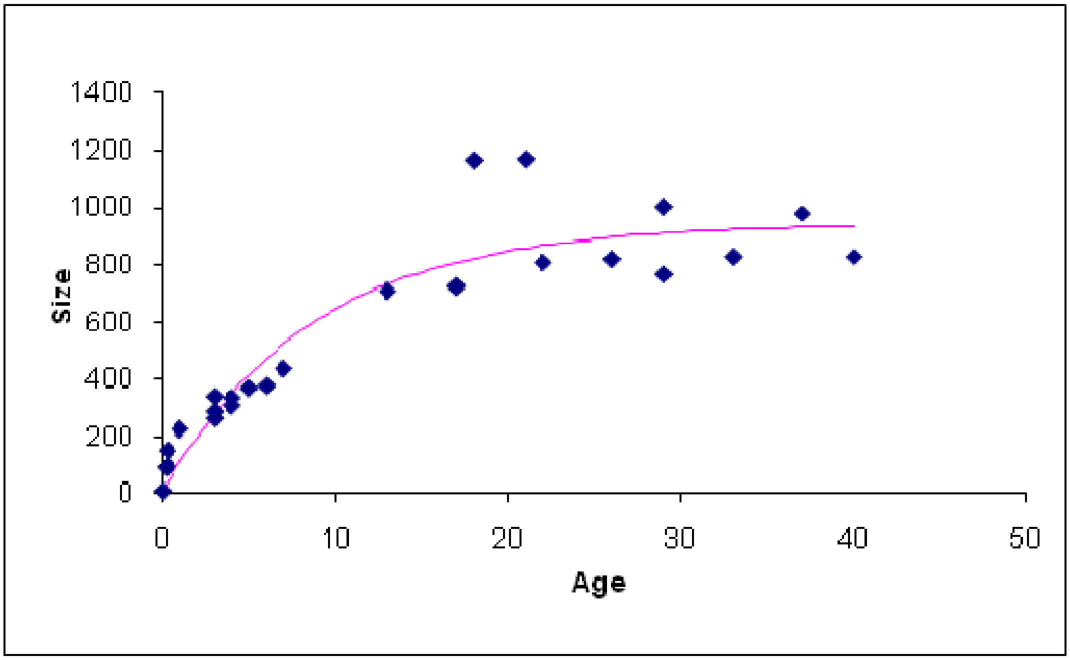
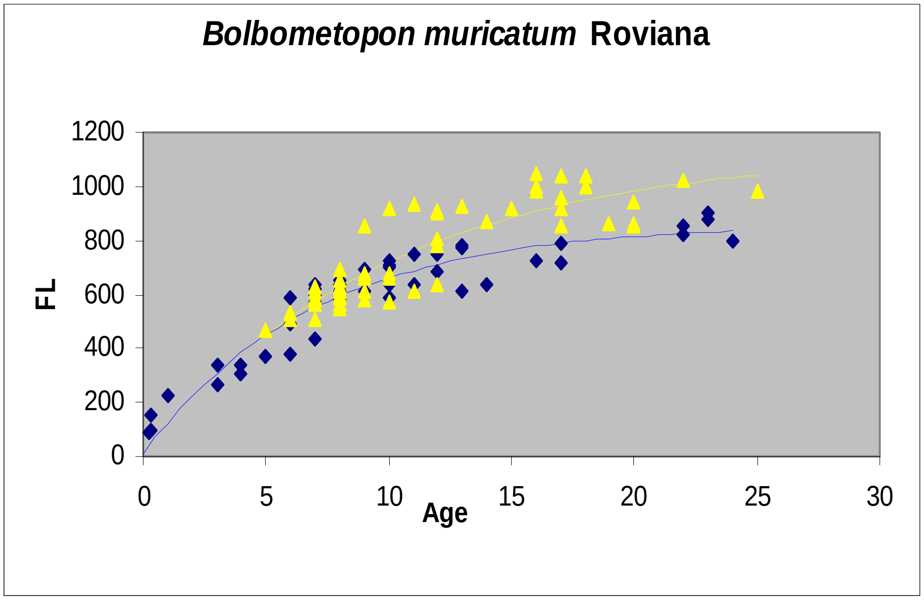


Figure 12.--Length (mm TL) at age (years) growth curve for bumphead parrotfish (Choat, unpubl. data).

Data collected in the western Solomon Islands suggest differential growth between sexes for bumphead parrotfish. Studies indicate that males attain a larger asymptotic size than females and growth is slow but continuous throughout life (Choat, pers. comm.). In contrast, females exhibit more determinant growth characteristics with asymptotic size established at around age 15 years (Hamilton, 2004) (Figure 13).

The age and growth characteristics of juvenile bumphead parrotfish are less well known than those of adults. For instance, a pelagic larval duration estimate of 31 days was made for bumphead parrotfish using pre-transitional otolith increments from one specimen and counts of daily otolith increments from a few juveniles (< 8 yrs old) collected from Cocos-Keeling (Brothers and Thresher, 1985; Choat, pers. comm.).

The average size of individual bumphead parrotfish observed from Secretariat of the Pacific Community PROCFish surveys was 59.7 cm TL (SD = 20.8), with the largest individual being 110 cm and the smallest being 14 cm (Table 7). Notable size differences were observed at different locations. These size differences could reflect variable habitat-related growth conditions, or more likely differences in the intensity of harvest and the degree to which size structure of populations has been truncated.



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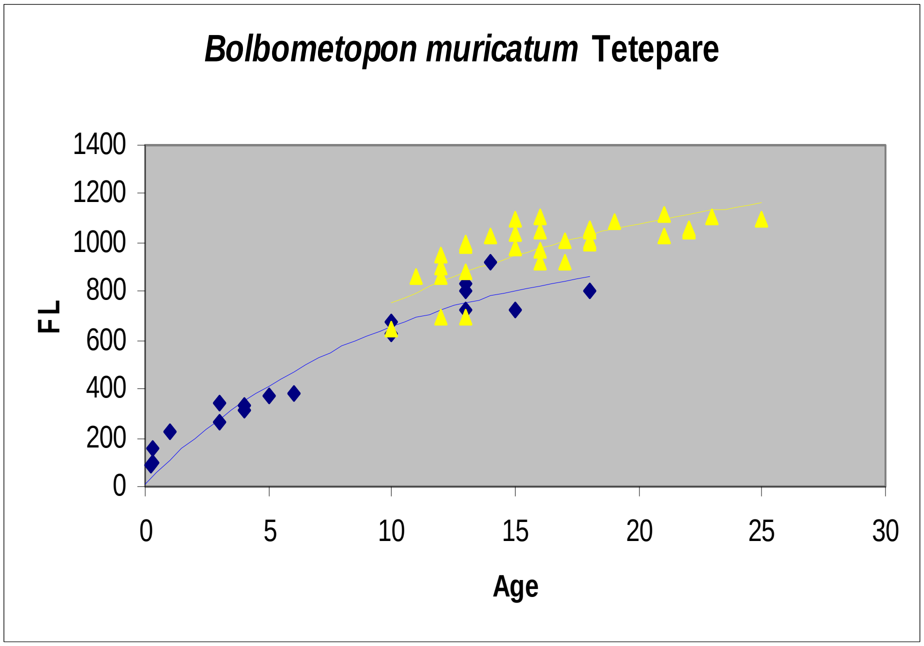


B.

Figure 13.--Demography and sex-specific growth rates. A. male (yellow triangles) and female (blue diamonds) growth rates in Roviana Lagoon. B. male and female growth rates in Tetepare. (Choat and Hamilton, pers. comm.).

Table 7.--Secretariat of the Pacific Community data on bumphead parrotfish fish size (TL cm) from PROCFish diver surveys.

Country	Average size	SD	Minimum	Maximum	Sample size
Fiji	70.75	23.78	38	95	58
Federated States of Micronesia	50.21	13.75	38	95	87
New Caledonia	53.17	23.84	18	100	188
Palau	63.24	18.02	38	100	294
Papua New Guinea	67.54	25.46	14	110	109
Solomon Islands	51.71	15.40	28	70	14
Tonga	47.50	11.90	35	60	6
Vanuatu	81.00	17.71	50	100	52
Wallis And Futuna	100.00	-	100	100	1
Grand Total	59.75	20.81	14	110	809

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish age and growth", the bumphead parrotfish appears to have a reasonably well characterized growth curve and approaches its maximum size at approximately 10-20 years of age with a longevity estimated at approximately 40 years; with most of the individuals seen in the adult habitat likely older than approximately 5 years of age.

2.5 Adult Movement and Behavior

Movement patterns of bumphead parrotfish are not well understood. In an effort to identify their diel movements and home ranges, bumphead parrotfish were tracked using telemetry methods at a site in the Solomon Islands (Hamilton, 2004). Valuable information regarding bumphead movement patterns was obtained; however, the process of capturing, tagging, and releasing individuals had limited success (Hamilton, 2004). Captured individuals suffered high rates of mortality during the tagging and recuperation process, as well as on release. This mortality was principally a result of predation by sharks. Despite limited tagging success, the tracking study demonstrated that adult bumphead parrotfish range up to 6 km from nocturnal resting sites. Bumphead parrotfish movement patterns are distinct between day and night. Diurnal movement patterns are characterized by groups of individuals foraging among forereef, reef flat, reef pass, and clear outer lagoon habitats at depths of 1-30 m (Donaldson and Dulvy, 2004). The bumphead parrotfish is a gregarious species that can be observed foraging during the day in schools of 20 to more than 100 individuals (Bellwood et al., 2003; Gladstone, 1986). Groups of foraging parrotfish are highly mobile and often travel distances of several kilometers throughout the day. At dusk, schools of parrotfish move to nocturnal resting sites found among sheltered forereef and lagoonal habitats. Bumphead parrotfish remain motionless while resting and use caves, passages, and other protected habitat features as refuge during the night. Although bumphead parrotfish travel great distances while foraging, groups of parrotfish consistently return to specific resting sites that serve as important nighttime refuges (Aswani and Hamilton, 2004). The bumphead's size and nocturnal behavior render it vulnerable to nighttime spearfishing throughout its range (Bellwood et al., 2003; Donaldson and Dulvy, 2004; Dulvy and Polunin, 2004).

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish adult movement and behavior", the bumphead parrotfish is gregarious, appears to stay within well-defined home ranges along discrete portions of the reef, and has a predictable movement pattern from daytime foraging to nighttime sleeping habitats.

2.6 Feeding and Trophic Role

Parrotfishes as a family are primarily considered herbivores. A majority of parrotfishes inhabiting areas around rocky substrates or coral reefs use their fused beak-like jaws to feed on the benthic community. Although parrotfishes forage on similar items on the substrate, feeding modes differ among species. Based on differences in morphology, parrotfishes are separated into two distinct functional groups: scrapers and excavators (Bellwood and Choat, 1990; Streelman et al., 2002). Scrapers feed by taking numerous bites, removing material from the surface of the substratum, while excavators take fewer bites using their powerful jaws to remove large portions of both the substrate and the attached material with each bite. As a result of even moderate levels of foraging, both scrapers and excavators can have profound impacts on the benthic community. Thus, it is widely recognized that parrotfishes play an important functional role as herbivores and bioeroders in reef habitats (Bellwood et al., 2003; Hoey and Bellwood, 2008).

Bumphead parrotfish are classified as excavators feeding on a variety of benthic organisms including corals, epilithic algae, sponges, and other microinvertebrates (Bellwood et al., 2003; Calcinai et al., 2005; Hoey and Bellwood, 2008; Randall, 2005). Bumphead parrotfish are assigned a trophic level of 2.67 (SE 0.41) based on an assessment of food items consumed (Fishbase.com). A foraging bumphead parrotfish often leaves distinct deep scars where benthic organisms and substrate have been removed. As such, their contribution as a major bioeroder is significant. A single individual is estimated to ingest more than 5 tons of reef carbonate each year (Bellwood et al., 2003); hence, even small numbers of bumphead parrotfish can have a large impact on the coral reef ecosystem.

Bumphead parrotfish show little evidence of feeding selectivity; however, a significant portion (up to 50%) of their diet consists of live coral (Bellwood and Choat, 1990; Bellwood et al., 2003; Hoey and Bellwood, 2008). On the Great Barrier Reef, bumphead parrotfish are considered major coral predators, removing up to 13.5 kg m^{-2} of live coral each year (Bellwood et al., 2003). It has been suggested that bumphead parrotfish use their bulbous head as a battering ram to break up corals (Lieske and Myers, 1996), but this behavior has not been well documented (Bellwood, Choat, and Randall, pers. comm.). Slightly more foraging activity was directed towards epilithic algae (non-crustose algae growing on the surface substrate) and coralline algae than on living coral, based on studies on the Great Barrier Reef (Bellwood et al., 2003). Bite counts and examination of the substrate in another instance indicated that live coral and algal turf were consumed in approximately equivalent amounts (Randall, pers. obs.). Some evidence indicate that bumphead parrotfish avoid the consumption of *Montipora* sp. coral (Bellwood et al., 2003).

The diet of juvenile bumphead parrotfish is not well documented but is likely to include a broader spectrum of softer benthic organisms until the excavating (and possibly the ramming) capability and morphology are developed. Additionally, some of the shallow lagoonal areas where juveniles occur may also be lacking high densities of coral.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish feeding and trophic role", the adult bumphead parrotfish is a facultative corallivore and/or generalist benthic grazer and is capable of having a large impact on the surrounding benthic community and rates of bioerosion.

2.7 Natural Mortality

The natural mortality of bumphead parrotfish is generally thought to be low, especially when compared to other scarids (Choat, pers. comm.). Disease, parasites, and competition have not been documented to be significant components of natural mortality in this species. However, even with bumphead parrotfish achieving a greater size than that of all other scarids, adults of this species are not immune to predation, especially by sharks (Davis, pers. comm.). Juveniles are likely to be vulnerable to the many reef and lagoon piscivores (i.e., there are no documented defensive mechanisms such as toxicity, distastefulness, spination, inflation, mimicry, camouflage, etc.). Anecdotal observations suggest that the juveniles are behaviorally inconspicuous and adept at sheltering in shallow and/or turbid areas among coral heads, foliate algae, seagrasses or mangroves (Bellwood and Choat, 1989).

Human activity may influence natural mortality (mortality caused directly by human activity, e.g., by fishing, is discussed later). There is anecdotal evidence that injury to this fish, whether caused by natural or human-induced events (e.g., injury from spearing attempts, tagging, nighttime fright response), can increase its vulnerability to shark predation (Davis, Hamilton, pers. comm.). The exact mechanisms behind this relationship are unclear but appear to be related to loss of scale(s), predator olfactory cues, and stress response of the injured individual. This is tempered by other observations of scarred and damaged individuals in the adult populations that otherwise appear seemingly healthy (Bellwood and Choat, pers. comm.).

Demographic studies on bumphead parrotfish have evaluated mortality rates, using both age-based estimates and length-frequency ELEFAN I type models, for individuals collected in Palau, New Caledonia, and Western Solomon Islands (Couture and Chauvet, 1994; Hamilton, 2004; Kitalong and Dalzell, 1994). Estimates have been published for instantaneous rates of total mortality (Z) and natural mortality (M), but anecdotal evidence based on age structure suggests possible selective fishing for larger males may lead to an underestimation of mortality rates in certain locations (Couture and Chauvet, 1994; Hamilton, 2004; Kitalong and Dalzell, 1994). Mortality studies are summarized in Table 8.

Table 8.--Summary of mortality studies for bumphead parrotfish.

Source	Total mortality (Z)	Natural mortality (M)	Growth coefficient (k)	Maximum length (L_∞)
(Couture and Chauvet, 1994)	0.207	0.1	0.063	157
(Kitalong and Dalzell, 1994)	0.398	0.278	0.1	106.4
(Hamilton, 2004)	?	?	0.11	122.5

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish natural mortality", bumphead parrotfish natural mortality is likely low and principally based on shark predation; however, there are concerns that this particular source of mortality could be elevated as a result of interactions with humans.

2.8 Maturation and Spawning

Unlike most parrotfishes which are protogynous hermaphrodites, bumphead parrotfish appear to be functionally gonochoristic. The typical pattern of male reproductive development for parrotfishes features diandry, or primary males which developed directly as males and secondary males which undergo sex reversal to become male (Robertson and Warner, 1978). Based on histological study of gonads, bumphead parrotfish display nonfunctional anatomical hermaphroditism. All males pass through an immature female (or bisexual) phase with all adult testes retaining an ex-ovarian lumen and sperm sinuses in the gonad wall. However, the authors note that protogynous diandric hermaphroditism could not be excluded because sampling may have missed transitional individuals (Hamilton et al., 2007). There is some suspicion that the gonochoristic social structure may have been in response to anthropogenic harvest pressure on the population studied (Hamilton, pers. comm.).

Females reach sexual maturity over a broad size range. While they begin to reach sexual maturity at about 500 mm TL, 100% of the females do not attain maturity until about 700 mm TL and age 11 yrs.; the size at 50% maturity is 550-650 mm TL at age 7-9 yrs. Males also reach maturity over a wide size range similar to females, but males begin maturing at smaller sizes and younger ages than females. For example, the smallest mature male was 470 mm TL and age 5 yrs., while the smallest mature female was 490 mm TL and age 6 yrs (Hamilton, 2004; Hamilton et al., 2007).

Spawning may occur in most months of the year. Hamilton et al. (2007) found ripe males and females every month of an August-July sampling period in the Solomon Islands. However, females with hydrated ova were only found from February to July.

Spawning may have a lunar periodicity, with most spawning occurring in the early morning around the full moon in reef passage habitats (Gladstone, 1986; Choat, pers. comm.; Colin, pers. comm.). Hamilton et al. (2007) found hydrated ova indicative of imminent spawning (Colin et al., 2003) from females captured from reef passages and along the outer reef. Bumphead parrotfish are serial spawners with an undocumented but presumably very large batch fecundity, considering the large body and gonad size coupled with small egg size.

Observations of spawning have involved a single male and female. In other scarids Thresher (1984) describes the establishment of temporary spawning territories by males, with females being courted by males as they passed through spawning territories, and an assemblage of individuals acting as a spawning school. There may be a similar nonrandom or lek-like breeding system for bumphead parrotfish. Although Gladstone (1986) described a simple mobile group of individuals from which pair spawning took place, others have described what appeared to be a dominant male pair spawning with females and smaller sneaker males attempting to participate in spawning (Choat, pers. comm.; Colin, pers.comm.). The putative dominant male displayed bright green coloration during spawning (Choat, pers. comm.). That males grow to larger sizes than females (Hamilton, 2004) supports the existence of a nonrandom mating system where a reproductive advantage is conferred to larger dominant males (Ghiselin, 1969).

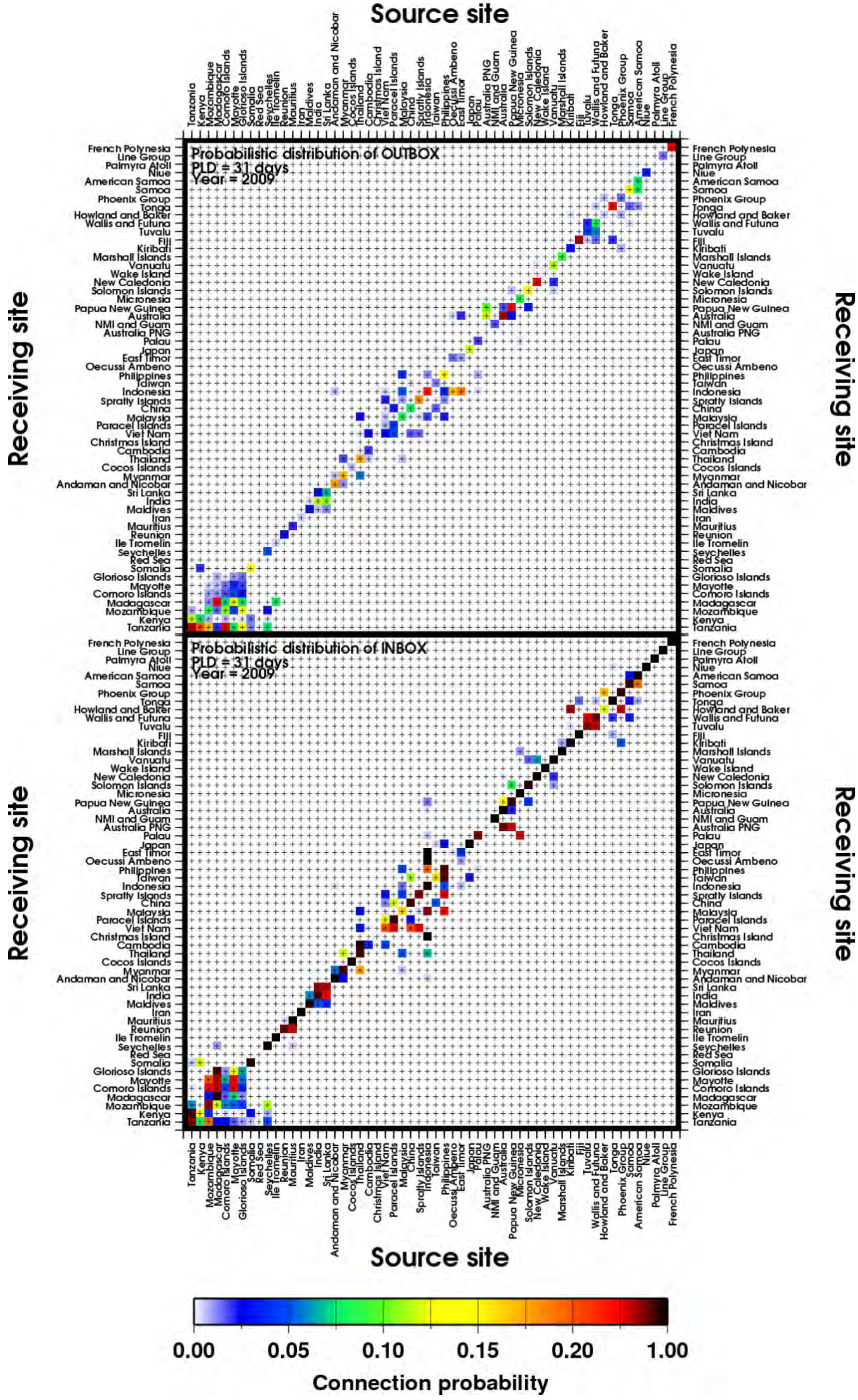
The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish maturation and spawning", the bumphead parrotfish has an extended spawning season, a complex social organization, and appears to be a functionally gonochoristic derivative of the sequential hermaphroditism normally found in most other parrotfishes; however, more work in this area is clearly needed, particularly with regard to fecundity and total reproductive output.

2.9 Early Life History and Connectivity

Details of the early life history of bumphead parrotfish are largely unknown and rely on familial or subfamilial characteristics. The eggs are pelagic, small, and spindle shaped (1.5-3 mm long and 0.5-1 mm wide) in the other members of the subfamily scarinae (Leis and Rennis, 1983). The time to hatching is unknown, but is likely between 20 hours and 3 days (Colin and Clavijo, 1988). The larvae of parrotfish are relatively elongate and otherwise unremarkable except for an oddly ovoid or narrow-shaped eye (Leis and Rennis, 1983). One estimate of pelagic larval duration for this species is 31 days using pre-transitional otolith increments (Brothers and Thresher, 1985); however, it should be noted that only a single specimen was examined. The pelagic ecology of this species is unknown, but successful settlement appears to be limited to shallow lagoonal habitats characterized by low-energy and plant life (e.g., mangroves, seagrass, or plumose algae). High relief coral heads (e.g., *Turbinaria*) in sheltered areas also seem to be a suitable juvenile habitat. The mechanisms by which settling bumphead parrotfish larvae find these locations are unknown, although recent research on other species of coral reef fish larvae suggest a variety of potential cues could be used for active orientation (Leis, 2007).

Connectivity in bumphead parrotfish was addressed using a computer simulation of larval transport (using similar approach as Rivera, et al., 2011). A dispersal kernel was estimated using weekly (5-6 day interval) NOAA OSCAR current data from calendar year 2009 (http://www.oscar.noaa.gov/) and an extensive grid of 42,524 releasing and receiving sites. The OSCAR current data are derived from satellite altimeter and scatterometer measurements (Lagerloef et al., 1999). The releasing and receiving sites were identified as locations of coral reef habitat using the 0.03 degree global grid generated from data available at the Reefs at Risk project (http://www.wri.org/publication/reefs-at-risk#data) as described in the Appendix. Since the OSCAR data does not resolve currents within the Red Sea or Persian Gulf, geographic strata in these areas (Djibouti, Egypt, Eritrea, Saudi Arabia, Sudan, and Yemen in the Red Sea; Iran in the Persian Gulf) were treated in proxy by sites located in the Indian Ocean immediately adjacent to the mouths of the Red Sea and Persian Gulf, respectively. For each of the 42,524 sites, 100 propagules were released at the midpoint of every month in the calendar year of 2009 and tracked using a Lagrangian approach (Polovina et al., 1999). Surface currents at a resolution of 1 degree of latitude and longitude were used with a simulated pelagic larval duration (PLD) of 31 days for bumphead parrotfish (Brothers and Thresher, 1985) with a settlement radius of 25 km. The results using the 42,524 sites were collapsed to 58 strata representing countries and islands. The graphical dispersal kernel is shown in Figure 14, which represents single generation connection probabilities. Multigenerational connectivity was also investigated using a population simulator (1000 generations), which uses the larval transport transition probabilities iteratively through many generations. This approach applies simple demographic controls (fixed population sizes in each stratum and uniform mortality schedules) and has been shown to be a useful indicator of population structuring (Rivera et al., 2011). The graphical dispersal kernel for the multigenerational simulation is shown in Figure 15. Two key sets of nonretentive probabilities (forward probabilistic distribution of outgoing propagules and rearward probabilistic sourcing distribution of successful settlers) were examined separately and averaged for the full set of 58 sites to provide an indication of seeding potential. These results are presented in Figure 16. A number of sites appear to have significant potential as “stepping stones” with a broad range of input and output strata interconnected in a multigenerational context. Most of the sites with significant seeding potential are located in close proximity to other sites (e.g., east Africa, central Indo-Pacific).

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of “bumphead parrotfish early life history and connectivity”, the bumphead parrotfish likely has an interconnected population structure due to oceanographic transport of the pelagic eggs and larvae, with this effect being most pronounced among closely adjacent geographic strata and nearer to the centroid of the species range; but also exhibits some degree of isolation in both the eastern and western edges of the species range.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Receiving site
Probabilistic distribution of OUTBOX
PLD = 31 days
Year = 2009
Probabilistic distribution of INBOX
PLD = 31 days
Year = 2009
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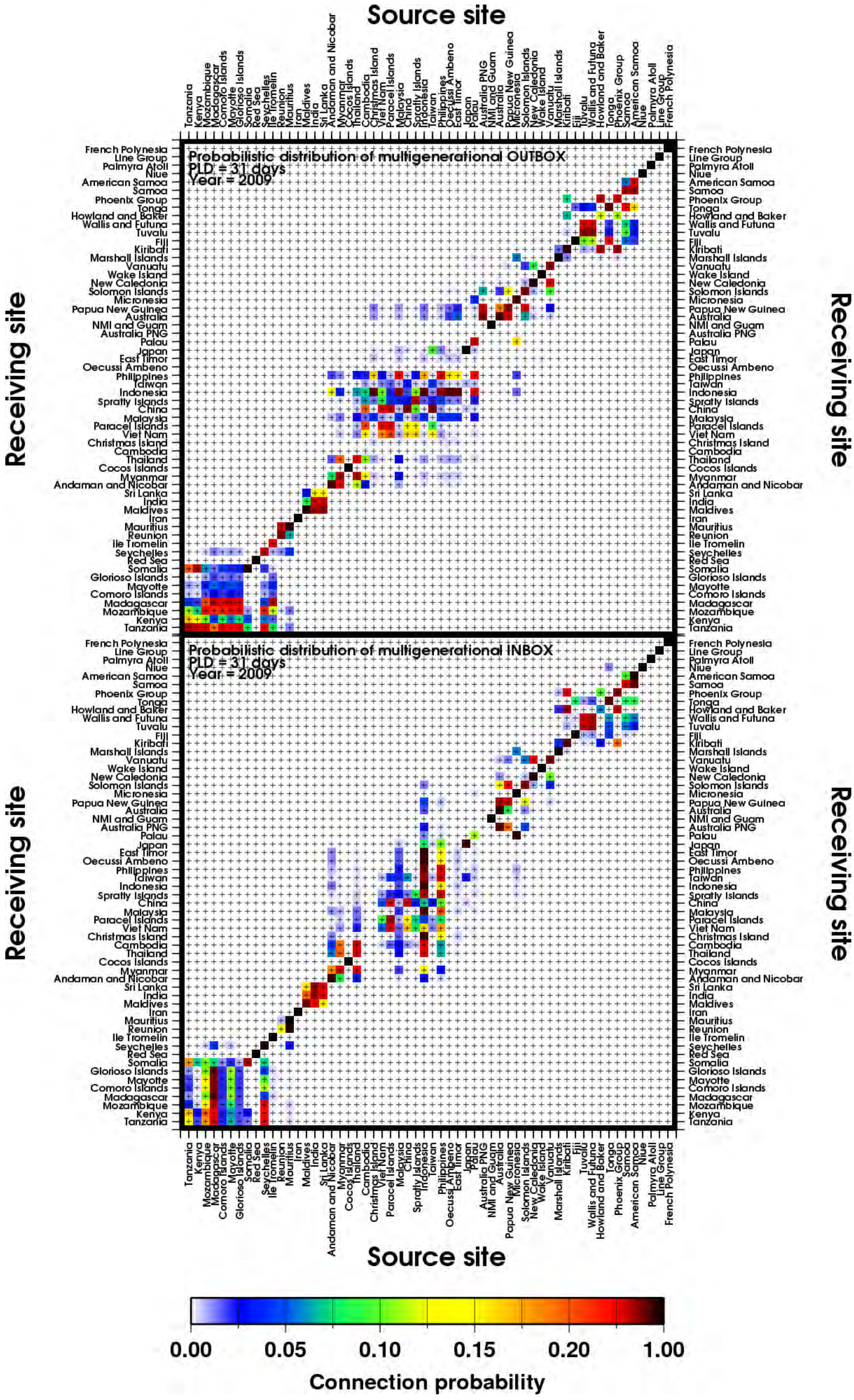
Comoro Islands
Mayotte
Glorioso Islands
Somalia
Red Sea
Seychelles
Ile Tromelin
Reunion
Mauritius
Iran
Maldives
India
Sri Lanka
Andaman and Nicobar
Myanmar
Cocos Islands
Thailand
Cambodia
Christmas Island
Viet Nam
Paracel Islands
Malaysia
China
Spratly Islands
Indonesia
Taiwan
Philippines
Oecussi Ambeno
East Timor
Japan
Palau
Australia PNG
NMI and Guam
Australia
Papua New Guinea
Micronesia
Solomon Islands
New Caledonia
Wake Island
Vanuatu
Marshall Islands
Kiribati
Fiji
Tuvalu
Wallis and Futuna
Howland and Baker
Tonga
Phoenix Group
Samoa
American Samoa
Niue
Palmyra Atoll
Line Group
French Polynesia
0.00
0.05
0.10
0.15
0.20
1.00
Connection probability

Figure 14 (previous page).--Single generation connection probabilities with PLD = 31 days using NOAA OSCAR surface currents in 2009 and average monthly propagule releases throughout the year. Upper panel is standardization from an outgoing perspective, and lower panel is standardization from incoming perspective. A coral reef habitat grid of 42,524 locations was examined with the results collapsed to these 58 geographic strata. Sequencing of strata in the plot corresponds to longitudinal position across the Pacific basin.


Source site
Receiving site
Probabilistic distribution of multigenerational OUTBOX
PLD = 31 days
Year = 2009
Probabilistic distribution of multigenerational INBOX
PLD = 31 days
Year = 2009
French Polynesia
Line Group
Palmyra Atoll
Niue
American Samoa
Samoa
Phoenix Group
Tonga
Howland and Baker
Wallis and Futuna
Tuvalu
Fiji
Kiribati
Marshall Islands
Vanuatu
Wake Island
New Caledonia
Solomon Islands
Micronesia
Papua New Guinea
Australia
NMI and Guam
Australia PNG
Palau
Japan
East Timor
Oecussi Ambeno
Philippines
Taiwan
Indonesia
Spratly Islands
China
Malaysia
Paracel Islands
Viet Nam
Christmas Island
Cambodia
Thailand
Cocos Islands
Myanmar
Andaman and Nicobar
Sri Lanka
India
Maldives
Iran
Mauritius
Reunion
Ile Tromelin
Seychelles
Red Sea
Somalia
Glorioso Islands
Mayotte
Comoro Islands
Madagascar
Mozambique
Kenya
Tanzania
0.00
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1.00
Connection probability

Figure 15 (previous page).--Multigeneration connection probabilities with PLD = 31 days using NOAA OSCAR surface currents in 2009 and average monthly propagule releases throughout the year. Upper panel is standardization from an outgoing perspective, and lower panel is standardization from incoming perspective. A coral reef habitat grid of 42,524 locations was examined with the results collapsed to these 58 geographic strata. Sequencing of strata in the plot corresponds to longitudinal position across the Pacific basin.

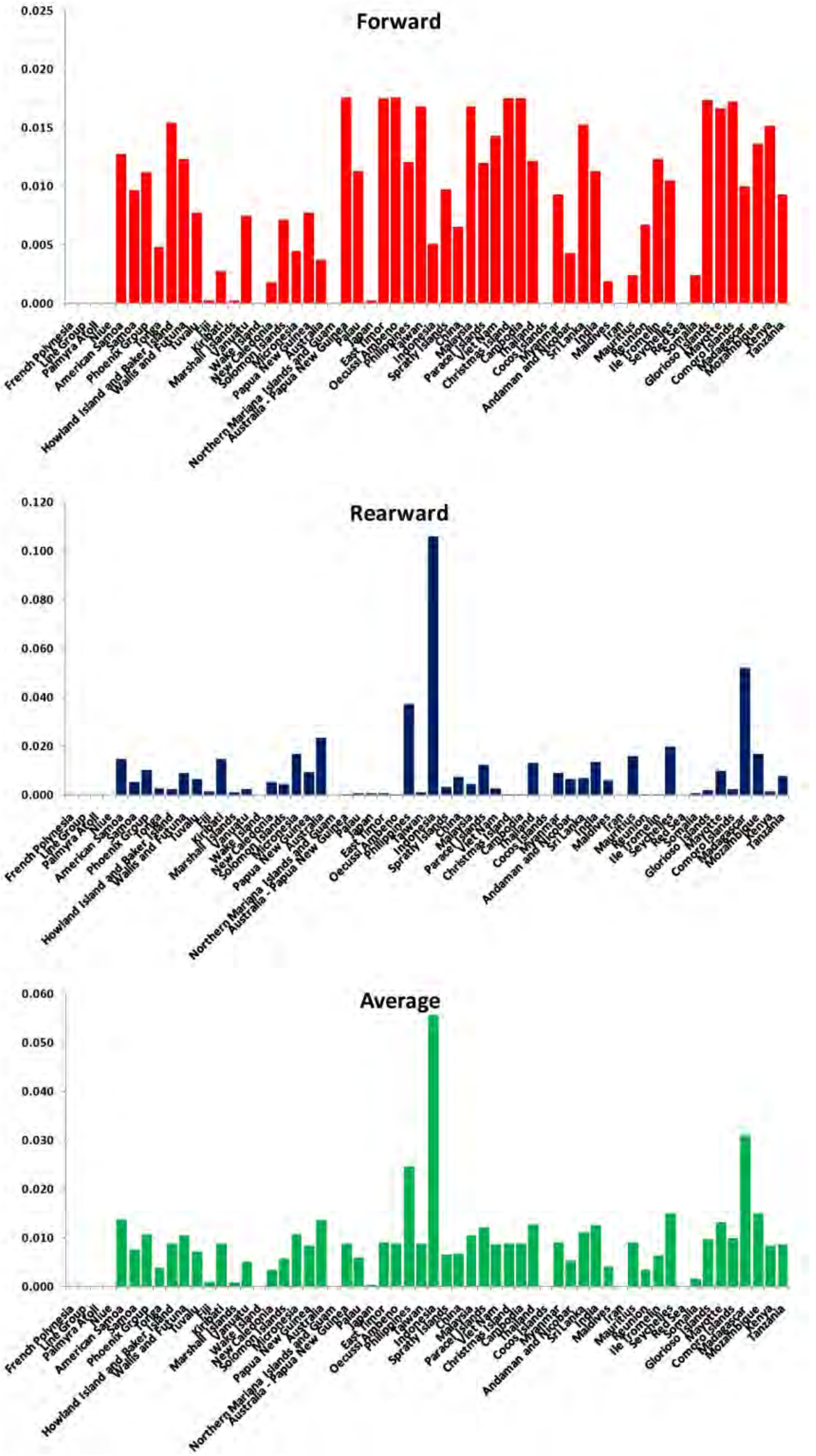

Figure 16.--Average multigenerational (*n* = 1000) connection probabilities of forward, rearward, and average standardizations across 58 geographic strata using NOAA OSCAR weekly surface currents for 2009. Propagules which were lost or scored as natal retention were not used in this summary.

2.10 Settlement and Recruitment

As with eggs and larvae, not much is known about the processes following settlement of larvae to the benthic environment. Juveniles appear to gradually work their way towards adult habitats on the forereef areas, but the timing and duration of this movement are unknown. It has been noted that the smallest size which enters the adult population on the forereef areas is approximately 40 cm TL (Choat, pers. comm.). The juveniles are not often seen in surveys and may remain cryptic until adopting the wide-ranging swimming and foraging behavior of the adults. It remains notable that certain areas, for example the Great Barrier Reef, do not appear to receive significant recruitment (Bellwood and Choat, in press). The adults on the Great Barrier Reef are thought to originate from elsewhere (north), which may explain the latitudinal trend of decreasing abundance to the southern portions of the Great Barrier Reef (Bellwood and Choat, pers. comm.).

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish settlement and recruitment", the bumphead parrotfish apparently settles into shallow lagoonal habitat and eventually migrates to the adult habitats at approximately 5 years of age; and that small individuals are not seen on the Great Barrier Reef, perhaps indicative of settlement and/or recruitment shortage.

2.11 Ecosystem Consideration and Interspecific Interactions

Bumphead parrotfish (and herbivores in general) are thought to be key components of the coral reef ecosystem and there is extensive scientific literature to document this. Despite their usually low numbers, bumphead parrotfish can have a disproportionately large impact as a result of their size and active nature. Their role in nonselective grazing is likely important for maintaining species diversity of corals and other benthic organisms. For example, certain species of coral (i.e., plate-forming) and algae can quickly monopolize the substrate if unchecked. Nonselective grazing prevents any one organism from dominating the benthic ecosystem. The role of bumphead parrotfish in bioerosion and sand generation is also of notable importance; this effect is clearly seen by the persistence of dead coral skeletons in areas where excavating herbivores have been reduced (Bellwood et al., 2004). It is also conceivable that the constant cropping of a coral colony could improve its resistance to physical damage. There are no documented interspecific interactions which would factor into extinction risk of bumphead parrotfish. The Team is of the belief that live coral is not an absolute requirement for bumphead parrotfish species persistence (it is not considered an obligate corallivore nor are there biochemical dependencies noted); however, some species of coral and other benthic organisms, as well as overall ecosystem species diversity, may depend critically on the presence of large grazers such as bumphead parrotfish.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "ecosystem consideration and interspecific Interactions", bumphead parrotfish (and herbivorous fishes in general) are likely a critically important component of the coral reef ecosystem.

2.12 Carrying Capacity

There is no conclusive scientific evidence regarding limiting factors for bumphead parrotfish population growth, particularly under pristine conditions. Some likely limiting factors (risk factors) are presented in the following table and discussed below. The column designated "plausible limiting factor" indicates the Team's consensus decision whether this particular factor is likely to be a limiting factor to bumphead parrotfish historically, currently, and/or in the future. If different considerations occur for different time intervals, these are presented; otherwise, the discussion and plausibility determination pertain to all time intervals equivalently.

Factor considered	Discussion	Plausible limiting factor?
Adult daytime habitat	The species has been shown to have a large home range or territory in the high-energy environment of the forereef and adjacent areas. However, sheer space on the forereef or other areas of likely preference does not seem to be a limiting factor. The species is gregarious and is often seen in open waters adjacent to the reef, so that swimming space or areal extent of reef would not likely prevent more individuals from residing at the location. If reef structures are physically lost, then this risk would become stronger in the future but would unlikely be the limiting factor for the species.	No
Adult sleeping habitat	This species sleeps at night in sheltered areas of the reef, either in caves or in some instances on the reef top in shallow water. Adequate reef rugosity with channels and spur/groove habitat in deeper water is likely necessary for optimal survival while sleeping. Shallow-water sleeping may not be optimal for survival, due to increased vulnerability to human harvest or mechanical injury due to water motion. Predation from large sharks may be countered by shallow-water sleeping, however. Adequate sleeping habitat is a plausible limitation to the population growth of this species in the past, present, and future. As with adult daytime habitat, this risk could become stronger if reef structures are physically lost.	Yes

Factor considered	Discussion	Plausible limiting factor?
Juvenile habitat	The juveniles of this species settle/recruit to shallow, low-energy, lagoonal areas with either plumose algal beds, seagrass, mangroves, or high relief coral formations. Absence or reductions of these habitats could likely limit the influx of juveniles via settlement/recruitment processes. This specific habitat requirement is considered to be a plausible limiting factor to population growth of this species. It is recognized that this risk factor may become stronger in the future as a result of shoreline development and other human impacts in or on the nearshore environment.	Yes, and becoming more important

Factor considered	Discussion	Plausible limiting factor?
Adult food	The species is a facultative corallivore and has been observed feeding on algae, sponges, and other benthic organisms, both plant and animal. They are known to be nonselective benthic foragers. It therefore follows that adult food is an unlikely limiting factor. The species would be at risk if the environment were only bare rock or dead coral, sand, or any other completely inorganic, sterile benthic substrate. The species would not be able to subsist on other fishes or plankton. There is no documented or suspected biochemical dependency on coral.	No
Juvenile food	The diet of juveniles appears to be as or more opportunistic than adults. This is not considered to be a plausible limiting factor for population growth of this species.	No
Settlement / recruitment	The influx of smaller, younger individuals to the population is a strong concern. Areas of the Great Barrier Reef, for example, appear to be lacking juveniles. The pelagic larval duration is relatively short at 31 days, so that local retention may be demographically as important as incoming propagules. It remains unclear whether any shortages of juveniles reflect shortages of egg/larval supply or is indicative of bottlenecks in older life history stages. Since recruitment limitation is commonly documented in other reef fish species, this is a plausible limiting factor for population growth of this species. This risk may become stronger in the future if depensatory factors are enabled because of reduced adult abundance.	Yes, and becoming more important
Conspecifics	The species displays a relatively complex social behavior. It is plausible that density-dependent effects could hinder initial population growth as has been shown in some reef fishes preferentially recruiting to areas with conspecifics. It remains difficult to envision how recruitment might be hindered by high densities of adults, since the juvenile habitat is spatially separate and the species is not known to be cannibalistic or aggressive towards conspecifics. Below a certain threshold of adult abundance there may be inadequate sizes/ages/genders/reproductive conditions to facilitate effective spawning and subsequent settlement/recruitment.	Maybe

Factor considered	Discussion	Plausible limiting factor?
Marine predators	The species is gregarious, grows to a large size, can maneuver adeptly around the benthos, and is likely difficult to prey upon once adult size and behavior are attained. The primary predators of adults would be large sharks. Predation of sleeping adults could be a concern, but they appear to possess an effective flight response based on diver observations. Juveniles are probably subject to many of the reef piscivores, but tend to remain in shallow lagoonal habitat where there is likely adequate refuge and where large predators may not be as common. There is no existing scientific or anecdotal evidence to suggest that predators are a limiting factor for population growth in this species in the past, present, or future. It should be noted, however, that predation and competition are thought to regulate certain other species of coral reef fish (e.g., Hixon and Jones, 2005). This is worthy of further investigation in this species, but at a lower priority than other issues thought to be more important towards species survival.	Not likely

Factor considered	Discussion	Plausible limiting factor?
Human harvest/ other impacts	Human harvest of adults is a likely limiting factor in some areas. However, many pristine locations with apparently suitable habitat and within colonization range of propagules remain devoid of the species. Hence, there are likely other strong population regulatory mechanisms in place. Human harvest of the juveniles for food or the aquarium trade is also a likely strong impact in populated areas. It is recognized that the strength of this risk is likely to increase due to increasing human populations and a commensurate increasing demand for nourishment and/or revenue.	Yes, and becoming more important
Competitors	Based on its large size and gregarious behavior, this species is unlikely to be outcompeted for swimming space, forage or sleeping holes. Competitors are unlikely to be a limiting factor for population growth in this species. It should be noted, however, that predation and competition are thought to regulate certain other species of coral reef fish (e.g., Hixon and Jones, 2005). This is worthy of further investigation in this species, but at a lower priority than other issues thought to be more important towards species survival.	Not likely
Temperature / salinity / oxygen / depth / pH / light /water clarity / climate / weather / acidification	The adequacy of the abiotic environment is important for the survival of all organisms. However, there are no plausible variables that have been show in the past, or presently serve to, or are likely in the future, to limit the population growth of this species. Ocean acidification could have severe long-term impacts on the coral reef ecosystem but bumphead parrotfish do not exclusively rely on living coral for food or shelter and, as discussed in the threat section, for most environmental changes it remains extremely difficult to ascertain directionality of net effect.	Not likely
Other	There are no other documented interspecific interactions that could plausibly function as a means of limiting the population growth of this species. There are no other aspects of the abiotic environment that could plausibly function as a means of limiting the population growth of this species. The Team realizes that this species is data poor and while no regulatory mechanism is presently recognized or suspected in this category, more research is clearly needed.	Not likely

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "bumphead parrotfish carrying capacity", the most likely limiting factors for past/present/future bumphead parrotfish population growth are, in no particular order: lack of settlement and recruitment, lack of juvenile habitat, lack of adult sleeping habitat, lack of requisite abundance of conspecifics, and excessive human harvest in populated areas; with most of these risk factors likely to become stronger over time.

3. TEAM RESPONSE TO PUBLIC COMMENTS

The Team reviewed all 10 sets of public comments received during and after the public comment period following the 90-day NMFS finding. Several issues raised in the public comments were taken up by the Team for discussion and investigation. As mentioned earlier, 6 of the comments essentially reiterated other materials available to the Team. Two sets of comments were strongly in support of listing the species at American Samoa and Guam. These comments also strongly argued for the existence of distinct population segments at these areas. However, scant evidence was presented for the latter claims and, as stated earlier, the Team considered the bumphead parrotfish as a single stock over its entire geographic range based on consultations with numerous ichthyologists and experts on this species. The information supporting the argument for listing in American Samoa and Guam was carefully considered by the team since some of this was new material. The information substantiated the role of fishing in the decline of bumphead parrotfish around heavily populated and/or visited areas, which is well documented in the published and unpublished information sources. The 2 remaining sets of public comments presented strong opposition to the listing petition and methodically attempted to discredit each argument made in the petition. Many points raised in the comments were legitimate concerns but often were speculative and/or narrowly focused on specific portions of the species' range.

4. ASSESSMENT OF EXTINCTION RISK

4.1 Status of Species

A synthesis of data presented in earlier sections of the report will be used to portray the likely status of the bumphead parrotfish species. First, the spatial pattern of abundance will be estimated from survey data. Second, the global population size will be estimated from a combination of survey data and habitat data. Third, trends in abundance will be estimated using the best available data and analytical methodologies. The reliance on unpublished data and general sparseness of data coverage over space and time necessitate that these results be considered preliminary estimates.

4.1.1 Contemporary Geographic Pattern of Abundance

The SPC PROCFish survey data and the ReefCheck survey data were combined to generate average bumphead parrotfish abundance for each of the geographic strata of range (termed "cells" for this exercise). This approach populates 49 of the 63 cells. An additional 4 cells (Palmyra, Wake Island, Howland and Baker, and the Line Group) were filled in using PIFSC/CRED survey data. These standardized density estimates were converted to a 0–3 score based on cutoff values of 0, 0.5, and 1.5 fish per 1000 m^2. The remaining 10 cells (primarily small islands) were assigned proxy scores of 0–3, based on their proximity and physical/demographic similarity to other cells populated with values. This exercise attempts to provide a comprehensive geographic summary of contemporary bumphead parrotfish abundance (Figure 17). The term contemporary is used since the data are an aggregation of survey results spanning a recent 13-year time interval (1997-2009).

4.1.2 Contemporary Global Population Size

There are inadequate data on bumphead parrotfish population dynamics, demography, and temporal/spatial variability to use even the most rudimentary of stock assessment models. The data simply do not exist to allow one to credibly estimate changes in population size, or even the magnitude of population size, structured over space and time in a proper framework of metapopulation dynamics and demographics. One approach in this data-poor situation is to take as much data as exist and cast them into a single global population estimate accounting for as much uncertainty as possible in a bootstrap randomization framework, essentially relying on the resampling process to fill in gaps of knowledge with computer simulation. The major assumption with this approach is that the available input data being resampled are representative of the whole species; this will be discussed below. This global population estimate of adult bumphead parrotfish is driven primarily by 3 items: 1) the geographic range of the bumphead parrotfish,

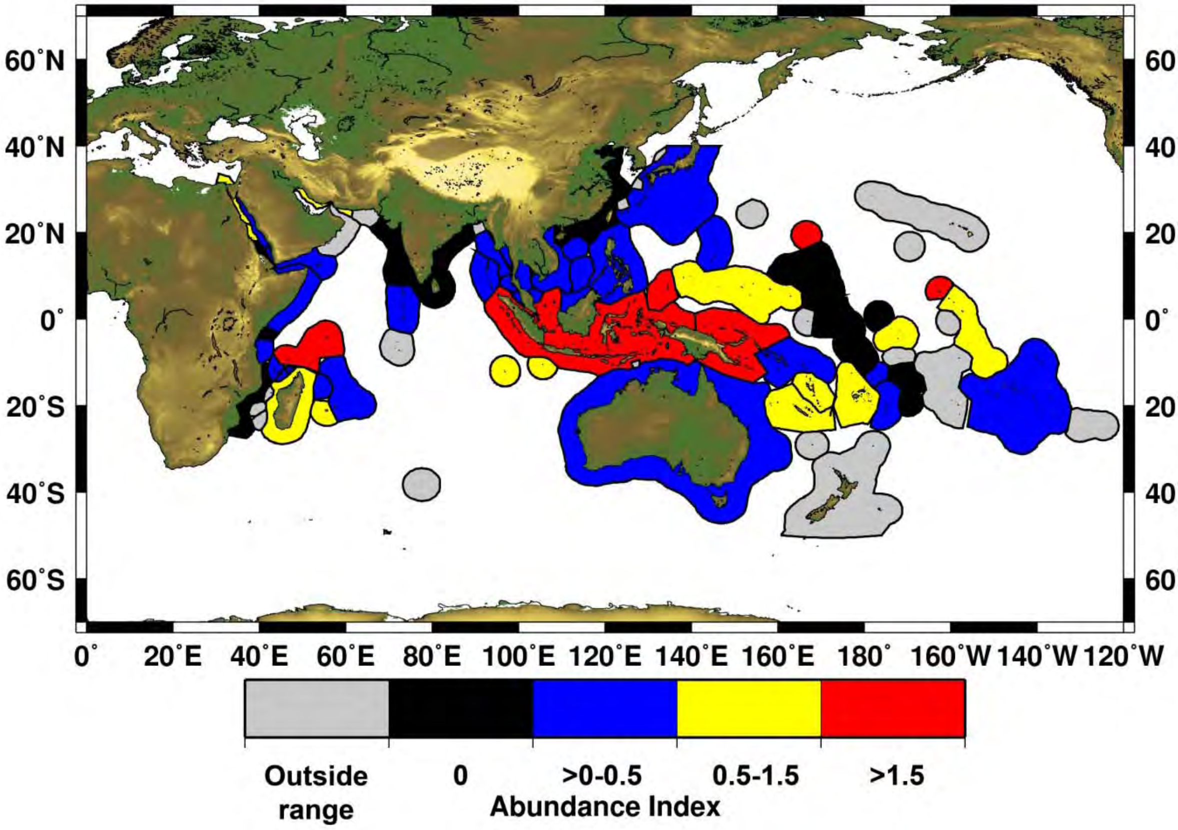

Figure 17.--Contemporary bumphead parrotfish standardized abundance (number of fish per 1000 m^2) over 63 geographic strata of range, using data from SPC PROCFish, ReefCheck, and PIFSC/CRED surveys spanning the 1997-2009 time interval. Note that EEZ polygons for countries/islands that are within the range of bumphead parrotfish are shaded in their entirety; however, this is not meant to imply that bumphead parrotfish occur in all waters around these islands, for example all around Australia or in the Mediterranean Sea (the EEZ of Egypt).

2) the amount of suitable adult bumphead parrotfish habitat in each stratum of the range, and 3) the density of adult bumphead parrotfish in each stratum of the range. The range and habitat estimates are considered fixed quantities and are validated from available published sources and other credible sources of information. The density estimates are data-poor when considering the wide expanse of the species' geographic range and limited extent of available survey information. The bootstrapping approach was applied to this data-poor component of the global population estimation exercise — bumphead parrotfish density estimates.

The density estimates of adult bumphead parrotfish were gleaned from 2 sources and combined for a resampling-based bootstrapping approach. The fundamental input to this approach is a "universe" of density estimates from which to resample. Ideally, this universe could be completely stratified over space and time, but given the data-poor nature of this species a single universe was used, combining as much survey data as possible (although see "matched-case" permutation below). For this exercise, 6561 density estimates were used (earlier presented in Figure 11), of which 6087 are at a value of zero (~ 93% of observations). Since this was a non-parametric bootstrapping exercise, which does not assume a particular probability distribution for the data, the zero values are easily incorporated into the analysis without transformation or concerns of normality. The first set of density estimates were obtained from ReefCheck (Hodgson, 1999) surveys from 1997 to 2009, covering 44 geographic strata with 4990 transects. The second set of density estimates were obtained from the Secretariat of the Pacific Community standardized PROCFish surveys from 2001 to 2008, covering 20 geographic strata with 1571 transects. In all, these merged survey data cover 49 of the 62 range strata with at least some survey effort (Figure 18). While this coverage is less than ideal, it represents 79% of the range strata and spans a wide range of exploitation rates (e.g., possibly locally extirpated in Fiji and Samoa, and protected and/or abundant in portions of Australia and Palau). All density estimates were standardized to represent the numbers of adult bumphead parrotfish per 1000 m^2 of surveyed habitat. Survey data from outside of the known range of bumphead parrotfish were not used (e.g., Cook Islands, Tokelau, and Nauru). The term contemporary is used in this section since this data is a necessary aggregation of surveys spanning a 13-year time interval (1997-2009).

The bootstrapping simulation begins by looping through each of the 62 strata. For each stratum, a density estimate is drawn randomly from the 6561 values in the density estimate universe. The selected density estimate is applied to the scaled area of forereef habitat derived from the global 4 km coral grid for the particular stratum. Operationally, the area in km^2 is multiplied by the density estimate in number of bumphead parrotfish per 1000 m^2; then the resulting quantity is multiplied by 1000 to accommodate the change in units. This results in an estimate of the number of bumphead parrotfish for the particular stratum. This is repeated for all 62 strata and the total bumphead parrotfish abundance over all strata is tabulated for this iteration; this total is one bootstrap realization of the global bumphead parrotfish population. The process is repeated 5000 times (with replacement) to incorporate variability and uncertainty, producing a distribution of bootstrap estimates.

The attributes of the resulting non-parametric bootstrap distribution were then examined. The median of the distribution — 3.9 million adult bumphead parrotfish (Table 9A) — was taken as the most reasonable estimate of global population size in the sense that the likelihood of a smaller value, and of a larger value, are equal. To examine the sensitivity of this finding, an additional "worse-case" bootstrapping exercise was undertaken, in which the bumphead parrotfish habitat was reduced by 50%. The "worse-case" scenario results in a median population size estimate of 2.2 million adult bumphead parrotfish globally. Since the observed density estimates were confined to specific strata, one additional scenario was explored whereby the bootstrap density values were matched spatially to those source strata when possible (49 of 62 instances), and resampled from the aggregated universe when matched data were not available (13 of 62 instances). Based on the sparse nature of the data in some geographic strata, this third scenario, referred to as the "matched-case" scenario, is not necessarily considered a superior estimate. This approach provides a median population estimate of 4.5 million adult bumphead parrotfish (Table 9A).

An additional scenario termed "virgin-case" was explored to estimate the global number of bumphead parrotfish in a pristine (virgin, historical, absent human influence[4]) state. In this scenario, the bootstrap exercise resampled only the 7% of observed density values which were non-zero; i.e., this only used data when bumphead parrotfish were observed on a survey transect; transects during which no bumphead parrotfish were observed were ignored. This scenario produced a median estimate of 131.2 million adult bumphead parrotfish (a density of ~ 9.2 fish per 1000 m^2). A somewhat more straightforward approach to estimating a pristine population level is to use the density information presented in the abundance section of this report, which indicates that a density of 3 fish per 1000 m^2 represents a relatively high abundance (Table 3, Table 5, Figure 9) and that bumphead parrotfish adult habitat covers approximately 17,000 km^2 globally (Table 1). Taking the product of these 2 quantities, and then multiplying by 1000 to account for the difference in units, gives an estimate of approximately 51 million adult bumphead parrotfish globally under a condition of high abundance. Both of these approaches assume that the amount of habitat has remained unchanged over time, a plausible assumption considering that the species does not rely exclusively on living coral for habitat, or forage for that matter.

The 3 scenarios of contemporary global abundance, when compared to the 2 estimates of virgin abundance, suggest that the contemporary global population has been reduced from the virgin abundance. It should be emphasized, however, that the estimates of virgin abundance and related inferences about degree of population reduction are highly speculative and subject to a great deal of uncertainty. For example, Table 9B presents the 95th percentile of the estimated reduction when using the bootstrapped data in conjunction with either the bootstrapped virgin abundance estimates or the single point estimate of virgin abundance. Based on the former, the BRT can postulate that there has been at least ~50% decrease in bumphead parrotfish; whereas in the latter instance the BRT can postulate that there has been at least ~35% decrease in bumphead parrotfish. The latter instance ignores the matched-case simulation runs due to their close proximity to the point estimate virgin abundance, which does not allow any reduction at all to be postulated, based on the 95th percentile approach. The range of the remaining 5 comparisons

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[4] The timing of the "virgin-case" situation is hypothesized to be a time period prior to ~100-300 years in the past, reflecting a situation where human impact may exist but yet not to the level of causing a significant change to the population trajectory of bumphead parrotfish; whereas in later times the effects of human population growth, European contact, industrialization, availability of rubber slings, dive-lights, swim goggles, etc. contributed to population declines of bumphead parrotfish, particularly in human-populated regions.

suggests that the bumphead parrotfish population has been reduced at least from ~35% (contemporary regular-case and virgin point estimate) to ~82% (contemporary worse-case and virgin bootstrap estimate).

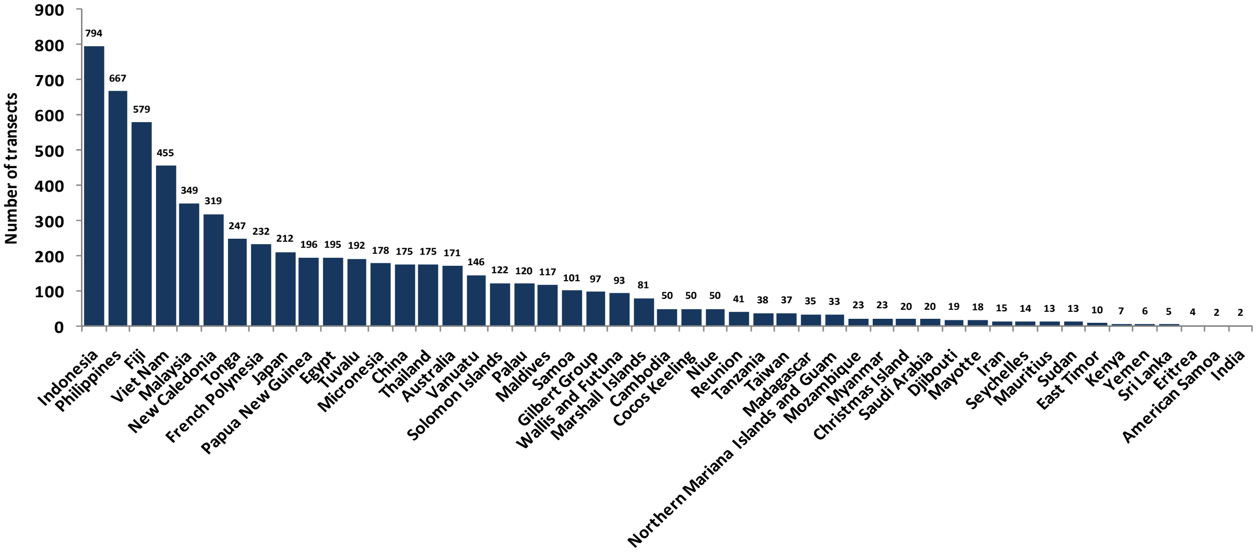

Figure 18.--Number of survey transects from combined SPC PROCFish and ReefCheck data.

Table 9A.--Summary statistics of “regular-case”, “worse-case”, “matched-case”, and “virgin-case” bootstrapping exercises for bumphead parrotfish global population estimation. The numbers represent the total number of fish globally, summed over 62 geographic strata of range, upon examination of 5000 simulation runs. Estimates of total population size discussed in the text are based on values of the median for each scenario.

Statistic	"Regular-case"	"Worse-case"	"Matched-case"	"Virgin-case"
Min	0	0	0	49274190
Max	271673200	471580200	387429900	1500700000
Median	3927545	2229639	4571099	131286700
Mean	9651040	6281646	14703073	167531800
Lower 2.5%	68723	28402	17384	66524326
Lower 5%	207728	89956	100697	71282300
Lower 10%	546806	246942	399457	80916100
Lower 33%	2017776	1101429	2041139	110437600
Upper 66%	6908675	3997819	9206460	161488900
Upper 90%	20981970	12741630	36785720	264687890
Upper 95%	33512549	26244610	67048020	328891910
Upper 97.5%	61148820	36100980	86121686	434330900
N	5000	5000	5000	5000

Table 9B. Modeling results for 95th percentile of the population reduction percentage. The BRT can postulate that the population has declined by at least this amount given the uncertainty and assumptions involved in the modeling approach. The matched-case and virgin point estimate comparison does not yield a value greater than zero, i.e. for that combination there is no certainty that a decline has occurred.

Contemporary	Virgin	Population reduction 95th percentile
Regular-case	Bootstrap estimate	73.53%
Worse-case	Bootstrap estimate	82.09%
Matched-case	Bootstrap estimate	49.86%
Regular-case	Point estimate	35.40%
Worse-case	Point estimate	49.41%
Matched-case	Point estimate	NA

4.1.3 Population Time Series and Trends

It is difficult to make inferences about bumphead parrotfish population time series and trends because of a lack of available fishery-dependent and independent data over a reasonable temporal scale[5]. In more data-rich settings, such information is often used to compute indices of abundance and assess trends over time. Currently there are no fisheries assessments or monitoring programs that could support an assessment of trends. Additionally, the large geographic range of the species increases the difficulty of making inferences about bumphead parrotfish over a large spatial scale. Despite the lack of rigorous population data, three sources of time-series information were evaluated by the Team.

The first source of time-series data originated from an assessment of the inshore coral reef fisheries in Palau (Kitalong and Dalzell, 1994; Figure 19). Fisheries-dependent data in the form of landings data were collected from the Palau Federation of Fishing Associations (PFFA) fish market from 1976 to 1990. The catch data show a pronounced peak in catch in the mid-1980s followed by a decline in landings. Regulations are currently in place making it illegal to export, harvest, buy or sell bumphead parrotfish of any size in waters surrounding Palau according to the Palau Division of Marine Resources, Ref. 27 PNCA 1204. It should be noted, however, that catch data by itself is not a reliable proxy for population abundance; it is presented here for reference only.

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[5] The previous section attempted a rearward aggregate population projection because a pristine condition can be constructed from a single defensible abundance estimate representing a situation of high fish abundance. Projection into the future is much more difficult because of the requisite spatially-explicit dynamics that would have to be incorporated to be defensible (i.e., some strata are unfished, some strata are heavily fished, some strata may be trending independently of human impact). This suite of spatial dynamics is not readily available to incorporate into a projection; hence, a forward projection is not attempted here.

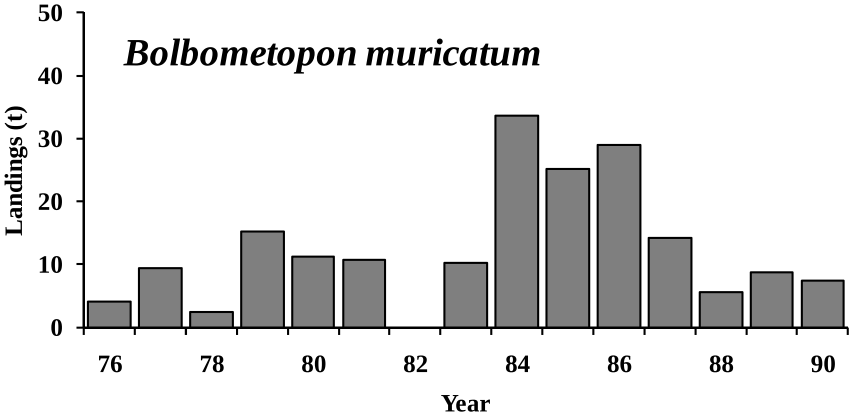

Figure 19.--Landings data for bumphead parrotfish collected by commercial fishing in Palau 1976-1990. Figure reproduced from data in (Kitalong and Dalzell, 1994).

The second source of time-series information comes from the NOAA PIFSC's Reef Assessment and Monitoring Program (RAMP, Table 10). Towed-diver surveys were conducted on a biennial basis from 2005 to 2009 at Wake Atoll in the western Pacific Ocean. Survey results show a slight decrease in the mean observed abundance of bumphead parrotfish from 2005 to 2007 followed by a substantial increase in 2009. The overall mean observed abundance of bumphead parrotfish for all years combined was ~ 300 fish^{-2} (SE 207.11).

Table 10.--Summary results of NOAA Reef Assessment and Monitoring Surveys at Wake Atoll. Survey effort in the towed-diver surveys is indicated for each year long with estimates of mean abundance of bumphead parrotfish by year and standard errors of the mean (PIFSC/CRED data).

		Abundance (individuals per km^2)	
Year	**Survey effort**	**Mean**	**SD**
2005	19	142.84	52.87
2007	19	133.72	42.07
2009	13	759.56	342.63
Total (All Years)	51	296.64	207.11

A third source of time-series information was obtained by fitting a generalized additive model (GAM) to the unpublished SPC PROCFish and ReefCheck standardized survey data. The R-language package *mgcv* was used to perform a GAM with bumphead parrotfish density as the dependent variable, geographic strata and survey type (SPC PROCFish or ReefCheck) as categorical variables, and year expressed as a smooth numeric function, using a quasipoisson link function. One of the GAM outputs is an estimated temporal pattern of the bumphead parrotfish density conditioned upon the other input variables (Figure 20). It should be noted, however, that this is a composite temporal effect over aggregated geographic strata, and is not likely to represent the temporal pattern at any given geographic stratum. The units in the GAM plot are additive with respect to the initial quantity being modeled (number of fish per 1000 m^2). Hence, the trend in abundance corresponds to an approximate additive endpoint differential of -1 to -2 fish per 1000 m^2 per decade.

A simpler way to analyze the merged survey data is to consolidate the data using a simple stratification and averaging (Excel pivot table of year) and examine geographic strata for which there are multiple years of data available. While this simple averaging is not as statistically rigorous as the GAM, it allows investigation into the variability of temporal abundance patterns over the geographic range of the species. Fourteen geographic strata were reasonably well represented in the merged survey data (qualifying with at least 6 years of survey data and averaging at least 10 transects per year) and are shown in Figures 21A and 21B. These results indicate a large degree of site-specific dynamics and warrant caution in putting forth general statements of temporal population change.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "status of species", bumphead parrotfish varies widely in abundance over both spatial and temporal scales; with evidence of a large overall decline and continuing trend of decline despite lack of strong spatial coherence. The Team conducted a wide variety of quantitative analyses that are reported here for the first time.

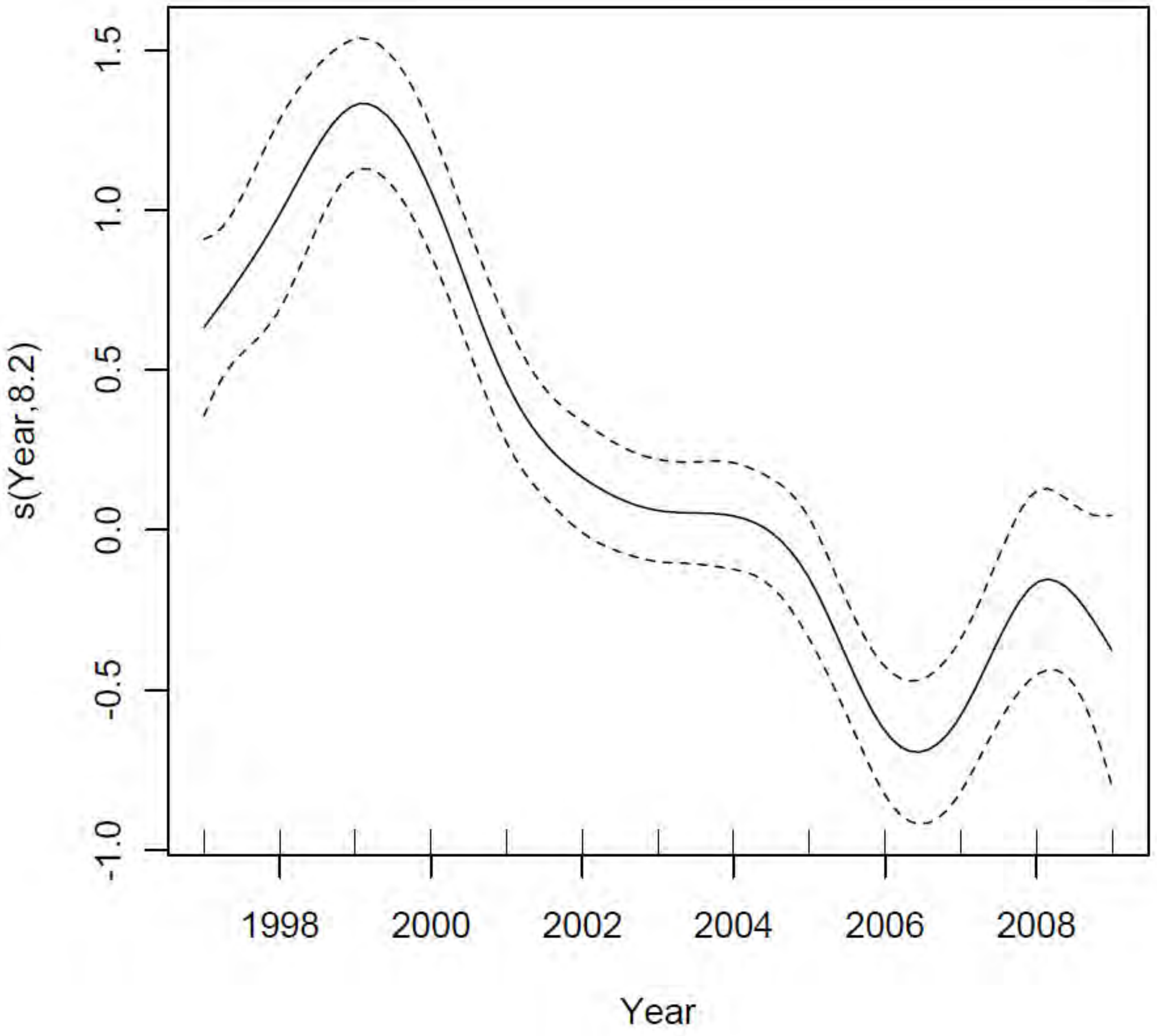

Figure 20.--Temporal pattern in bumphead parrotfish abundance (number of fish per 1000 m^2) estimated from a generalized additive model applied to merged SPC PROCFish and ReefCheck survey data.

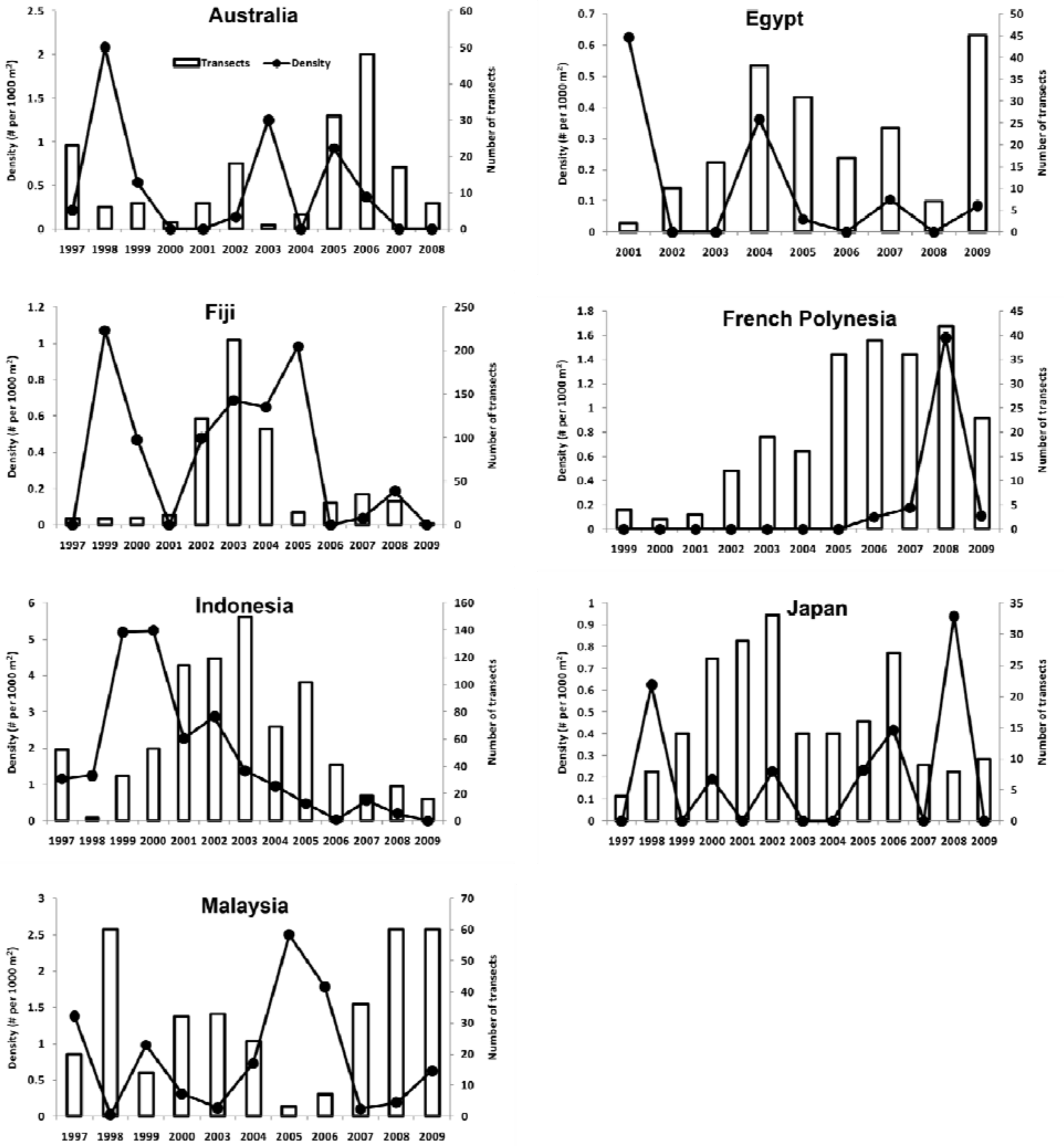

Figure 21A.--Average bumphead parrotfish density by year from merged SPC PROCFish and ReefCheck surveys (1997-2009). Geographic strata are shown if sample size criteria were met (average transects per year ≥ 10 and at least 6 years of survey data). Lines and symbols represent the annual density estimates; bars represent the annual sample size in number of transects.

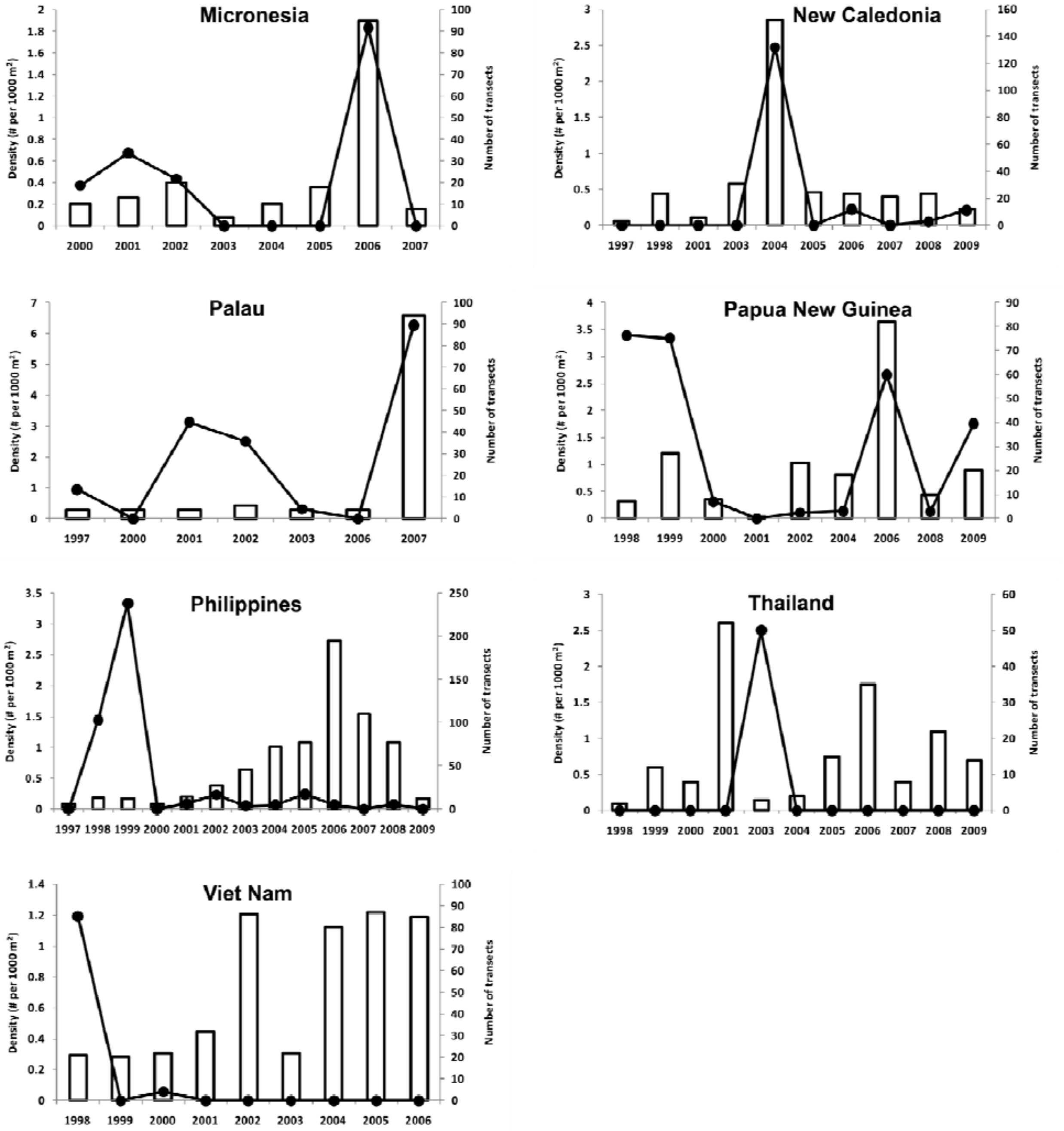

Figure 21B.--Average bumphead parrotfish density by year from merged SPC PROCFish and ReefCheck surveys (1997-2009) [continued from Figure 21A].

4.2 Threats to the Species

This section of the report summarizes some of the critical inhibitors of bumphead parrotfish population growth, either identified in previous sections of this report or considered noteworthy for discussion based on scientific findings for other ecologically similar species. This section will conclude with a discussion of threats in the context of the ESA regulatory framework and a Threat Table for bumphead parrotfish.

4.2.1 Habitat Loss

Loss and/or degradation of juvenile habitat remain significant concerns to the Team. Shallow lagoonal habitats are susceptible to pollution, modification, and increased harvest pressure, among other anthropogenic issues. The juvenile habitat specificity highlights this phase of the life history as highly vulnerable. There is a critical need for further study of the exact habitat requirements of the settling larvae, juveniles, and subadults. This habitat needs to be carefully inventoried across the range of the species.

In contrast to juvenile habitat, the Team concluded that adult habitat loss and/or degradation is not a high priority concern. Bumphead parrotfish appear to be opportunistic foragers and would likely cope with any likely ecosystem shifts in the coral reef community, based upon their behavior and ecology. For example, shifts in benthic species composition (changes in the breakdown of hard corals, soft corals, coralline algae, fleshy algae, sponges, bryozoans, tunicates, etc.) would not adversely affect bumphead parrotfish given their nonselective diet. Some components of the coral reef ecosystem are likely more affected by the presence or absence of bumphead parrotfish than vice-versa. Drastic morphological changes to the coral reef might impact bumphead parrotfish if high-energy zones were somehow reduced or diffused, or if nocturnal resting/sleeping locations were no longer available. However, as with other sections of the report, the Team stresses that assessment of habitat loss for this species is very data poor; there are no experimental results or observational studies to confirm the above assertions.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "habitat loss", there is strong concern for the quantity and quality of juvenile bumphead parrotfish habitat; and there is some similar concern for the nighttime sleeping habitat for adult bumphead parrotfish.

4.2.2 Harvest

Bumphead parrotfish are highly prized throughout their range, and are harvested primarily by spearfishing while free-diving or using scuba. Other less common methods of harvest include gill net, shallow-water seine, and hook and line (e.g., fly fishing in the Seychelles Islands) (Adams and Dalzell, 1994; Donaldson and Dulvy, 2004; Dulvy and Polunin, 2004; Kitalong and Dalzell, 1994). In addition to their commercial value, bumphead parrotfish are culturally significant for many coastal communities and used in feasts for specialized ceremonial rites (Severance, pers. comm.; Riesenberg, 1968). As such, fisheries for this species have been in place since human inhabitation of these coastal regions (Johannes, 1978; 1981).

The large adult size of bumphead parrotfish and their distinctive behavior make them especially vulnerable to harvest. Large schools foraging in shallow and mid-depth reef habitats by day and aggregating in the same protected shallow habitats at night have made them easy targets (Dulvy and Polunin, 2004). Historically, fishing took place at night while fish were motionless in their nocturnal resting sites. Fishermen armed with hand spears would paddle wooden canoes or simply walk across shallow reef habitats using a torch assembled from dried coconut fronds in search of resting fish (Dulvy and Polunin, 2004). With the advent of dive lights, scuba, freezers, and more sophisticated spears and spear guns, the ability to exploit bumphead parrotfish has increased dramatically over the last several decades (Aswani and Hamilton, 2004; Hamilton, 2003).

Data pertaining to harvest are sparse, incomplete, or lacking for a majority of regions across the range of bumphead parrotfish. Despite limited available catch data, efforts have been made over the past 30 years to obtain fisheries harvest information for reef fisheries at a few sites in the central and western Pacific. However, most of the available harvest data combine all parrotfish species into one category (e.g., parrotfishes), making it difficult to identify bumphead parrotfish harvest amounts. Of the known fisheries assessment efforts, harvest data specific to bumphead parrotfish include Palau (Kitalong and Dalzell, 1994), Guam (NOAA, The Western Pacific Fisheries Information Network), Solomon Islands (Aswani and Hamilton, 2004; Hamilton, 2003), Fiji (Dulvy and Polunin, 2004), and Papua New Guinea (Wright and Richards, 1985).
In Palau, efforts to assess commercial landings of reef fishes were made from 1976 to 1990 (Kitalong and Dalzell, 1994). All harvest data were collected at the main commercial landing site, the Palau Federation of Fishing Associations (PFFA), and were obtained from receipts issued during each financial transaction. It is estimated that these data accounted for 50-70% of the total commercial catch. Overall, bumphead parrotfish represented 10% of reef fisheries landings in Palau during the assessment period, making it the second most important commercial reef fish. It was estimated that an average of 13 metric tons of bumphead parrotfish were sold annually between 1976 and 1990. The highest landings were recorded in the mid-1980s with a maximum of 34 metric tons sold in 1984. Declines in total catch were observed following the mid-1980s, creating concern over the conservation of bumphead parrotfish stocks. As a result, restrictions were put on the harvest of bumphead parrotfish in 1998; as stated earlier, it is now illegal to export, harvest, buy or sell with the intent to export bumphead parrotfish of any size in waters surrounding Palau.

Harvest data for Guam were obtained from the NOAA Western Pacific Fisheries Information Network (David Hamm, pers. comm.). Creel surveys and commercial purchase records represent the two sources of harvest data for the bumphead parrotfish. Creel survey data were collected from 1982 to 2009. Data pertaining to commercial sales of parrotfish are provided for individual sales and, it is assumed, correspond to the same time period. Based on the results of the creel surveys, a total of 10 bumphead parrotfish (0.12 metric tons) were harvested in Guam during the survey period. The highest landings were observed in 1989 with 3 bumphead parrotfish weighing 84 kilograms. No landings have been reported since 2001 from creel surveys. Commercial sale data estimated a harvest of 9 fish or 0.45 metric tons. There are currently no restrictions on the harvest of bumphead parrotfish in Guam or the Northern Mariana Islands (Donaldson and Trianni, pers. comm.).

Solomon Islands (New Georgia Group) harvest data were obtained using creel surveys from August 2000 and July 2001 (Aswani and Hamilton, 2004; Hamilton, 2003). Bumphead parrotfish accounted for 60% of the reef fish catch in Roviana lagoon (Kalikoqu). Total harvest of bumphead parrotfish for the survey period was 0.63 metric tons. Fish caught ranged from 28.5 to 102.0 cm TL with a mean size of 62.7 cm TL; very few individuals were larger than 100 cm TL. There is currently a ban on harvest of any species while using SCUBA; however, there are no restrictions on the harvest of bumphead parrotfish using other extraction methods (Hamilton, pers. comm.).

Harvest data for Fiji are based on the results of a fisheries development program at Kia Island carried out by the Fiji Department of Agriculture in 1970 and from the 1990 Fiji Fisheries Division Annual Report (Adams, 1969; Richards et al., 1993). During the period of the fisheries development program, bumphead parrotfish accounted for 70% of the total reef fisheries catch and yielded 22.3 metric tons. In 1990 bumphead parrotfish accounted for 5% of total commercial landings and represented 230 metric tons (Dulvy and Polunin, 2004).

In Papua New Guinea, harvest data were obtained from of an assessment of a small-scale artisanal fishery conducted in the Tigak Islands (Wright and Richards, 1985). Harvest data were collected from the only commercial site for selling fish in Kavieng, New Ireland. A total of 636 bumphead parrotfish were collected during the survey period (13 months starting in November 1980) and represented 5% of the total fisheries catch. The mean size of fish harvested was 57 cm TL. No regulations are currently in place for the harvest of bumphead parrotfish (Dalzell, pers. comm.).

Data pertaining to the harvest of juvenile bumphead parrotfish are sparse. Bumphead parrotfish have been observed to reach sexual maturity at 55-65 cm TL for females and 47-55 cm TL for males (Hamilton et al., 2007). Consequently, juvenile bumphead parrotfish are defined as any fish less than about 50 cm TL. Similar methods are used to harvest bumphead parrotfish across all size classes with hand spear and spear gun being by far the most common. Fisheries typically target larger individuals, but all size classes are harvested opportunistically. It is likely that juvenile bumphead parrotfish are more vulnerable to harvest in populated regions based on their aggregating behavior and tendency to inhabit shallow lagoonal environments. Bumphead parrotfish of all size classes are vulnerable to harvest at night while resting in shallow protected habitats. During the day, larger (> 50 cm TL) adult bumphead parrotfish may be afforded greater protection from harvest by spending this period foraging on the forereef (Donaldson and Dulvy, 2004). Conversely, juvenile parrotfish are susceptible to harvest by remaining in shallow lagoonal environments that are frequented by daytime fishermen.

Given the lack of data on the harvest of bumphead parrotfish, it is difficult to evaluate the impact of fisheries exploitation across the entire geographic range of the species. Nevertheless, there are numerous reports of declining bumphead parrotfish populations (Bellwood et al., 2003; Chan et al., 2007; Donaldson and Dulvy, 2004; Dulvy and Polunin, 2004; Dulvy and Sadovy, 2003; Hoey and Bellwood, 2008; Kitalong and Dalzell, 1994). These studies primarily use fisheries independent data in the form of in situ surveys using SCUBA and various interview methods to estimate bumphead parrotfish abundance (fish per 1000 m^2). Bumphead parrotfish can be found in great local abundance at sites isolated from population centers or protected from exploitation

(Dulvy and Polunin, 2004). Sites where bumphead parrotfish are found in abundance (densities as high as 300 fish per km^2) include portions of the Great Barrier Reef Marine Park (Bellwood et al., 2003; Bellwood, pers. comm.; Choat, pers. comm.), sites in the Seychelles (Friedlander pers. comm.), Wake Atoll and Palmyra Atoll, U. S. Pacific Islands (Zgliczynski, et al., In prep), Rowley Shoals Marine Park (Bellwood, pers. comm.; Choat, pers. comm.), isolated regions of Papua New Guinea (Dalzell, pers. comm.), portions of the Red Sea (Bogorodsky, pers. comm.), protected sites in Palau (Colin, pers. comm.), and remote sites in the Solomon Islands (Hamilton, pers. comm.). The observations at remote sites, with minimal to no harvest are not restricted to one specific geographic region but span across the geographic range of the bumphead parrotfish. Sites with high human population densities and associated fisheries exploitation have lower densities of bumphead parrotfish compared to remote and uninhabited locations (Chan et al., 2007; Donaldson and Dulvy, 2004; Dulvy and Sadovy, 2003; Hoey and Bellwood, 2008; Kitalong and Dalzell, 1994). Although fisheries harvest data are lacking, the implication is that lower densities of bumphead parrotfish in more heavily populated areas are due to fishing and other human activities.

In conclusion, human harvest is considered by the Team to be one of the primary hazards to the short- and long-term status of bumphead parrotfish. The Team recognizes the critical importance of improved fishery management for this species throughout its range. The Team finds it noteworthy that, in some areas of high abundance, bumphead parrotfish can and have become protected via nonregulatory mechanisms; for example, the increasing recognition of these fish as a tourist attraction (SCUBA divers) affords them effective “grass-roots” driven protection, as observed in some parts of the Red Sea and Malaysia (Randall, pers. comm.). The economic value of the living fish can easily exceed the value of its dead flesh, but success of such non-extractive resource utilization policies obviously requires considerable cooperative effort, education, and strict enforcement.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of “harvest”, there is extremely strong concern for both the magnitude and nature of bumphead parrotfish harvest; and this is one of the primary hazards with respect to species survival.

4.2.3 Competition, Disease, Parasites, and Predation

There is very little information on the impacts of competition, disease, parasites, and predation on bumphead parrotfish, despite a number of scientific studies on bumphead parrotfish populations spanning different years and locations. The lack of habitat specificity or diet specificity would likely reduce the role of competitive processes. An exception might be competition for adult sleeping habitat if other large organisms (sharks, wrasses, other parrotfishes, etc.) are vying for the same nighttime shelters. Occasional predation by sharks has been discussed in several parts of this report, but this is not thought to be important for bumphead parrotfish population dynamics. There is no indication that any of these issues will play a significant role individually or cumulatively in the short- or long-term outlook for bumphead parrotfish populations. There is not much known about egg/larval and juvenile biology, but it is likely that predation on these earlier phases of the life-history may be a more significant issue than with the adults. These subjects are data poor, but the Team is of the opinion that there are no “red flags” to raise under this category with respect to bumphead parrotfish extinction risk.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of “competition, disease, parasites, and predation”, there is little information for guidance but that these threats are not thought to be strong concerns with respect to species survival.

4.2.4 Starvation

The Team does not consider starvation to be a major issue with respect to maintenance of existing populations of bumphead parrotfish or its future extinction risk. Neither juvenile nor adult bumphead parrotfish exhibit sufficient dietary specificity to warrant concerns of depleted food sources. Contaminated or otherwise altered food sources could be an issue if bumphead parrotfish were to not derive adequate nutrition from their forage. However, this is entirely speculative and there is no biochemical or physiological dependency mapped out in this species that could act in such a manner. Larval starvation is an entirely unknown issue but could be important if oligotrophic regions of the world oceans continue to increase in size (Polovina, et al., 2008), with corresponding decreases in larval forage (Lo-Yat et al., 2010). The spatial and temporal distribution of larval forage is not well documented but overall decreases in larval food supply will likely make existing food patches much more significant (e.g., pelagic hot spots, frontal areas, upwellings, convergences, surface slicks, coastal areas).

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of “starvation”, there is little information for guidance but that this threat is not thought to be a strong concern with respect to species survival.

4.2.5 Climate Change and Ocean Acidification

The Team recognizes that certain changes are likely to occur in the world’s oceans, including habitat for the bumphead parrotfish, based on long-term (on the order of centuries) changes in global mean temperature and other ocean properties, some anthropogenic. The principal changes in bumphead parrotfish habitat over the next century that the Team recognizes are summarized as follows: 1) ocean temperature will increase 0.6-4.0°C (IPCC, 2007), 2) sea level will rise 0.5–1.4 m (Rahmstorf, 2007), and 3) ocean acidity will increase, with pH falling 0.3–0.4 pH units due to increasing atmospheric and oceanic CO_2 (Doney et al., 2009). These changes in the environment are thought to have impacts on productivity and restructuring of ecosystems (e.g., Edwards and Richardson, 2004). As discussed in the section on carrying capacity, the Team is of the opinion that these factors and other abiotic effects are not thought to be plausible drivers of bumphead parrotfish population dynamics, either now or in the foreseeable future of 40-100 years. Some discussion of these specific environmental changes and their potential impacts on bumphead parrotfish species survival will follow.

Impacts of ocean acidification on coral abundance and/or diversity are arguably significant; however, bumphead parrotfish is not an obligate corallivore and the direct and indirect linkages remain tenuous. The adult bumphead parrotfish does not appear to be food limited or space limited in any portions of its range. The species also appears to be adaptable to a variety of biotic and abiotic conditions, given its wide geographic range and observations of it residing (foraging, sleeping) in both shallow and deep water. The existing nearshore variability and the nearshore buffering capability against oceanic shifts both serve to reduce the effects of climate change and ocean acidification on bumphead parrotfish. Short- or long-term changes in climate are unlikely to have a strong impact on bumphead parrotfish populations unless it is via some unknown direct or indirect effect on egg/larval survival and subsequent recruitment dynamics. For example, if jellyfish blooms were linked to ocean acidification and/or climate change (Brodeur et al., 1999; Mills, 2001; Richardson et al., 2009) and if their predation impact on bumphead parrotfish eggs/larvae were to increase, then it is quite conceivable that such changes would reduce survival of the species. However, if the bloom were of a forage species for larvae, juveniles, or adults, then such a shift could be beneficial. Some researchers have pointed out that increased CO_2 (lower pH) could enhance seagrass productivity (Guinotte and Fabry, 2008; Palacios and Zimmerman, 2007; Poloczanska et al., 2009), with presumably the same effect on other plants such as mangroves (Gilman et al., 2008). This is an interesting consequence with respect to bumphead parrotfish because, as noted earlier, such seagrass and mangrove areas can be critically important nursery areas for juvenile bumphead parrotfish. However, accurately predicting the magnitude of environmental change and the resultant ecosystem or food web responses is extremely difficult and, as such, the net directional of environmental impacts on bumphead parrotfish species survival is difficult to ascertain.

The increase in oligotrophic areas mentioned earlier or other combinations of change in water temperature and productivity could generally affect larval reef fish survival (e.g., Lo-Yat et al., 2010). Sea-level rise could promote human depopulation of certain geographic strata within the range, perhaps relaxing fishing pressure, and it may decrease or increase the size of seagrass or mangrove areas. Ocean acidification could potentially enhance adult bumphead parrotfish forage under the “naked coral hypothesis” (Fine and Tchernov, 2007; Stanley, 2003). Many scenarios, both negative and positive, are plausible; however, little data exist to support any such assertions. The Team has examined the available scientific evidence and does not conclude that climate change factors will significantly affect bumphead parrotfish in the foreseeable future, either individually or cumulatively (e.g., through synergistic effects.) The Team is of the opinion that the bumphead parrotfish has the ability to cope with myriad sources of environmental variability throughout its life history, but is more susceptible to issues raised elsewhere in this report (e.g., other factors influencing juvenile habitat, adult sleeping habitat, recruitment variability, human harvest of adults, etc.).

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of “climate change and ocean acidification”, there are many potential impacts to bumphead parrotfish, but the net direction of impacts is difficult to assess.

4.2.6 Pollution

Pollution events (e.g., oil spills) can be catastrophic to the coral reef ecosystem. However, such events remain episodic and are usually localized in the context of a widely distributed, mobile species. Habitat modification as a result of pollution is most likely to be an issue with juvenile habitat since it is more exposed to such anthropogenic impacts because of proximity, shallowness, and tendency to be more contained (e.g., lagoons, as opposed to open coastal waters). Once shallow lagoon areas are identified as nursery habitat for bumphead parrotfish, they should be carefully protected, as should all nursery areas. The Team remains very concerned about the effects of pollution on the quantity and quality of juvenile habitat, but does not extend as much concern to adult habitat since the adult habitat is larger and less contained.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "pollution", this threat is very important with respect to juvenile habitat, and can be locally devastating to all habitats, but that most catastrophic events are unlikely to be of the scope to impact species survival.

4.2.7 Synergistic and Other Effects

No other plausible threats, hazards, and drivers of bumphead parrotfish population dynamics were identified by the BRT. There are no data to draw conclusions or even speculate on synergistic effects. Given the lack of such data, it would be precautionary to assume that any combination of hazards will work together with a net effect greater than the sum of their separate effects. For example, hazards that reduce the abundance of bumphead parrotfish may trigger the hypothetical density-dependent process discussed earlier in which a minimum density of adult conspecifics is required for successful settlement/recruitment. This process is not documented but is plausible. Investigation and tracking of this synergy could be fruitful, especially since the influx of younger fish is known to be scant in some areas (e.g., GBR). Bumphead parrotfish may be recruitment overfished in some areas, and this is presently being investigated (Warner, Choat, pers. comm.). The Team recognizes that this species is extremely data poor and should be the focus of continued study.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "synergistic and other threats", this category of threat is very important and underscores the need to better understand density-dependent population dynamics in this species.

4.2.8 Bumphead Parrotfish Threat Table

Section 4(a)(1) of the ESA requires the agency to determine whether the species is endangered or threatened because of any one or a combination of the following factors:

1) destruction or modification of habitat;
2) overutilization for commercial, recreational, scientific, or educational purposes;
3) disease or predation;
4) inadequacy of existing regulatory mechanisms; or
5) other natural or human factors.

The Team organized its assessment of threats according to these Section 4(a)(1) factors using a Threat Table. The Team evaluated the potential role that each factor listed in the table may have played in the decline of bumphead parrotfish and the likelihood it will limit their recovery in the foreseeable future of 40-100 years. Within the limiting factor categories, specific threats were ranked according to severity, geographic scope, the level of certainty that bumphead parrotfish are affected, using Team discussion and consensus to arrive at a scoring for individual threats. Some factors, such as the inadequacy of existing regulatory mechanisms, will be presented in a separate report being prepared by the regulatory branch of NMFS. The terms used in **Table 1** are defined as follows:

ESA Factor – The specific factors responsible for a species' decline, using the statutory ESA Section 4(a)(1)(A)-(E) terminology. Factors for decline may or may not persist and limit the viability of the species.

Threats = Those human or natural events/actions that are responsible for, contribute to, or could contribute to population limiting factors. Threats can be described according to time frame, as follows:

- **Historic Threats** = threats that occurred in the past and may or may not be occurring presently.
- **Current Threats** = threats that are occurring now.
- **Future Threats** = threats that are likely to affect bumphead parrotfish over the next 40-100 years of the foreseeable future.

Severity, geographic scope, and level of certainty were scored as defined below, by team consensus.

Severity = The level of damage to the species that can reasonably be expected within 40-100 years under the current circumstances and trends. Specific rankings for this category are defined as follows:

- **High:** The threat is *likely to seriously reduce or eliminate* the species' population numbers over some portion of its range.
- **Medium:** The threat is *likely to moderately reduce* the species' population numbers over some portion of its range.
- **Low:** The threat is *likely to only slightly reduce* the species' population numbers over some portion of its range.

- **Nil:** The threat is *likely to not at all or negligibly reduce* the species' population numbers over some portion of its range.
- **NA:** The threat has *an unknown impact* to the species' population numbers because there are insufficient data to characterize the effect.
- **+/-**: The "+" or "-" sign may be appended to the ranking to indicate a value believed to be on the upper or lower end of the range of value, respectively.

Geographic Scope = The geographic scope of impact on the species that can reasonably be expected within 40-100 years under the current circumstances and trends. Specific rankings for this category are defined as follows:

- **Widespread:** The threat is likely to be widespread or pervasive in its scope and affect the species *throughout its range*.
- **Moderate spread:** The threat is *likely to be occurring at more than some to many, but not all, areas* in its scope and to affect the species at *a number of locations within its range*.
- **Localized:** The threat is *likely to be confined* in its scope and to affect the species in a *limited portion of its range*.
- **NA:** The threat has *an unknown geographic scope* to affect the species because there are insufficient data to characterize the effect.
- **+/-**: The "+" or "-" sign may be appended to the ranking to indicate a value believed to be on the upper or lower end of the range of value, respectively.

Level of Certainty = The level of certainty that the threat will affect the species with the severity and geographic scope ascribed in the next 40-100 years. Specific rankings for this category are defined as follows:

- **High:** There are *definitive* published and unpublished data to support the conclusion that this threat is likely to affect the species with the severity and geographic scope ascribed.
- **Medium:** There are *some* published and unpublished data to support the conclusion that this threat is likely to affect the species with the severity and geographic scope ascribed.
- **Low:** There are *few* published and unpublished data to support the conclusion that this threat is likely to affect the species with the severity and geographic scope ascribed.
- **NA:** There are *no* data to support the conclusion that this threat is likely to affect the species with the severity and geographic scope ascribed.
- **+/-**: The "+" or "-" sign may be appended to the ranking to indicate a value believed to be on the upper or lower end of the range of value, respectively. Additionally, a "?" may be appended which represents the Team's best estimate in instances with inadequate data to characterize.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "threat table", the primary current and future threats are issues related to juvenile habitat, human harvest, and recruitment variability.

Table 11.--Bumphead Parrotfish Threat Table generated by Team consensus. Some scoring in need of further explanation is addressed as footnoted material. [6]

		Historic Impact				**Current Impact**			**Future Impact (40-100 years)**		
ESA Factor	**Threat**	**Period of impact**	**Severity**	**Geographic scope**	**Level of certainty**	**Severity**	**Geographic scope**	**Level of certainty**	**Severity**	**Geographic scope**	**Level of certainty**
Habitat Destruction, Modification, or Curtailment	Adult habitat loss or loss of quality, including nighttime shelters	~40 yrs ago	Low	Low	Low	Medium	Medium	Medium	Medium+	Medium+	Medium
	Juvenile habitat loss or loss of quality	Pre-WW2	Medium	Low	Low	High	Medium	Medium	High	Medium	Medium
	Pollution	40-100 yrs ago	Low	Low	Low	Low	Low	Low	Medium-	Medium-	Medium-
Overutilization	Harvest or harvest related adult mortality	Pre-WW2	High	Low	Medium	High	Low+	Medium	High	Medium	Medium
	Capture or capture related juvenile mortality	Pre-WW2	Nil	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
Disease and Predation	Competition	40-100 yrs ago	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Disease	40-100 yrs ago	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Parasites	40-100 yrs ago	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Predation	40-100 yrs ago	Low	Medium	Low	Low-	Medium	Medium	Low-	Medium	Medium
	Starvation	40-100 yrs ago	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Natural or Manmade Factors	Low population effect (depensation, genetic, etc.)	40-100 yrs ago	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Recruitment limitation or variability	40-100 yrs ago	Low	Medium	Low	Medium	Medium+	Medium	Medium+	Medium+	Medium
	Global warming	40-100 yrs ago	Low	Low	Low	Medium	Medium	Medium	Medium+	Medium+	Medium
	Ocean acidification	40-100 yrs ago	Nil	Low	Low	Nil+	Medium	Medium	Low-	Medium+	Medium

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[6] The BRT assigned a medium+ ranking for global warming threat severity and geographic scope. The BRT felt that the impact of global warming, despite the extreme difficulty of ascertaining net directionality over all life history stages of bumphead parrotfish, should be treated as a medium+ level of threat over the longest time scales examined (40-100 years). The BRT felt that adult (and likely juvenile) bumphead parrotfish are ecologically resilient to minor environmental modification, yet there remains the distinct possibility that the eggs and larvae are not so adaptable, and that temperature increases of 0.6 - 4.0°C and pH reductions of 0.3–0.4 pH units are cause enough for concern in the medium+ range of ecological effect. This potential threat could be manifested as physical conditions exceeding biological tolerances and/or indirect ecological effects propagated through the ecosystem with negative consequence to bumphead parrotfish eggs and larvae.

4.3 Human Population Change

The human population size and changes thereof are not considered to be standalone threats to bumphead parrotfish species survival. However, they can influence many of the direct threats presented in the previous section, and as such will be discussed here. The general discussion will be followed by a detailed breakdown of population metrics for each geographic stratum within the range of bumphead parrotfish.

The human population is estimated to be approximately 6.9 billion people globally in 2010 (U.S. Census Bureau, http://www.census.gov/ipc/www/idb/worldpopinfo.php). Projections of the population into the next 90 years are shown in Figure 22. The human population is expected to increase over the next few decades despite a gradual decrease in the growth rate (U.S. Census Bureau, http://www.census.gov/ipc/www/idb/worldpopinfo.php). In 2009 the annual growth rate was 1.1% and trending linearly downward (Figure 23).

Regionally, the population breakdown and percent changes are shown in Table 12 for geographic strata covering the bumphead parrotfish range. These values are expressed in geographic format in Figure 24 and Figure 25, respectively. The bulk of the population data originate from the United Nations Population Division (**http://data.un.org/Data.aspx?d=PopDiv&f=variableID%3a12**), with supplemental information for a few small islands and Taiwan gleaned from other online resources such as the CIA Database (**https://www.cia.gov/library/publications/the-world-factbook/**). The forecasts used for the percent change calculation are based on the medium growth rate assumption of Figure 22.

Most of the geographic strata in the bumphead parrotfish range are predicted to experience moderate to above-average human population growth. Depopulation trends in some areas might occur, but overall there will be more humans and commensurate increases in demand for resources to support the increasing numbers of people. Accordingly, anthropogenic impacts to bumphead parrotfish are likely to increase over the next 40-100 years.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "human population change", this is a serious concern over the next century as most areas within the range of bumphead parrotfish will be increasing in human population.

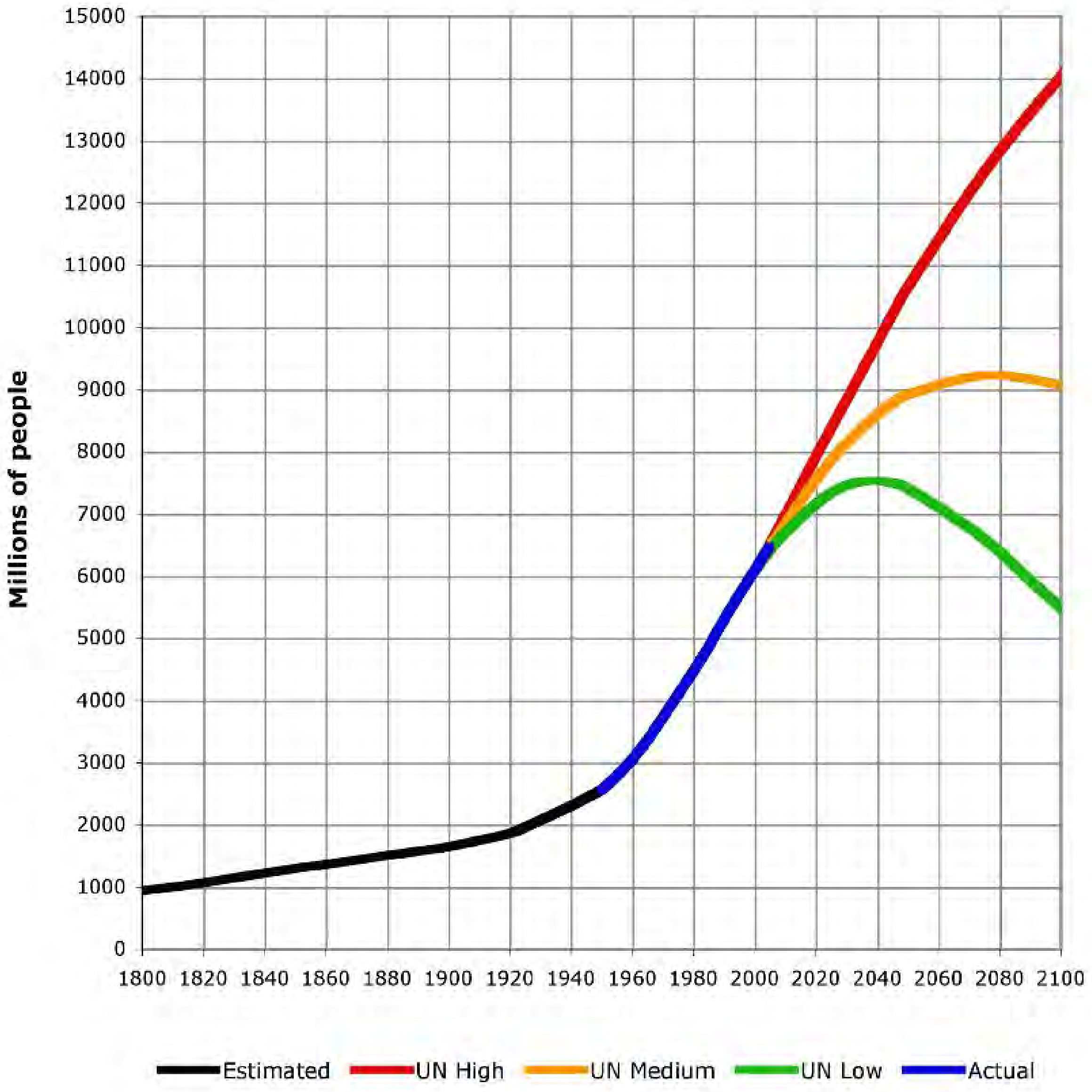

Figure 22.--World population from 1800 to 2100. Black (1800-1950) denotes estimated historical values, blue (1950-2005) denotes actual values, and the red, orange, and green denote predictions based on assumptions of high, medium, or low growth rates, respectively, thought to bracket the actual future trajectory from 2005-2100 (data from the U.S. Census Bureau and United Nations).

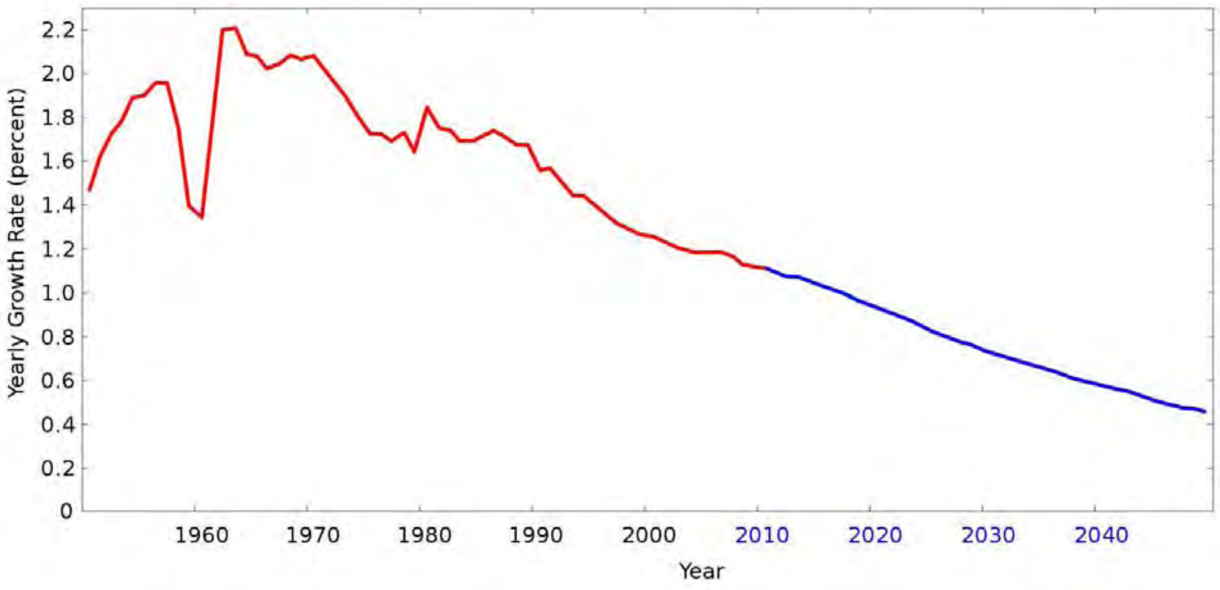

Figure 23.--Human population growth rate 1950-2010 (red) and predicted changes in world population growth rate 2010-2050 (blue) based on data from the U.S. Census Bureau.

Table 12.--Summary of 2010 population sizes and predicted increases for geographic strata in the bumphead parrotfish range. The percent changes were averaged over 40 years to 2050. Data from United Nations Population Division.

Name	Population in 2010 (thousands)	Average predicted percent increase from 2010
China	1354146.44	0.11
India	1214464.31	0.82
Indonesia	232516.77	0.61
Japan	126995.41	-0.52
Philippines	93616.85	1.42
Viet Nam	89028.74	0.65
Egypt	84474.43	1.34
Iran	75077.55	0.73
Thailand	68139.24	0.19
Myanmar	50495.67	0.64
Tanzania	45039.57	3.60
Sudan	43192.44	1.91
Kenya	40862.90	2.74
Malaysia	27913.99	1.05
Saudi Arabia	26245.97	1.67
Yemen	24255.93	3.07
Mozambique	23405.67	2.23
Taiwan	23000.00	0.23
Australia	21511.89	0.84
Sri Lanka	20409.95	0.14
Madagascar	20146.44	2.83
Cambodia	15053.11	1.46
Somalia	9358.60	3.83
Papua New Guinea	6888.39	2.20
Eritrea	5223.99	2.66
Mauritius	1296.57	0.24
East Timor	1171.16	4.38
Djibouti	879.05	1.71
Fiji	854.10	0.18
Reunion	837.09	0.78
Comoro Islands	691.35	1.95
Micronesia	573.13	1.02
Solomon Islands	535.70	2.23
Andaman and Nicobar	356.00	0.00
Maldives	313.92	1.13
French Polynesia	272.39	0.75
Northern Mariana Islands and Guam	268.30	1.17
New Caledonia	253.74	1.07
Vanuatu	245.79	2.43
Mayotte	199.07	2.37
Samoa	178.94	0.24
Tonga	104.26	0.53
Seychelles	84.60	0.39
American Samoa	68.51	1.43
Marshall Islands	63.40	1.15
Oecussi Ambeno	57.00	0.00
Line Group	33.18	1.33
Phoenix Group	33.18	1.33
Kiribati	33.18	1.33
Palau	20.53	0.78
Wallis and Futuna	15.45	0.23
Tuvalu	9.97	0.28
Niue	1.44	-0.45
Cocos Islands	0.60	0.00
Palmyra Atoll	0.00	0.00
Howland Island and Baker Island	0.00	0.00
Wake Island	0.00	0.00
Australia - Papua New Guinea	0.00	0.00
Spratly Islands	0.00	0.00
Paracel Islands	0.00	0.00
Christmas Island	0.00	0.00
Ile Tromelin	0.00	0.00
Glorioso Islands	0.00	0.00

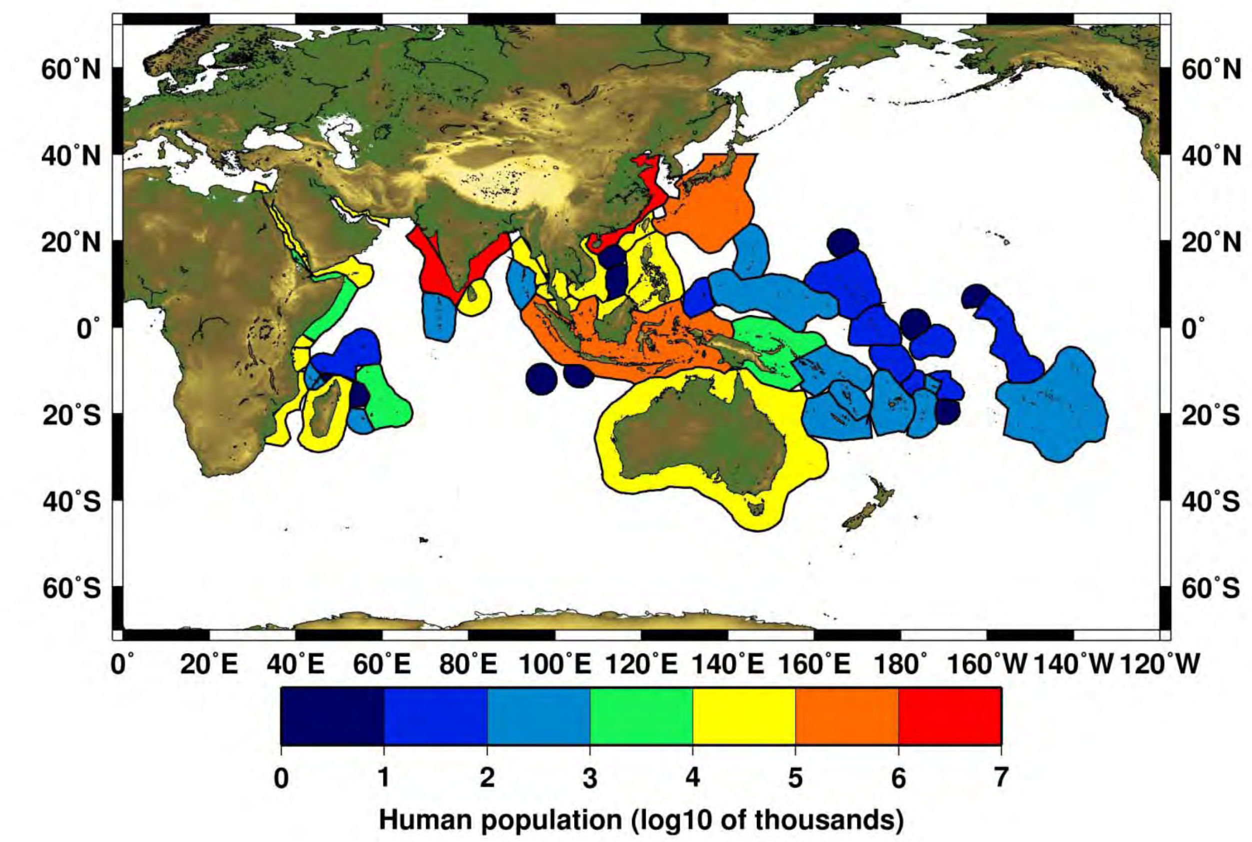

Figure 24.--Total human population in 2010 for geographic strata in the bumphead parrotfish range. Polygons denote entire boundary of EEZs and are not meant to indicate bumphead parrotfish range of occupancy.

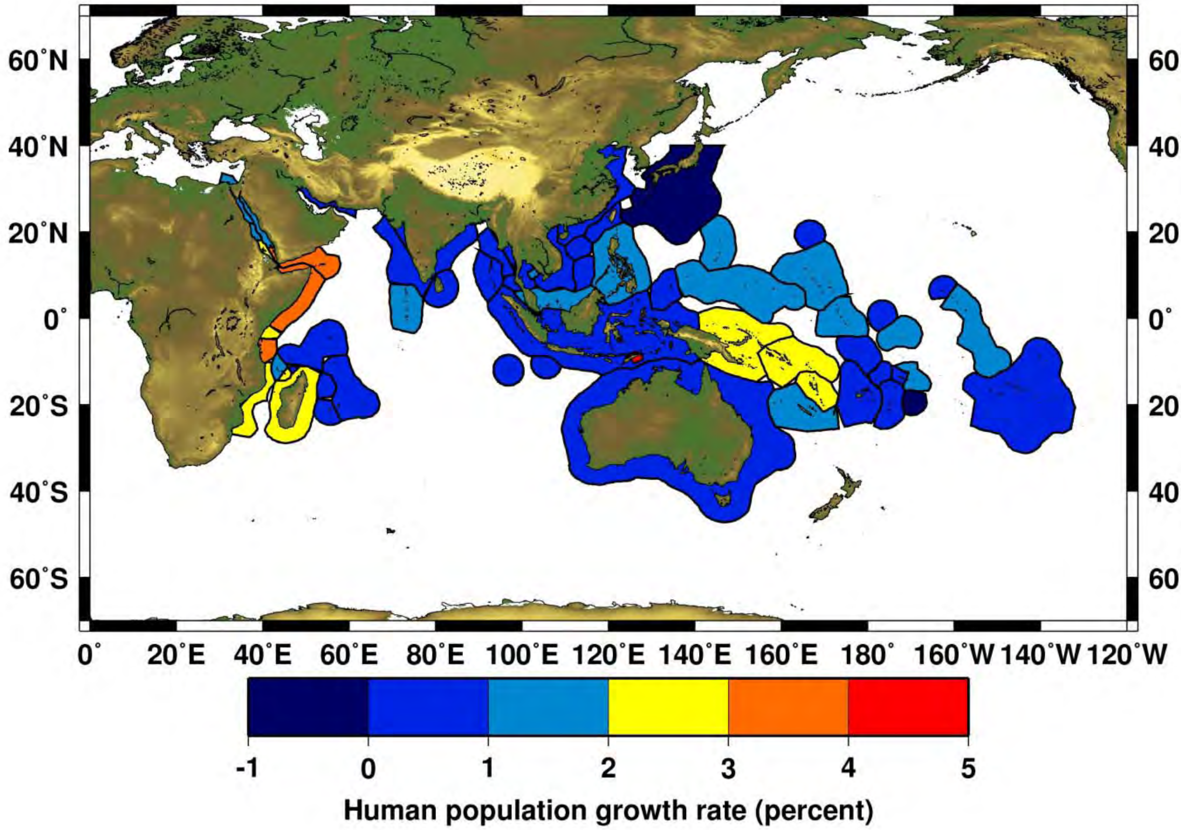

Figure 25.--Human population growth rate relative to 2010 levels for geographic strata in the bumphead parrotfish range. Polygons denote entire boundary of EEZs and are not meant to indicate bumphead parrotfish range of occupancy.

4.4 Extinction Risk Analysis

The following sections discuss the extinction risk issues as they pertain specifically to bumphead parrotfish. These findings represent the conclusions of the BRT after assimilation of all relevant scientific information concerning this species.

4.4.1 SPOIR

Significant portion of its range--"Significant" as used in this context is defined in the Webster's dictionary as "of a noticeably or measurably large amount". Technical guidance (Vucetich et al., 2005; Waples et al., 2007) suggests determining SPOIR on a case-by-case basis after examining the ecological setting rather than choosing any particular universal value of percentage of range (e.g., 33%). The bumphead parrotfish BRT adopted criteria for determining what portion of areal range is ecologically significant. These criteria include the size of the subarea of range scaled qualitatively by factors including, but not limited to: 1) location of the subarea with respect to the overall range and apparent natural pattern of biogeographic abundance, 2) microhabitat characteristics of the subarea (see list below of key juvenile and adult factors), and 3) potential connectivity of the subarea to adjacent portions of range based on life-history characteristics, oceanography, and geography. Juvenile microhabitat characteristics which characterize SPOIR include: habitats in shallow, low-energy, lagoonal areas; abundance of seagrass/mangrove/fleshy macroalgae (*Halimeda* spp., *Dictyota* spp., *Sargassum* spp.); patch reef coral (*Turbinaria* spp., *Acropora* spp.); mixed live coral and macroalgal assemblages; and adequate depth range (approximately 0-10 m). Adult microhabitat characteristics which characterize SPOIR include: habitats in hard bottom, high-energy, forereef and lagoonal areas; adequate depth (0-30 m approximate); live coral; encrusting/fleshy algal/turf algal assemblages and benthic invertebrates; reef complexity; spur/groove habitat with channels; and adequate shelters for nocturnal resting/sleeping.

The Team realizes that a complete database inventory of factors important for delineating this ecological SPOIR over the complete range of this species does not exist, and will not likely exist at any time in the near future. However, a tentative first step can be made using existing data. An ecological SPOIR index was created using 5 factors combined together in additive fashion:

- First, to account for some component of the underlying biogeographic pattern, a simple distance measurement was calculated for each geographic stratum representing the distance of the habitat centroid of that stratum to the centroid of the Philippine Islands (center of Indo-Pacific marine shore fish biodiversity, Carpenter and Springer, 2005). This distance was standardized and scaled from 0-1 with 0 being the farthest and 1 being the nearest. Separate scale multipliers for east/west and north/south were utilized to give approximately equal weighting in all directions until the range boundaries were reached.
- Second, to account for adult habitat availability importance, an areal measurement of adult habitat was estimated. Coral reef area was used as a proxy for adult habitat and was obtained from the Reefs at Risk global database (http://www.wri.org/publication/reefs-at-risk#data). The data were not adjusted or scaled to forereef area as done for the global estimation of population (Appendix) since the index is relative and not absolute. The data were log transformed to buffer the effect of extremely large geographies.
- Third, to account for juvenile habitat availability importance, an areal measurement of juvenile habitat was estimated. Mangrove area was used as a proxy for juvenile habitat in this exercise and was obtained from ReefBase (http://www.reefbase.org/main.aspx) and other sources (Ellison, 2009; Gilman, et al., 2006). The areas were transformed into 0–1 indices with 1 being the largest areas. It should be noted that an attempt was made to tabulate lagoonal habitat for each geographic stratum using the 2-minute resolution Smith and Sandwell global bathymetric database (Smith and Sandwell, 1997) estimated from satellite altimetry (http://topex.ucsd.edu/marine_topo/mar_topo.html). However, the Team was unable to identify lagoonal type areas separately from non-lagoonal shallow waters and continental shelf areas. Therefore, mangrove area was assumed to be proportional to the area of shallow, lagoonal habitat that juvenile bumphead parrotfish require. The data were log transformed to buffer the effect of extremely large geographies.

- Finally, to account for demographic importance, 2 simple connectivity measurements — one forward looking, the other rearward looking — were obtained for each stratum from the multigenerational simulations presented in the report section pertaining to Early Life History and Connectivity. Forward-looking connectivity averages were constructed representing the average probability of non-natal, non-lost outgoing contributions to all other geographic strata. Rearward-looking connectivity averages were constructed representing the average probability of non-natal incoming contributions from all other geographic strata. Both of these averages represent linkages that are demographically important. Ideally, if both types of linkages are high, then the geographic strata can serve as a key node in a "stepping stone" context. The forward and rearward averages were transformed into 0-1 indices with 1 representing the maximum connectivity linkage.

These 5 important ecological components were used in additive fashion to construct a composite SPOIR index. This index is presented in Table 13 and is geographically represented in Figure 26. It should be kept in mind, however, that this is only a preliminary delineation of SPOIR for this species, and is only useful as a relative reference (i.e., the absolute magnitude of this SPOIR is not ecologically interpretable in present form). The utility of this SPOIR index is primarily to compare different strata and/or combinations of strata for their potential importance to the species. It should also be noted that a variety of methodologies are available to combine disparate data into a single index. It is recommended that they be further explored as the SPOIR database expands; for example, a multiplicative combination of factors would allow any single component at zero or near-zero value to diminish the resultant index if it were found that certain components were absolutely critical and with identifiable thresholds. It is also quite possible that a mixture of approaches may be necessary, e.g., to establish the lower bound, a law of the minimum type approach, which maps minimally acceptable strata, might be used, whereas a combinatorial approach may be useful for the positive characterization of strata once basic ecological needs are ascertained.

The last column of Table 13 indicates whether the additive SPOIR index is at or above the median value of the index (0.4506) over all geographic strata. The 32 strata with a SPOIR index greater than the median value are considered part of the SPOIR. In this approach, the assumption is that SPOIR occupies half (note: by number of strata, not area) of the overall geographic range, and geographic strata are sorted by the additive SPOIR index to determine which would qualify as SPOIR. The choice of the median value as a conservative threshold is reasonable based upon the earlier definition of the term SPOIR, in which "significant" means a large portion, i.e., more than half. The species is able to persist in most, if not all, of the geographic strata presented; therefore, concerns of underestimating the actual minimum threshold would appear unlikely; i.e., there is no compelling evidence to suggest that the SPOIR index threshold should be greater than the median, and is more likely lower than the median, hence it is suggested here that SPOIR is conservatively delineated in this exercise.

Table 13.--Summary of preliminary SPOIR estimation for bumphead parrotfish. Higher values indicate geographic strata that are more ecologically important based on the input criteria. The far right column indicates if the SPOIR index is at or above the overall median value (0.4506) as suggested criteria for identification of SPOIR geographic strata.

Name	Distance	Distance Index	Coral	Coral Index	Mangrove	Mangrove Index	Forward	Forward Index	Rearward	Rearward Index	Sum	SPOIR Index	SPOIR?
Line Group	41.80	0.23	534.44	0.58	0.00	0.00	0.0000	0.00	0.00	0.00	0.82	0.20	
Palmyra Atoll	38.10	0.30	114.14	0.44	5.00	0.17	0.0000	0.00	0.00	0.00	0.91	0.23	
Niue	45.78	0.16	130.79	0.45	0.00	0.00	0.0000	0.00	0.00	0.00	0.61	0.15	
American Samoa	41.78	0.23	278.70	0.52	19.35	0.28	0.0127	0.73	0.01	0.14	1.91	0.47	Y
Samoa	40.79	0.25	669.95	0.60	7.17	0.20	0.0097	0.55	0.01	0.05	1.66	0.41	
Phoenix Group	35.00	0.36	386.51	0.55	0.00	0.00	0.0112	0.64	0.01	0.09	1.64	0.41	
Tonga	43.26	0.21	1618.38	0.69	38.35	0.34	0.0048	0.27	0.00	0.03	1.54	0.38	
Howland and Baker	33.26	0.39	190.90	0.49	0.00	0.00	0.0154	0.88	0.00	0.02	1.78	0.44	
Wallis and Futuna	38.05	0.30	508.49	0.58	0.00	0.00	0.0123	0.70	0.01	0.08	1.66	0.41	
Tuvalu	34.95	0.36	877.49	0.63	0.40	0.03	0.0077	0.44	0.01	0.06	1.52	0.38	
Fiji	39.83	0.27	9029.77	0.85	406.55	0.56	0.0003	0.02	0.00	0.01	1.71	0.42	
Kiribati	27.81	0.49	1770.36	0.69	2.58	0.12	0.0027	0.16	0.01	0.14	1.60	0.40	
Marshall Islands	23.35	0.57	5310.34	0.80	0.04	0.00	0.0003	0.02	0.00	0.01	1.40	0.35	
Vanuatu	35.12	0.36	1994.44	0.71	22.90	0.30	0.0075	0.43	0.00	0.02	1.81	0.45	
Wake Island	24.18	0.56	13.57	0.24	0.00	0.00	0.0000	0.00	0.00	0.00	0.80	0.20	
New Caledonia	37.34	0.32	6473.71	0.81	287.00	0.53	0.0018	0.10	0.01	0.05	1.81	0.45	
Solomon Islands	27.09	0.50	6017.23	0.81	603.00	0.60	0.0072	0.41	0.00	0.04	2.36	0.58	Y
Micronesia	14.36	0.74	3929.57	0.77	85.64	0.42	0.0044	0.25	0.02	0.16	2.34	0.58	Y
Papua New Guinea	23.45	0.57	15695.63	0.90	4588.90	0.79	0.0078	0.44	0.01	0.09	2.79	0.69	Y
Australia	31.57	0.42	33612.18	0.97	11500.00	0.88	0.0037	0.21	0.02	0.22	2.70	0.67	Y
NMI and Guam	12.31	0.77	120.76	0.45	3.17	0.13	0.0000	0.00	0.00	0.00	1.35	0.34	
Australia PNG	22.11	0.59	14.17	0.25	0.00	0.00	0.0175	1.00	0.00	0.00	1.84	0.46	Y
Palau	6.86	0.87	954.92	0.64	46.39	0.36	0.0113	0.64	0.00	0.00	2.52	0.62	Y
Japan	16.12	0.70	1521.45	0.68	4.00	0.15	0.0002	0.01	0.00	0.01	1.55	0.38	
East Timor	18.83	0.66	321.81	0.54	0.00	0.00	0.0175	1.00	0.00	0.01	2.19	0.54	Y
Oecussi Ambeno	19.25	0.65	9.45	0.21	0.00	0.00	0.0175	1.00	0.00	0.00	1.86	0.46	Y
Philippines	0.00	1.00	14205.32	0.89	1607.00	0.69	0.0121	0.69	0.04	0.35	3.62	0.90	Y
Taiwan	12.18	0.78	355.26	0.55	339.00	0.55	0.0168	0.96	0.00	0.01	2.84	0.70	Y
Indonesia	13.77	0.75	47625.22	1.00	42550.00	1.00	0.0051	0.29	0.11	1.00	4.04	1.00	Y
Spratly Islands	3.95	0.93	1775.98	0.69	0.00	0.00	0.0097	0.55	0.00	0.03	2.21	0.55	Y
China	12.44	0.77	1148.76	0.65	339.00	0.55	0.0065	0.37	0.01	0.07	2.41	0.60	Y
Malaysia	6.04	0.89	2882.41	0.74	6424.00	0.82	0.0168	0.96	0.00	0.04	3.45	0.85	Y
Paracel Islands	8.12	0.85	592.89	0.59	0.00	0.00	0.0119	0.68	0.01	0.12	2.24	0.56	Y
Viet Nam	6.25	0.89	690.32	0.61	2525.00	0.74	0.0143	0.82	0.00	0.03	3.07	0.76	Y
Christmas Island	22.11	0.59	174.22	0.48	0.00	0.00	0.0175	1.00	0.00	0.00	2.07	0.51	Y
Cambodia	9.04	0.83	4.71	0.14	851.00	0.63	0.0175	1.00	0.00	0.00	2.61	0.65	Y
Thailand	11.19	0.79	1422.05	0.67	2641.00	0.74	0.0121	0.69	0.01	0.13	3.02	0.75	Y
Cocos Islands	25.45	0.53	93.67	0.42	0.00	0.00	0.0000	0.00	0.00	0.00	0.96	0.24	
Myanmar	14.74	0.73	2043.34	0.71	3786.00	0.77	0.0093	0.53	0.01	0.08	2.82	0.70	Y
Andaman and Nicobar	14.52	0.73	4443.51	0.78	0.00	0.00	0.0043	0.25	0.01	0.06	1.82	0.45	Y
Sri Lanka	21.57	0.60	663.63	0.60	89.00	0.42	0.0152	0.87	0.01	0.07	2.56	0.63	Y
India	23.28	0.57	1806.20	0.70	6700.00	0.83	0.0113	0.64	0.01	0.13	2.87	0.71	Y
Maldives	25.18	0.54	5990.51	0.81	350.00	0.55	0.0019	0.11	0.01	0.06	2.06	0.51	Y
Mauritius	42.27	0.23	755.37	0.62	0.00	0.00	0.0023	0.13	0.02	0.15	1.12	0.28	
Ile Tromelin	42.53	0.22	9.22	0.21	0.00	0.00	0.0123	0.70	0.00	0.00	1.13	0.28	
Seychelles	38.80	0.29	1505.77	0.68	29.00	0.32	0.0105	0.60	0.02	0.19	2.07	0.51	Y
Somalia	38.22	0.30	978.41	0.64	910.00	0.64	0.0024	0.14	0.00	0.01	1.72	0.43	
Glorioso Islands	43.58	0.20	135.86	0.46	0.00	0.00	0.0173	0.99	0.00	0.02	1.66	0.41	
Mayotte	44.60	0.18	448.51	0.57	10.00	0.22	0.0167	0.95	0.01	0.09	2.02	0.50	Y
Comoro Islands	44.92	0.18	215.57	0.50	26.21	0.31	0.0172	0.98	0.00	0.02	1.99	0.49	Y
Madagascar	48.15	0.12	3116.87	0.75	3403.00	0.76	0.0100	0.57	0.05	0.49	2.69	0.67	Y
Mozambique	47.69	0.13	2580.51	0.73	925.00	0.64	0.0136	0.78	0.02	0.16	2.43	0.60	Y
Kenya	42.89	0.21	873.17	0.63	530.00	0.59	0.0152	0.87	0.00	0.02	2.31	0.57	Y
Tanzania	44.67	0.18	3238.01	0.75	1155.00	0.66	0.0093	0.53	0.01	0.07	2.20	0.54	Y
Djibouti	39.40	0.28	506.08	0.58	10.00	0.22	0.0000	0.00	0.00	0.00	1.08	0.27	
Eritrea	41.11	0.25	4899.51	0.79	581.00	0.60	0.0000	0.00	0.00	0.00	1.63	0.40	
Egypt	46.67	0.14	3272.39	0.75	861.00	0.63	0.0000	0.00	0.00	0.00	1.53	0.38	
Saudi Arabia	44.13	0.19	4925.25	0.79	292.00	0.53	0.0000	0.00	0.00	0.00	1.51	0.37	
Sudan	43.35	0.21	1933.93	0.70	937.00	0.64	0.0000	0.00	0.00	0.00	1.55	0.38	
Yemen	39.92	0.27	1634.11	0.69	81.00	0.41	0.0000	0.00	0.00	0.00	1.37	0.34	
Reunion	45.66	0.16	62.59	0.38	0.00	0.00	0.0067	0.38	0.00	0.00	0.93	0.23	
French Polynesia	54.58	0.00	6941.57	0.82	0.00	0.00	0.0000	0.00	0.00	0.00	0.82	0.20	
Iran	37.85	0.31	601.54	0.59	207.00	0.50	0.0000	0.00	0.00	0.00	1.40	0.35	

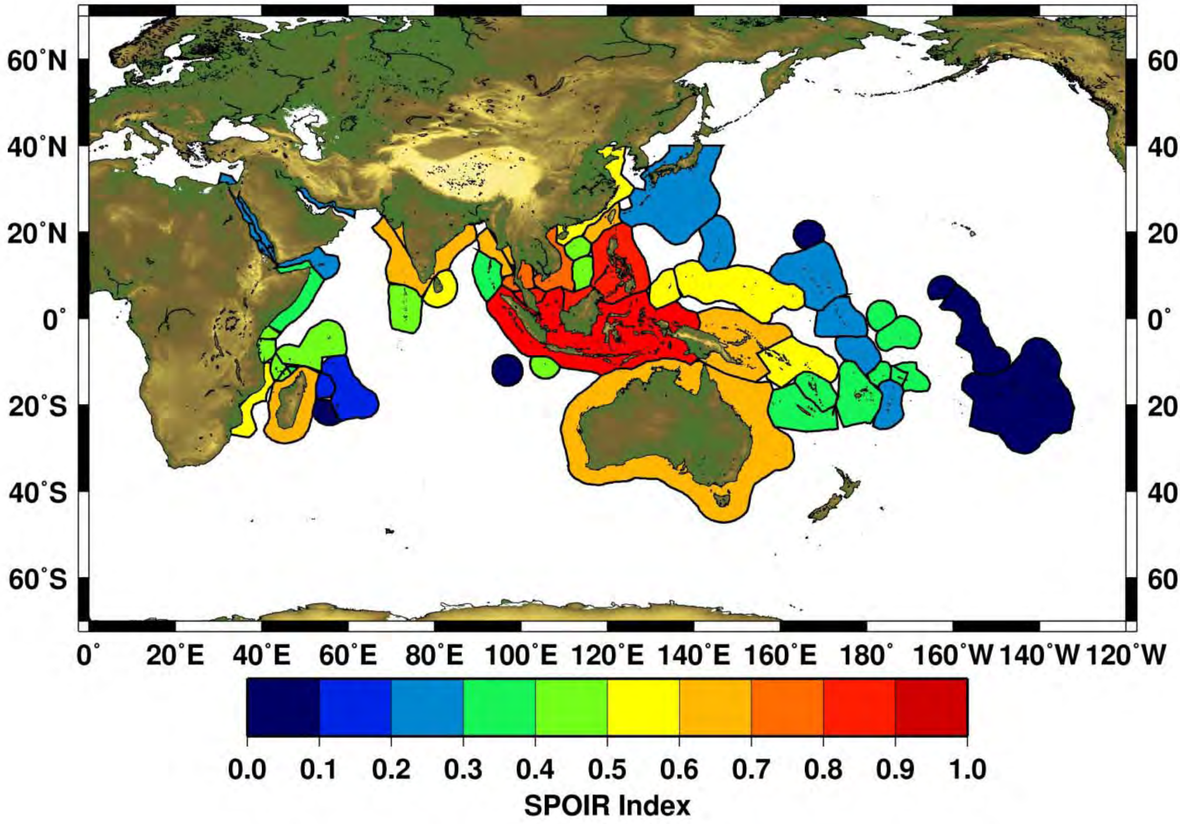

Figure 26.--Preliminary estimation of ecological SPOIR using 5 additive components. Higher values indicate geographic strata that are more ecologically important based on the input criteria. The polygons outline the entire geographic stratum for each country and/or island, for reference.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "SPOIR", the likely portions of geographic range which make up SPOIR using a preliminary suite of ecological characteristics would be American Samoa, Andaman and Nicobar, Australia, Australia PNG, Cambodia, China, Christmas Island, Comoro Islands, East Timor, India, Indonesia, Kenya, Madagascar, Malaysia, Maldives, Mayotte, Micronesia, Mozambique, Myanmar, Oecussi Ambeno, Palau, Papua New Guinea, Paracel Islands, Philippines, Seychelles, Solomon Islands, Spratly Islands, Sri Lanka, Taiwan, Tanzania, Thailand, and Viet Nam.

4.4.2 Critical Risk Threshold

In its analysis of extinction risk, the Team used an approach which characterizes extinction risk in terms of the certainty that the species' condition will decline below a Critical Risk Threshold (CRT) within a certain time period; below the CRT the species is of such low abundance or so spatially fragmented that it is at risk of extinction. The CRT is not defined as a single abundance number, density, spatial distribution or trend value; but rather it is a qualitative description encompassing multiple life-history characteristics and other important ecological factors. Establishing the CRT level involves consideration of all factors affecting the risk of bumphead parrotfish extinction, including depensatory processes, environmental stochasticity, and catastrophic events. Depensatory processes include reproductive failure from low density of reproductive individuals and genetic processes such as inbreeding. Environmental stochasticity represents background environmental variation. Catastrophes result from severe, sudden, and deleterious environmental events. The certainty of the species dropping below the CRT is described on a categorical scale shown below in Figure 27.

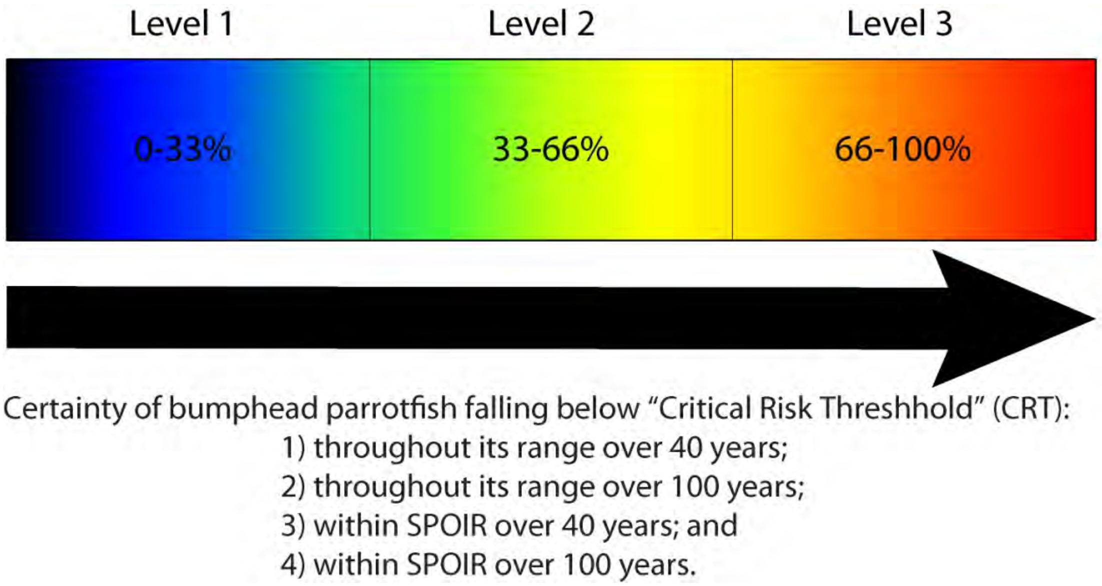

Figure 27.--Scale and categories of certainty used to evaluate extinction risk in bumphead parrotfish using the "Critical Risk Threshold" approach.

Assessing the degree of uncertainty involved weighing individual opinions of the BRT members. To capture the degree of conviction of each BRT member about extinction risk, each member distributed 10 "plausibility points" among the 3 uniform tercile categories of certainty as shown in Figure 27. The terciles are simply referred to as "Level 1" for the first (lowest) category of certainty, "Level 2" for the second (medium) category of certainty, and "Level 3" for the third (highest) category of certainty. The average plausibility point distribution amongst the 3 levels of uncertainty is reported as the overall summary result from the BRT analysis with respect to extinction risk. Four scenarios were evaluated corresponding to whether the geographic area considered was the entire range of the species or the SPOIR, and whether the foreseeable future was 40 years or 100 years, respectively.

The Team finds that, with respect to scientific evidence pertaining to the risk of bumphead parrotfish extinction, under the broad category of "critical risk threshold", the resolving capability of status determination is best reflected in uniform terciles of certainty due to lack of sufficient data.

4.4.3 Results

The BRT qualitatively assessed the severity, geographic scope, and level of certainty of potential individual and cumulative threats to bumphead parrotfish. Because the severity and scope of individual threats may change over time, each threat was evaluated based on its historical impact, its current impact, and its future potential for impact. The factors that are believed to have had the greatest potential to contribute to the decline of bumphead parrotfish are overharvesting, loss of juvenile habitat, lack of adult nighttime shelters, and recruitment variability. Given the possible threats to the species and all other information assimilated by the team, the BRT made the following conclusions with respect to extinction risk of the bumphead parrotfish species, using the tercile approach of certainty with l1 certainty reflecting the first tercile of certainty (0-33% certainty), Level 2 certainty reflecting the second tercile of certainty (33-66% certainty), and Level 3 certainty reflecting the third tercile of certainty (66-100% certainty). The individual Team member votes are presented in Table 14.

- For the entire geographic range over a 40-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 56% of plausibility points to this category, with 40% in the ***Level 2 certainty*** category, and 4% in the ***Level 3 certainty*** category.

- For the entire geographic range over a 100-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 48% of plausibility points to this category, with 46% in the ***Level 2 certainty*** category, and 6% in the ***Level 3 certainty*** category.

- For SPOIR over a 40-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 1 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 52% of plausibility points to this category, with 42% in the ***Level 2 certainty*** category, and 6% in the ***Level 3 certainty*** category.

- For SPOIR over a 100-year foreseeable future, the Team is of the opinion that bumphead parrotfish is at ***Level 2 certainty*** to fall below the Critical Risk Threshold, assigning an aggregate majority of 48% of plausibility points to this category, with 46% in the ***Level 1 certainty*** category, and 6% in the ***Level 3 certainty*** category.

The Team finds that, using all available evidence pertaining to the risk of bumphead parrotfish extinction, there is a low plausibility (4-6%) of bumphead parrotfish being at the highest certainty tercile of falling below the "Critical Risk Threshold" in the next 40-100 years over its entire range or over SPOIR. The Team is of the opinion that, while there are geographic areas of concern with low abundance or local extirpation, the species as a whole is unlikely to be driven extinct over the time and space scales examined as a result of widespread distribution across the Indo-Pacific, persistent abundance in some geographic areas, high fecundity, flexible ecological requirements, and dispersive capability via adult movement or egg and larval transport.

Table 14.--Summary of BRT plausibility voting for bumphead parrotfish extinction risk under 4 scenarios. Within each scenario, the order of team members is randomized.

CRT Vote 1:	Degree of certainty that bumphead parrotfish will below "Critical Risk Threshold" (CRT) throughout its range over 40 years		
	Level 1 certainty	Level 2 certainty	Level 3 certainty
Number of plausibility points:			
BRT member	4	5	1
BRT member	4	5	1
BRT member	6	4	0
BRT member	7	3	0
BRT member	7	3	0
Average	5.6	4	0.4
Percentage of plausibility	56.0%	40.0%	4.0%

CRT Vote 2:	Degree of certianty that bumphead parrotfish will fall below "Critical Risk Threshold" (CRT) throughout its range over 100 years		
	Level 1 certainty	Level 2 certainty	Level 3 certainty
Number of plausibility points:			
BRT member	6	4	0
BRT member	6	4	0
BRT member	4	5	1
BRT member	4	5	1
BRT member	4	5	1
Average	4.8	4.6	0.6
Percentage of plausibility	48.0%	46.0%	6.0%

CRT Vote 3:	Degree of certainty that bumphead parrotfish will fall below "Critical Risk Threshold" (CRT) within SPOIR over 40 years		
	Level 1 certainty	Level 2 certainty	Level 3 certainty
Number of plausibility points:			
BRT member	3	6	1
BRT member	4	5	1
BRT member	5	4	1
BRT member	7	3	0
BRT member	7	3	0
Average	5.2	4.2	0.6
Percentage of plausibility	52.0%	42.0%	6.0%

CRT Vote 4:	Degree of certainty that bumphead parrotfish will fall below "Critical Risk Threshold" (CRT) within SPOIR over 100 years		
	Level 1 certainty	Level 2 certainty	Level 3 certainty
Number of plausibility points:			
BRT member	6	4	0
BRT member	6	4	0
BRT member	3	6	1
BRT member	4	5	1
BRT member	4	5	1
Average	4.6	4.8	0.6
Percentage of plausibility	46.0%	48.0%	6.0%

4.5 Research Recommendations

The BRT developed the following list of research recommendations that will assist in a better understanding of bumphead parrotfish status. Juvenile habitat in lagoonal systems should be carefully inventoried throughout the range of the species. Patterns of human harvest need further study with continued attempts to mitigate this source of adult mortality. Recruitment variability and connectivity need further study to better understand the biogeography of this species and its ability to repopulate areas where it may receive protection.

5. ACKNOWLEDGMENTS

The BRT thanks Ms. Kathryn Stanaway of the NMFS Pacific Islands Regional Office (PIRO), Protected Species Division (PRD) for her diligent and conscientious work, some of it in volunteer status, during all phases of the BRT process leading up to the completed status report. The BRT also thanks Mr. Patrick Opay (PIRO PRD) for effectively and diplomatically leading the team along the correct procedural path. The BRT thanks Mrs. Joyce Miller and Ms. Megan Moews of the NMFS Pacific Islands Fisheries Science Center (PIFSC), Coral Reef Ecosystem Division (CRED) for their capable support roles for the team. The legal advice provided by Mr. Frederick Tucher (PIRO General Counsel) was also greatly appreciated by the BRT. Dr. Lance Smith (PIRO PRD), Dr. Erin Oleson (PIFSC PSD), and Dr. Dwayne Meadows (NMFS Office of Protected Resources) also provided valuable procedural guidance. The NMFS Wiki was an invaluable resource for the Team, and the BRT appreciates the tutoring by Wiki gurus Ms. Mariska Weijerman (PIFSC CRED) and Ms. Amanda Toperoff (PIFSC CRED). The final report benefited greatly from the inputs provided by 3 CIE reviewers and by the many PIRO and General Counsel staff who reviewed earlier versions of the report. Lastly, and most importantly, the BRT is extremely grateful to the many fish experts who shared information (publications, unpublished data, anecdotal observations, photographs, etc.) and/or volunteered valuable time to prepare and give presentations to the BRT. This list of valued scientific contributors to the report include Gerry Allen, Judy Amesbury, Jake Asher, Dave Bellwood, Chuck Birkeland, Sergey Bogorodsky, Dave Booth, Paul Callaghan, Frank Camacho, Howard Choat, Eric Clua, Pat Colin, Paul Dalzell, Gerry Davis, Chuck Daxboeck, Aymeric Desurmont, Terry Donaldson, Nick Dulvy, Nick Graham, Rick Hamilton, Gregor Hodgson, Phil Lobel, Jen McIlwain, Jenny Mihaly, Rob Myers, Jack Randall, Jan Robinson, Marlowe Sabater, Yvonne Sadovy, Bob Schroeder, Jason See, Craig Severance, Mohammad Reza Shokri, John Starmer, Mike Trianni, and Being Yeeting. The opinions contained herein remain solely the opinions of the 5 Team members.

6. ANNOTATED BIBLIOGRAPHY

Bolbometopon muricatum Green humphead parrotfish. www.fishbase.org. Accessed on August 2010. Summary of listing and global status, life history, ecology and importance, and threats. Common names in many languages are given, as well as taxonomy.

Adams, A.
1969. The value of the reef and the dangers of over-exploitation. A Symposium convened by the Agriculture Department, Fisheries Division, Suva, Fiji. 42 p. This paper addresses the need to learn about the biology and ecology of BHP at Kia Island. They make up 70% of the catch here, and the authors are concerned about the affects of fishing on the reef system. They suggest looking to see if the average length has decreased over time.

Adams, P., C. Grimes, J. Hightower, S. Lindley, and M. Moser.
2002. Status review for North American green sturgeon, *Acipenser medirostris*. 57 p. This is an ESA status review for the green sturgeon. In the status review, two DPSs are evaluated because there are two populations that feed and spawn in two different, unconnected estuaries. Not much is known about these two populations and this is where most of the harvesting occurs. A majority of the BRT team concluded for both DPSs that there was not sufficient information to show green sturgeon were in danger of extinction. A minority of the team concluded green sturgeon are not currently in danger of extinction, but are likely to become so in the foreseeable future.

Adams, P., C. Grimes, J. Hightower, S. Lindley, and M. Moser.
2005. Green sturgeon (*Acipenser medirostris*) status review update. 35 p. U.S. Department of Commerce. This is an update to the previous 2002 status review. With additional scientific information (genetic analyses, oceanic distribution and behavior, freshwater distribution, and catch data), the BRT concludes that the Southern DPS is likely to become endangered in the foreseeable future throughout all of its range.

Adams, T., and P. Dalzell.
1994. Artisanal fishing. East-West Center Workshop on Marine Biodiversity Issues in the Pacific Islands. University of Hawaii. 19 p. Artisanal fishing, in this paper, refers to small-scale subsistence and commercial fishing. The authors were looking at the coastal zone including lagoons, shores, shallow reefs, outer slopes of reefs to abyssal depths. This type of fishing is usually non-target specific and carried out part-time. Success depends on the fish population density and species replacement. Artisanal fishing also includes destructive fishing practices, like using explosives or poisons, and can have a negative impact on overfishing slow-growing species. The authors looked at various Pacific Island nations and examined examples of species impacted by artisanal fishing. Most notable to the BHP, the article shows weight in tones and percentage of catch for the domestic fish market in Fiji and Palau.

Aswani, S.

2002. Assessing the effects of changing demographic and consumption patterns on sea tenure regimes in the Roviana Lagoon, Solomon Islands. Ambio 31:272-284. This paper looks at how sea tenure in Roviana Lagoon are mediated among the population, consumption, and the environment. It explains how the growth in population and consumption alters sea tenure and shows regional differences in sea tenure.

Aswani, S., and R. Hamilton.

2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumhead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. Environ. Conserv. 31:69-83. This article explains the rational behind establishing a network of small MPAs in the Western Solomon Islands. The researchers chose riparian and marine habitats protecting flagship species such as BHP. MPAs were most effective if chosen using biological and sociocultural rational in this region. Biological rational includes (1) protecting vulnerable species and habitat, (2) protecting susceptible life history stages and (3) enhancing fisheries productivity in the region. The sociocultural factors that went into designing MPAs took into account that adjacent portions of the reef could be controlled by different customary chiefs or elders. Effective MPAs must include consideration of customary sea tenure as well as biological factors.

Bellwood, D.

1994. A phylogenetic study of the parrotfishes family Scaridae (Pisces: Labroidei), with a revision of genera. Rec. Aust. Mus. 20:1-86. The author looks at the comparative morphology of Scaridae. The main objectives of the paper are to assess monophyly of the family, identify groups of species within the family, and determine phylogenetic relationships of groups. They used osteology and soft anatomy. Pictures of the BHP's jaws are featured, and the genus *Bolbometopon* is mentioned.

Bellwood, D., and J. Choat.

1989. A description of the juvenile phase colour patterns of 24 parrotfish species (family Scaridae) from the Great Barrier Reef, Australia. Rec. Aust. Mus. 41:1-41. This paper gives descriptions of juvenile fish found on the Great Barrier Reef. Field observations and fresh and preserved specimens of BHP from all the locations listed were analyzed. A description of coloring, fin orientation, body form, and ecology are given.

Bellwood, D., and J. Choat.

1990. A functional analysis of grazing in parrotfishes (family Scaridae): the ecological implications. Environ. Biol. Fishes 28:189-214. Here, it was investigated whether parrotfishes (Scarids) have a uniform feeding mode by looking at behavioral and morphological studies. The authors looked at six factors including (1) jaw morphology, (2) bite form, (3) feeding rates, (4) bite rate, (5) bite speed and (6) feeding microhabitat utilization patterns (field observations). They focused on the oral jaw because it was a visible aspect of feeding behavior and probably influenced feeding preferences. In the 24 species they studied on the Great Barrier Reef, they found there are two groups, the excavators and the scrapers. Excavators remove pieces of strata, while scrapers remove

the surface algae from the strata. BHP were found to be excavators based on the first and second factor. The authors also found they have a low feeding rate, leave visible scars on the reef when feeding, and refer convex feeding surfaces. In Bellwood 1986, the diet of BHP was found to be 50% live coral, mostly *Acropora* species.

Bellwood, D., A. Hoey, and J. Choat.
2003. Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. Ecology Letters 6:281-285. The authors wanted to quantify bioerosion caused by the grazing activity of parrotfishes. They looked at 44 sites around the Indo-Pacific region (4 sites at each of the locations listed). Erosion rates were calculated using bite rates, bite scar volumes and fish abundances. The GBR locations were used as a baseline since there was no directed fishery for parrotfish. BHP was found to be the largest bioeroder on the outer shelf reefs on the GBR. Schools of 30 to 50 individuals were seen. Bioerosion rates were calculated to be 2.33 m^3 or 5.69 tones of carbonate per year feeding mostly on live scleractinian corals. The only sites where bioerosion from BHP was apparent were the GBR sites and Rowley Shoals, both protected marine areas. All other sites were not impacted by bioerosion. BHP were found in Togean Islands, Pohnpei, Kosrae, Tahiti and Moorea in low density. The authors suggest the loss of parrotfish will change the coral community structure and cause structural instability.

Bellwood, D., T. Hughes, C. Folke, and M. Nyström.
2004. Confronting the coral reef crisis. Nature 429:827-833. This paper is a review of the ecological roles of critical functional groups in reef environments. They wanted to understand resilience in these environments and how to avoid phase shifts to degraded systems. The authors looked at species richness and the composition of functional groups. The results from this paper have implications for restoration of degraded reefs, fisheries management, MPAs and biodiversity hot spots.

Bellwood, D., and O. Schultz.
1991. A review of the fossil record of the parrotfishes (Labroidei:Scaridae) with a description of a new *Calotomus* species from the middle miocene (Badenian) of Austria. Annalen des Naturhistorischen Museums in Wien 92:55-71. The paper reviews 7 fossil species, two of the fragments coming from *Bolbometopon*. A new species from Austria is identified.

Bellwood, D. R., and J. H. Choat.
2011. Dangerous demographics: The lack of juvenile humphead parrotfishes *Bolbometopon muricatum* on the Great Barrier Reef. Coral Reefs 30:549-554. This paper describes the demographic pattern of BHP on the GBR and highlights the lack of observed recruitment. This feature may place the GBR population in a higher risk category than previously considered.

Brodeur, R. D., C. E. Mills, J. E. Overland, G. E. Walters, and J. D. Schumacher.
1999. Evidence for a substantial increase in gelatinous zooplankton in the Bering Sea, with possible links to climate change. Fish. Oceanogr. 8:296-306. This paper shows that there has been an increase in large medusae in the Eastern Bering Sea over the time period

1979-1989, followed by a more pronounced increase in the 1990s. This may be due to anthropogenic impacts or an oceanographic regime shift.

Brothers, E., and R. Thresher.
1985. Pelagic duration, dispersal, and the distribution of Indo-Pacific coral-reef fishes. The Ecology of Coral Reefs 3:53-69. The authors investigated whether long larval duration correlates with broad dispersal and consequent broad distribution of fishes from the Eastern Pacific to remote islands like the Hawaiian Islands. They looked at the duration of pelagic larval stage development by examining the otolith of newly recruited individuals to the reef. The results suggest long pelagic durations are critical for colonization in geographically isolated areas. Also, due to passive drifting times exceeding larval pelagic life, colonization probably only takes place during strong countercurrents and is intermittent. This paper documents 31 pre-transition daily increments for 1 individual of BHP, suggesting that this corresponds to the pelagic larval duration for this species.

Butler, J., A. DeVogelaere, R. Gustafson, C. Mobley, M. Neuman, D. Richards, S. Rumsey, B. Taylor, and G. VanBlaricom.
2009. Status Review Report for Black Abalone (*Haliotis cracherodii* Leach, 1814). (NMFS Southwest Region, ed.) 135 p. U.S. Department of Commerce, Long Beach. This is an ESA status review for the black abalone. There was significant loss of the abalone population from Withering Syndrome. Legal harvest was suspended in 1993. The BRT team voted unanimously that without identification, development, and implementation of effective measures to counter population effects from Withering Syndrome, black abalone are likely to become effectively extinct in 30 years throughout all of their range.

Calcinai, B., G. Bavestrello, and C. Cerrano.
2005. Excavating sponge species from the Indo-Pacific Ocean. Zool. Stud. 44:5-18. This paper gives a description of six excavating sponge species in the Indo-Pacific. BHP was observed feeding on the sponge, *Cliona albimarginata* in Bunaken National Park (North Sulawesi, Indonesia).

Carpenter, K., and V. Springer.
2005. The center of marine shore fish biodiversity: the Philippine Islands. Environ. Biol. Fishes 72:467-480. This paper suggests that the Philippine Islands are the center of marine biodiversity, based on examination of geographic patterns of species richness and occurrences. This hypothesis is consistent with known patterns of vicariant and integrative events of land masses in the area.

Chan, T., Y. Sadovy, and T. Donaldson.
2007. IUCN status of *Bolbometopon muricatum*. Summary of BHP physical characteristics, habitat, spawning behavior, demography and threats. Also included are reasons and suggestions for protecting the fish. The authors give relative abundance data at locations around the world (these locations are given and sited on a Google map by the BRT team).

Choat, J., L. Axe, and D. Lou.
1996. Growth and longevity in fishes of the family Scaridae. Mar. Ecol. Prog. Ser. 145:33-41. Size-age plots were determined from 7 species, *Chlorurus gibbus*, *C. sordidus*, *Scarus frenatus, S. niger. S. psittacus, S. nvulatus,* and *S. schelgeli*. There was a linear relationship between sagittal increments and sagittal weights meaning there was continuous growth of the sagittal thickness over the fish's life span. All fish were protogynous with sex-specific patterns. Males were typically larger and younger than similar-sized females.

Choat, J., C. Davies, J. Ackerman, and B. Mapstone.
2006. Age structure and growth in a large teleost, *Cheilinus undulatus*, with a review of size distribution in labrid fishes. Mar. Ecol. Prog. Ser. 318:237-246. The authors look at the age-based demographics for *Cheilinus undulatus* in Northeastern Australia. They compare this fish to BHP saying it is more closely related to it than any of the other large wrasses. They also gave a latitudinal range for BHP of 30°N to 30°S, living in coral reef environments at depths of 2 to 35 m.

Choat, J., and J. Randall.
1986. A review of the parrotfishes (family Scaridae) of the Great Barrier Reef of Australia with description of a new species. Rec. Aust. Mus. 38:175-228. This paper describes the family Scaridae and gives a good summary description of morphology, physiology and habitat of BHP in the Great Barrier Reef. It gave a quantitative and qualitative assessment at multiple locations at GBR: Reef 21-072 (21°08S') had 5 adults, Elusive Reef was moderately abundant (21°06S'), small numbers were observed at Flinders Reefs, Herald, and Lihou Cays in the Coral Sea. No fish were seen at Creal, Little Bugatti, White tip, Little Stevens Reefs (21°36S').

Choat, J., and D. Robertson.
2002. Age-Based Studies of Coral Reef Fishes in Sale, P.F. *In:* Coral Reef Fishes, p. 57-80. Academic Press, San Diego. Here, the authors were interested in understanding age-based dynamics for coral reef fishes. They indicated that the best method for determining age is counting the annuli (sections of the sagittal otoliths). Next, they outlined differences between temperate and tropical reef fish and possible difficulties researchers could face when determining ages of tropical fish using methods employed on temperate fishes. They wanted to see if there was a phylogenetic influence on growth, and indicated most reef fish are perciforms with dispersive larvae. Other than that, they could make no generalizations across taxon. They tested five hypotheses using Acanthurids and Scarids and compared them to their Atlantic counterparts. The hypotheses were: (1) is the distribution of life-spans consistent or does it vary among regions, (2) is there a predictable relationship between body size and maximum age, (3) are there taxon specific patterns in growth curves, (4) are maximum age estimates and growth parameters consistent over time, and (5) in protogynous species, are size and age distribution concordant? The answers they found were the following: otolith growth patterns differ in Atlantic vs. West Pacific counterparts - they are thicker in Atlantic fish. Age to body size patterns differ from Atlantic to West Pacific fish; scarids have a predictable pattern, while acanthurids have no age to body size pattern. There is a positive relationship between

maximum age and latitude for West Pacific fish, but not those from the Atlantic due to sea-surface temperature influences. Finally, the pattern of age and body size is too complex for protogynous species because often the small mature females are the oldest rather than the large terminal males.

Colin, P., and I. Clavijo.
1988. Spawning activity of fishes producing pelagic eggs on a shelf edge coral reef, southwestern Puerto Rico. Bull. Mar. Sci. 43:249-279. Here, 26 species of reef fish were observed spawning on the shelf-edge of the coral reef in Puerto Rico. All produced pelagic eggs. The timing of spawning was determined by the need to coordinate activity of adults and not by oceanographic conditions.

Colin, P., Y. Sadovy, and M. Domeier.
2001. Manual for the study and conservation of reef fish spawning aggregations. Society for the Conservation of Reef Fish Aggregations Special Publications 1–98 p. This manual examines past and present methods for studying spawning aggregations and offers standardized methods. It was written in hopes of standardizing data gathered about coral reef fish aggregations and to learn the impact of fishing on spawning aggregations.

Cooper, A., and M. Mangel.
1999. The dangers of ignoring metapopulation structure for the conservation of salmonids. Fish. Bull. 97:213-226. The authors create a model of salmonid metapopulations highlighting source and sink relationships. Recognizing these data when implementing management plans can lead to more successful management strategies.

Couture, E., and C. Chauvet.
1994. Growth of the green humphead parrotfish (*Bolbometopon muricatum*) and its exploitation in New Caledonia. Twenty-fifth Regional Technical Meeting on Fisheries, Noumea, New Caledonia. The authors used the Ricker maximum yield per recruit model as a fishing stock assessment tool. The BHP grows slowly, and in this study the oldest individual was 16 years old using scale annuli increments. The northern stock in New Caledonia is well exploited and vulnerable to seine fishing. Using the model, the authors found fishing can be increased to twice the current level and still maintain the same yield per recruit. Geographic research still needs to be conducted around this area.

Donaldson, T., and N. Dulvy.
2004. Threatened fishes of the world: *Bolbometopon muricatum* (Valenciennes 1840) (Scaridae). Environ. Biol. Fishes 70:373. Summary of the fish's physical characteristics, habitat, spawning behavior, demography and threats.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas.
2009. Ocean Acidification: The Other CO_2 Problem. Annu. Rev. Mar. Sci. 1:169-192. This paper reviews the literature for biological responses to changes in CO_2 concentration. Calcifying species will likely experience reduced calcification and growth rates. Carbon fixation rates will likely increase for photosynthesizing species.

Dulvy, N., and N. Polunin.

2004. Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. Animal Conservation 7:365-374. Traditional and current methods were used to make inferences on the conservation status of BHP. For the traditional assessment, 13 islands in the Lau group of Fiji were used. Chiefs, village government officials, and fishers were given a questionnaire asking (1) the last time the fish was captured on the island and (2) the frequency of capture. Local knowledge indicated that the fish was rarely captured. Methods of capture include "leaf drives" (a form of net or seine fishing) and hand or gun spears. The authors also used current reviews of literature and grey literature to determine the abundance across the fish's range. They suggest the fish is most abundant in areas with the least fishing pressure (Great Barrier Reef, Seychelles, Sipidan Islands, Wake Island, Rowley Shoals, Papua New Guinea and the Solomon Islands). The reasons for reduced fishing pressure include reserve status of the area, a remote location not easily accessible or low human population density. They found a negative correlation between fishing intensity and local density in the Indo-Pacific region.

Dulvy, N., and Y. Sadovy.

2003. Extinction vulnerability in marine populations. Fish and Fisheries 4:25-64. The authors compiled a list of 133 local, regional and global extinctions of marine taxa. They noticed that there was a 53-year lag time between when the species was last sighted and the reported date of extinction. Often marine extinctions are underestimated because of low-detection power of the species itself. Causes of extinctions include exploitation, habitat loss, invasive species, climate change, pollution and disease. The authors suggest learning about the recovery, spatial dynamics and connectivity of subpopulations before we can understand the nature of response to a severe depletion. Marine taxa may exhibit vulnerability similar to mammals, birds and butterflies.

Edwards, M., and A. J. Richardson.

2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430:881-884. This paper examines ecosystem responses to climate changes and suggests that the seasonality of migration and reproduction is key towards understanding a species vulnerability to climate change. The match or mismatch of trophic levels and functional groups over the seasonal cycle will determine the community-level response.

Ellison, J.

2009. Wetlands of the Pacific Island Region. Wetlands Ecology and Management 17:169-206. This is a review of wetlands in American Samoa, Federated States of Micronesia, Fiji, French Polynesia, Kiribati, Marshall Islands, New Caledonia, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna. Wetlands are broken down into seven different systems: coral reefs, seagrass beds, mangrove swamps, riverine, lacustrine, fresh water swamp forests and marshes. There's a table outlining the number of species at wetland locations by country. They also talk about international management plans.

Fine, M., and D. Tchernov.
2007. Scleractinian coral species survive and recover from decalcification. Science 315:1811. This paper demonstrated that 2 species of Mediterranean scleractinian corals could survive an extended period of acidity (decrease of ~1 pH unit) and recover. The polyps decalcified but did not die.

Foley, P.
1997. Extinction models for local populations. *In:* Metapopulation Biology (I. Hanski, and M. Gilpin, eds.), p. 215-246. Academic Press, New York. This section reviews stochastic models of extinction within local populations. The main model represented is an analytical model of environmental stochasticity that fluctuates between a maximum (controlled by resource caps) and extinction (controlled by the number needed to successfully reproduce).

Forest Ecosystem Management Assessment Team.
1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. 1039 p. This paper was written to evaluate management alternatives of northern spotted owl habitat that comply with existing laws. Timber operations were stopped when northern spotted owls were listed as threatened. There were 10 ecosystem management strategies that were evaluated for the northern spotted owl, the marbeled murrelet, anadromous fish and late-successional/old-growth ecosystems. Seven of the ten options were considered to maintain a well-distributed habitat.

Ghiselin, M.
1969. The evolution of hermaphroditism among animals. Q. Rev. Biol. 44 p. This is a review of the selective advantages of hermaphroditism. Three advantages are when it is hard to find a mate, when one sex benefits from being larger or smaller, and when there are small, genetically isolated populations.

Gilman, E., H. Van Lavieren, J. Ellison, V. Jungblut, L. Wilson, F. Areki, G. Brighouse, J. Bungitak, E. Dus, M. Henry, I. Sauni Jr., M. Kilman, E. Matthews, N. Teariki-Ruatu, S. Tukia, and K. Yuknavage.
2006. Pacific Island Mangroves in a Changing Climate and Rising Sea. UNEP Regional Seas Reports and Studies No. 179. United Nations Environment Programme, Nairobi, Kenya. This paper reviews mangrove areas throughout the Pacific Basin and presents national and regional needs with respect to key vulnerabilities.

Gilman, E. L., J. Ellison, N. C. Duke, and C. Field.
2008. Threats to mangroves from climate change and adaptation options: A review. Aquat. Bot. 89:237-250. This paper reviews the climatic threats to mangrove forests. Sea level changes pose the most severe negative threat. It is noted that increased temperature and CO_2 levels are likely to increase mangrove productivity and expand the geographic range.

Gilpin, M., and M. Soule.
1986. Minimum viable populations: processes of species extinction. *In:* Conservation Biology: the Science of Scarcity and Diversity (M. Soule, ed.). Sinauer, Sunderland, MA. This chapter looks at population vulnerability analysis (PVA) as an estimate for determining minimum viable population (MVP). PVA identifies three important factors: (1) Working with a single species, (2) looking at population over time, and (3) including critical aspects of a species by distribution, size, and genetics that govern its probable decay from existence to extinction.

Gladstone, W.
1986. Spawning behavior of the bumphead parrotfish *Bolbometopon muricatum* at Yonge Reef, Great Barrier Reef. Jpn. J. Ichthyol. 33:326-328. The author observed spawning between two BHP on the 20th day of the lunar moon at Yonge Reef. It occurred at the mouth of a coral gutter on the edge of a channel on an outgoing tide. From a school of about 100 fish, two separated and spawned. He also mentioned observing schools of 20 to 100 fish at Lizard Island.

Guinotte, J. M., and V. J. Fabry.
2008. Ocean acidification and its potential effects on marine ecosystems. Ann.N. Y. Acad. Sci. 1134:320-342. This paper examines the impact of ocean acidification on different marine ecosystems. The impact on the coral reef ecosystem is expected to be negative. However seagrasses (and mangroves) are expected to increase in productivity and habitat range.

Gustafson, R., W. Lenarz, B. McCain, C. Schmitt, W. Grant, T. Builder, and R. Methot.
2001. Status Review of Pacific Hake, Pacific Cod, and Walleye Pollock from Puget Sound, Washington. U.S. Department of Commerce. This is an ESA status review for Pacific hake, Pacific cod, and walleye salmon. DPSs were determined for all three species based on various data from behavior to genetics to habitat. All three are not presently in danger of extinction in the foreseeable future in this DPS. A minority of the BRT determined that the Pacific cod DPS could be in danger in the future.

Hamilton, R.
2003. The role of indigenous knowledge in depleting a limited resource─a case study of the bumphead parrotfish (*Bolbometopon muricatum*) artisanal fishery in Roviana Lagoon, Western Province, Solomon Islands. Putting Fishers' Knowledge to Work: Conference Proceedings. In this paper, the author looks at the negative effects of new technology and economic pressure on a fishery, and how the use of traditional knowledge is not always sustainable. Traditional fishermen targeted aggregations of BHP at specific shallow-water sites during certain phases of the moon. They fished with a wooden spear from a dug out canoe. In the 1980s, a fishery opened up for BHP increasing the pressure on the stock. Now, coupled with new technology for fishing, these fish are being overfished locally.

Hamilton, R.

2004. The Demographics of Bumphead Parrotfish (*Bolbometopon muricatum*) in the Lightly and Heavily Fished Regions of the Western Solomon Islands. Doctor of Philosophy 295 p. The University of Otago. This thesis covers the ecology and status of the BHP (Topa) fishery in Roviana Lagoon. The author collected local knowledge on Topa ecology and was interested in a historical perspective of ecological and social changes in the fishery. He suggested that new technologies and market driven fisheries have contributed to overfishing of this fish. Fishery data was compared to Tetepare Island, Nusabanga and Munda (the latter two are in Roviana Lagoon). He collected information on the biology of this species in Roviana Lagoon and stated that Topa posses slow population turnover rates. He also had suggestions on management practices for the Roviana Lagoon fishery.

Hamilton, R., S. Adams, and J. Choat.

2007. Sexual development and reproductive demography of the green humphead parrotfish (*Bolbometopon muricatum*) in the Solomon Islands. Coral Reefs 27:153-163. The authors looked at the reproduction anatomy of BHP from three locations (Tetepare Island, Nusabanga and Munda (the latter two are in Roviana Lagoon)). They found they are largely gonochoristic with a anatomically nonfunctional hermaphrodite phase. All males pass through an immature female phase.

Helfman, G., and J. Randall.

1973. Palauan fish names. Pac. Sci. 27:136-153. Palauan name with scientific equivalents for local coral reef fishes.

Hilborn, R., T. Quinn, D. Schindler, and D. Rogers.

2003. Biocomplexity and fisheries sustainability. Proc. Natl. Acad. Sci. U.S.A.100:6564. Here, the authors use the sockeye salmon fishery in Bristol Bay, Alaska as an example of a sustainable fishery. They state that the fact that individual populations have unique characteristics is important for maintaining the entire population. With climate change in the past, some populations did better than others at different periods.

Hixon, M. A., and G. P. Jones.

2005. Competition, predation, and density-dependent mortality in demersal marine fishes. Ecology 86:2847-2859. This paper demonstrated that competition-mediated predation was a key factor determining community structure of coral reef fishes. Predation was an important proximate effect, yet the primary density-dependent factor was competition.

Hodgson, G.

1999. A global assessment of human effects on coral reefs. Mar. Poll. Bull. 38:345-355. This paper attempts to define objective measures of reef health based on a number of indicator organisms and other parameters affected by human activity. This program is called Reef Check and uses volunteers trained by marine scientists to conduct surveys of reef health. Surveys over 2.5 months of 300 reefs in 31 countries were reviewed. Overfishing, even in MPAs, was a major factor contributing to declining reef health. BHP were found to be affected by overfishing, dynamite fishing, and cyanide fishing.

Hoey, A., and D. Bellwood.
2008. Cross-shelf variation in the role of parrotfishes on the Great Barrier Reef. Coral Reefs 27:37-47. The authors quantify the roles of parrotfishes on the reefs in northern Great Barrier Reef. They describe how these roles vary across the continental shelf and among habitats within a single shelf. They also discuss the roles of parrotfish in eroding, grazing, coral predation, and sediment reworking. Twenty-four species were quantified over three reefs in three cross-self regions. BHP contribute to 87.5 % of the erosion and 99.5% of coral predation on the outer-shelf. There was little evidence of selective feeding (chart of bites on coral species). Also, the authors show the biomass of BHP present (only found in the outer shelf).

Hunter, C.
2001. Review of status of coral reefs around American Flag Pacific Islands and assessment of need, value, and feasibility of establishing a Coral Reef Fishery Management Plan for the Western Pacific Region. 31 p. Western Pacific Regional Fishery Management Council. This paper talks about the potential need for a Coral Reef Fisheries Management Plan under the Western Pacific Region. There is a need for baseline information to institute management measures. Coral reef area is presented for each region.

IPCC.
2007. Climate Change 2007: Synthesis Report. This report summarizes the consensus view for climate change among the Intergovernmental Panel on Climate Change.

Jennings, S.
1998. Cousin Island, Seychelles: a small, effective and internationally managed marine reserve. Coral Reefs 17:190-190. This is a brief summary of Cousin Island. It was designated as a bird reserve in 1968 and this management has also protected the marine environment. BHP is still commonly seen here.

Jennings, S., and N. Polunin.
1995. Comparative size and composition of yield from six Fijian reef fishes. J. Fish Biol. 46:28-46. This paper reviews the size and composition of finfish yield from six Fijian reef fisheries using catch records from voluntary log books (172 log books) from October 1992, February and June 1993. Catches were dominated by Serranidae and Lethrinidae. The Fijian name for BHP was given but there was no quantity of catch.

Jennings, S., and N. Polunin.
1996. Impacts of fishing on tropical reef ecosystems. Ambio 25:44-49. The authors explore whether fishing type leads to shifts in ecosystem function and the extent to which this is preventable and reversible. They also offer alternative approaches to management to obtain the maximum yield while minimizing the probability of unwanted ecosystem shifts. They mostly look at the use of explosives and poison and their direct and indirect impacts.

Johannes, R.
1978. Traditional marine conservation methods in Oceania and their demise. Ann. Rev. Ecol. Syst. 9:349-364. In this paper, the author examines past and present methods of marine

resource management in Oceania. They give examples of local enforcement (including a table of methods with location employed). They also talk about the impacts of westernization on Pacific Islands. Specifically, there's a paragraph on spearfishing that says BHP are vulnerable to this type of fishing. At the time this was written, Mokil (part of Micronesia) and Vanuatu had banned night spearfishing in parts of the islands. Also in Satawal (part of Micronesia) spearfishing had also been banned. There was a suggestion of Palau considering a ban on night spearfishing because BHP are being overharvested.

Johannes, R.
1981. Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia, University of California Press. This book is written by a marine biologist and investigates traditional fishing in Palau. Some specifics refernces to BHP: They were traditionally a favorite target and were fished at night using spears. Pressure on the fish increased with the invention of speargun and underwater flashlights. There's another section on Palauan naming and a reference to them eating urchins (although under a different Palauan name). For spawning, they are said to contain well-developed eggs from the 1st to the 9th day of the lunar month and form spawning aggregations.

Kitalong, A., and P. Dalzell.
2001. A preliminary assessment of the status of inshore coral reef fish stock in Palau. 43 p. South Pacific Commission, Noumea, New Caledonia. This paper compiles information from length frequency from 1990 to 1991. The authors suggested fish are moderately exploited because minimum capture length is similar to the optimum length. Specific for BHP include: From 1976 to 1990, BHP made up to 10.4% of the landings. It is perceived by fishermen to be getting scarcer and there was a decrease over time in landing volume. They are caught almost exclusively by spearfishing. The authors suggest a size limit of 70 cm and prohibiting exports.

Krahn, M., M. Ford, W. Perrin, P. Wade, R. Angliss, M. Hanson, B. Taylor, G. Ylitalo,
M. Dahlheim, J. Stein, and R. Waples.
2004. 2004 Status Review of Southern Resident Killer Whales (*Orcinus orca*) under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-NWFSC-62, 73 p. This is an update of the ESA status review for the Southern Resident killer whale. This update was done after a lawsuit where the court decided NMFS was in error considering the Southern Resident part of the global population when determining DPS. The BRT found *O. orca* were part of a subspecies including all resident, fish-eating killer whales of the North Pacific. Southern Resident killer whales do occupy a DPS seperate from the northern populaiton that includes residents and offshore whales. The team found there was an probability of extinction of less than 0.1 to 3% in 100 years using a PVA analysis.

Krahn, M., P. Wade , S. Kalinowski, M. Dahlheim, B. Taylor, M. Hanson, G. Ylitalo, R. Angliss,
J. Stein, and R. Waples.
2002. Status Review of Southern Resident Killer Whales (*Orcinus orca*) under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-NWFSC-54, 133 p. This is an ESA status review of the Southern Resident killer whale. The BRT found a greater than 10% probability of extinction in 100 years. Genetic

evidence yielded looking into the possibility of a DPS, but it was determined this population was not a DPS of the global species. There was a 20% decline in the population over a 27-year period possibly due to environmental sources.

Lagerloef, G. S. E., G. T. Mitchum, R. Lukas, and P. Niiler.
1999. Tropical Pacific near-surface currents estimated from altimeter, wind and drifter data. J. Geophys. Res. 104:313-323. This paper presents the OSCAR data product which uses remotely sensed sea surface altimetry and wind fields to construct global ocean current fields.

Lande, R.
1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. Am. Nat. 142:911. This paper exams factors affecting the demography of a single population to determine the relative risks of extinction from demographic stochasticity, environmental stochasticity, and random catastrophes. Large populations are most at risk from environmental stochasticity and random catastrophes and the effect depends on growth rate and magnitude and frequency of the disaster.

Leis, J.
2007. Behavior as input for modelling dispersal of fish larvae: behavior, biogeography, hydrodynamics, ontogeny, physiology and phylogeny meet hydrography. Mar. Ecol. Prog. Ser. 347:185-193. This paper focuses on the pelagic, dispersive stage of demersal, teleost fishes' behavior. It gives a summary of the kind of documented behaviors of fish larvae that are relevant to dispersal.

Leis, J., and D. Rennis.
1983. The larvae of Indo-Pacific coral reef fishes, University of Hawaii Press, Honolulu, Hawaii. A section of this book is specifically about parrotfish and offers a description of adult morphology, spawning mode, and larval development and morphology.

Lieske, E., and R. Myers.
1996. Coral Reef Fishes: Caribbean, Indian Ocean and Pacific Ocean including the Red Sea. This is a general guide to coral reef fishes, their distriubtion, abundance, and ecology.

Lo-Yat, A., S. D. Simpson, M. Meekan, D. Lecchini, E. Martinez, and R. Galzin.
2010. Extreme climatic events reduce ocean productivity and larval supply in a tropical reef ecosystem. Global Change Biology 2010. DOI:10.1111/j.1365-2486.2010.02355.x. This paper presents evidence suggesting that low-recruitment events may be linked to shortages of planktonic food for larval coral reef fishes. These shortages of food may be caused by warm ocean temperatures such as El Niño.

Middleton, D., and R. Nisbet.
1997. Population persistence time: estimates, models, and mechanisms. Ecol. Appl. 7:107-117. This paper uses data from the Acorn Woodpecker from Stacey and Taper 1992 in three models to help distinguish the effects of density dependence on birth or death rates.

The models used are (1) of a closed population with density-independence vital rates and an upper limit to population size, (2) of a regulated closed population, and (3) of a regulated subpopulation with immigration and emigration.

Mills, C. E.
2001. Jellyfish blooms: are populations increasing globally in response to changing ocean conditions? Hydrobiologia 451:55-68. This paper reviews a number of case studies of jellyfish ecology and attempts to explain blooms and changes in abundance (both increases and decreases). Disturbance and overfishing of the oceans is thought to be redirecting energy historically directed towards fish production now into jellyfish production. The mechanisms are complex and cumulative.

Mundy, B. C., R. Wass, E. DeMartini, B. Greene, B. Zgliczynski, R. E. Schroeder, and C. Musberger.
2011. Inshore fishes of Howland Island, Baker Island, Jarvis Island, Palmyra Atoll, and Kingman Reef. Atoll Res. Bull. 585:1-131. This paper presents a checklist of fish species encountered at selected areas of the Pacific Remote Island Areas.

Naseer, A., and B. Hatcher.
2004. Inventory of the Maldives' coral reefs using morphometrics generated from Landsat ETM+ imagery. Coral Reefs 23:161-168. The authors present exact measures of number, area, and basic morphometric statistics for a single reef in the Maldivian Archipelago from Landsat-7 ETM+ images. They compare these methods with previous approaches.

Oleson, E., C. Boggs, K. Forney, M. Hanson, D. Kobayashi, B. Taylor, P. Wade, and G. Ylitalo.
2010. Status Review of Hawaiian Insular False Killer Whales (*Pseudorca crassidens*) under the Endangered Species Act. U.S. Dep. Commer, NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-22, 140 p + Appendices. ESA status review of Hawaiian insular false killer whales.

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2007. Response of eelgrass *Zostera marina* to CO_2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats. Mar. Ecol. Prog. Ser. 344:1-13. This experimental study indicated that increased CO_2 levels increase the reproductive rate and growth rate of eelgrass.

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2009. Chapter 2 Vulnerability of Marine Turtles to Climate Change. *In:* Advances in Marine Biology (W. S. David, ed.), Volume 56, p. 151-211. Academic Press. This paper reviews the vulnerability of marine turtles to climate change. Of note is that seagrass beds, an

important foraging ground for some sea turtles, are thought to benefit from forseeable climate change.

Polovina, J. J., E. A. Howell, and M. Abecassis.
2008. Ocean's least productive waters are expanding. Geophysical Research Letters 35:3. This paper examines a time series of SeaWiFS remotely sensed ocean color and documents a time trend of shrinking productive areas on a global scale.

Polovina, J. J., P. Kleiber, and D. R. Kobayashi.
1999. Application of TOPEX-POSEIDON satellite altimetry to simulate transport dynamics of larvae of spiny lobster, *Panulirus marginatus,* in the Northwestern Hawaiian Islands, 1993-1996. Fish. Bull. 97:132-143. This paper uses geostrophic flow fields from remotely sensed sea surface altimetry to simulate larval transport of lobster.

Rahmstorf, S.
2007. A semi-empirical approach to projecting future sea-level rise. Science 315:368-370. This paper presents a methodology to predict future sea-level rise from changes in global temperature. The predicted sea-level rise in 2100 is 0.5 – 1.4 meters above the 1990 level.

Randall, J.
2005. Reef and Shore Fishes of the South Pacific; New Caledonia to Tahiti and the Pitcairn Islands, University of Hawaii Press, Honolulu, Hawaii. Summary of physical description, biology, and distribution.

Randall, J., G. Allen, R. and Steene.
1997. Fishes of the Great Barrier Reef and Coral Sea, University of Hawaii Press, Honolulu, Hawaii. Description of biology, ecology and habitat range.

Richards, A., M. Lagibalavu, S. Sharma, and K. Swamy.
2001. Fiji: Fisheries Resources Profiles. Forum Fisheries Agency Report No. 94/4, 231 p. This report summarizes the marine natural resources in Fiji.

Richards, B. L., I. D. Williams, M. O. Nadon, and B. J. Zgliczynski.
2011. A towed-diver survey method for mesoscale fishery-independent assessment of large-bodied reef fishes. Bull. Mar. Sci. 87(1):DOI: 10.5343/bms.2010.1019. This paper demonstrates a new technique for quantifying the distribution and abundance of large reef fishes. BHP were in this category of fishes which are difficult to assess using conventional methodologies.

Richardson, A. J., A. Bakun, G. C. Hays, and M. J. Gibbons.
2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends Ecol. Evol. 24:312-322. This paper discusses the proliferation of gelatinous zooplankton in many ecosystems. The shift from fish-dominated to jellyfish-dominated state can occur rapidly and may be persistent. This group of organisms is understudied and needs better understanding.

Riesenberg, S.
1968. The Native Polity of Ponape. Washington, D.C. Traditional cultural practices in Ponape are discussed, with focus on community structure, ceremonial rites, regional governance, and utilization of living resources.

Rivera, M., K. R. Andrews, D. R. Kobayashi, J. L. K. Wren, C. Kelley, G. K. Roderick, and R. J. Toonen.
2011. Genetic analyses and simulations of larval dispersal reveal distinct populations and directional connectivity across the range of the Hawaiian grouper (*Epinephelus quernus*). J. Mar. Biol. 2011:1-11. This paper examines genetic patterns and oceanographic circulation patterns to infer patterns of colonization and linkage throughout the Hawaiian Archipelago.

Robertson, D., and R. Warner.
1978. Sexual patterns in the labroid fishes of the western Caribbean. II. The parrotfishes (Scaridae). Smithson. Contrib. Zool. 255:1-26. This paper describes protogynous sex change in 10 species of parrotfishes.

Rohmann, S., J. Hayes, R. Newhall, M. Monaco, R. and Grigg.
2005. The area of potential shallow-water tropical and subtropical coral ecosystems in the United States. Coral Reefs 1-14. The authors use GIS system-based analysis to estimate the potential area of shallow-water tropical and subtropical coral ecosystems within the EEZ of the United States.

Schlosser, I., and P. Angermeier.
1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. Proceedings from the Evolution of the Aquatic Ecosystem: Defining Unique Units in Population Conservation Symposium, Bethesda, Maryland. American Fisheries Society, p. 392-401. This paper illustrates 5 metapopulation models that describe spatial variability in the demographic process. These include: (1) the classic metapopulation model, (2) the mainland-island or source-sink model, (3) the patchy population model, (4) a hybrid model of 2 and 3, and (5) the nonequalibrium metapopulation model.

Smith, S.
1978. Coral-reef area and the contributions of reefs to processes and resources of the world's oceans. Nature 273:225-226. This paper suggests that coral reefs are an important part of the quantitative assessment of global resources. To determine this, the author looked at the area, calcium mass balance, and fisheries yield of reef systems. Reef fisheries were a potential indictor of the quantitative significance of coral reefs.

Smith, W. H. F., and D. T. Sandwell.
1997. Global seafloor topography from satellite altimetry and ship depth soundings. Science 277:1957-1962. This paper presents a high-resolution global bathymetric database primarily generated from remotely sensed sea surface height anomalies.. This allows

construction of a database even in the absence of actual soundings data from a ship or mooring.

Spalding, M., and A. Grenfell.
1997. New estimates of global and regional coral reef areas. Coral Reefs 16:225-230. Here, a new estimate for coral reef coverage is presented by the World Conservation Monitoring Centre by mapping emergent reef crest and very shallow reef system. The new estimate is 255,000 km² and is done using 1 km² grid. This challenges the old estimate made by Smith (1978) of 600,000 km².

Spalding, M., C. Ravilious, and E. Green.
2001. World atlas of coral reefs, University of California Press. This book presents a regional summary of coral reefs around the world.

Stanley, G. D.
2003. The evolution of modern corals and their early history. Earth-Sci. Rev. 60:195-225. This paper discusses the evolution of corals and hypothesizes that "naked coral" have appeared several times since the Triassic times, and may have allowed survival during the Permian mass extinction. Lack of fossils of non-calcifying corals make this hypothesis difficult to verify.

Stout, H., R. Gustafson, W. Lenarz, B. McCain, D. VanDoornik, T. Builder, and R. Methot.
2001a. Status Review of Pacific Herring (*Clupea pallasi*) in Puget Sound, Washington. U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-NWFSC-45, 175 p. This is an ESA status review of the Pacific herring in Puget Sound. The BRT concluded there was a DPS in the Georgia Basin, but the population here was not at risk of extinction now or in the future. They concluded that two stocks within this DPS, Cherry Point and Discovery Bay should be considered vulnerable on the IUCN redlist.

Stout, H., B. McCain, R. Vetter, T. Builder, W. Lenarz, L. Johnson, and R. Methot.
2001b. Status Review of Copper Rockfish, Quillback Rockfish, and Brown Rockfish in Puget Sound, Washington. U.S. Dept. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-NWFSC-46, 158 p. This is an ESA status review of the copper rockfish, the quillback rockfish, and the brown rockfish in Puget Sound. All three species were considered not at risk of extinction now or in the future and were suggested to be put on the IUCN redlist as "vulnerable" within the Puget Sound DPS.

Strahler, A.
1969. Physical Geography, John Wiley & Sons, Inc. This is a standard textbook on geography and has some tabular information that was used by the BRT.

Streelman, J., M. Alfaro, M. Westneat, D. Bellwood, and S. Karl.
2002. Evolutionary history of the parrotfishes: biogeography, ecomorphology, and comparative diversity. Evolution 56:961-971. Here, the authors use nuclear and mitochondrial DNA to explore the evolutionary history of parrotfish. The DNA tree is

broken down by reproductive characteristics and feeding mode. BHP is most closely related to *Cetoscarus bicolor*.

Sullivan, P. J., J. M. Acheson, P. L. Angermeier, T. Faast, J. Flemma, C. M. Jones, E. E. Knudsen, T. J. Minello, D. H. Secor, R. Wunderlich, and B. A. Zanetell.
2006. Defining and implementing best available science for fisheries and environmental science, policy, and management. Fisheries 31:460-463. A standard paper for issues dealing with "best available science". This paper defines the term, suggests its limits, and presents potential improvements for the future.

Thresher, R.
1984. Reproduction in Reef Fishes, T.F.H. Publications, Inc. Ltd., Neptune City, New Jersey. This book mentions that BHP is dichromatic and spawns in pairs (p. 232 and 233).

Vecsei, A.
2004. A new estimate of global reefal carbonate production including the forereefs. Global Planet. Change 43:1-18. This paper gives a comparison of methods assessing reefal carbonate production. Estimates for global reef area, production in the reef-flat to forereef transects, and production of the world's reefs are given.

Vucetich, J., M. Nelson, and M. Phillips.
2005. The normative dimension and legal meaning of endangered and recovery in the U.S. Endangered Species Act. Conserv. Biol. 1-9. This paper presents some of the definitive and operational aspects for ESA terms.

Wainwright, T., and R. Kope.
1999. Methods of extinction risk assessment development for U.S. west coast salmon. ICES J. Mar. Sci. 56:444-448.This paper examines using a 5-point scale to determine degree of extinction risk to Pacific salmon. They looked at population abundance, trends in individual populations, ecological and genetic effects of hatchery fish, changes in life history traits, selective harvest, trends in freshwater habitat condition and climate variation.

Waples, R., P. Adams, J. Bohnsack, and B. Taylor.
2007. A biological framework for evaluating whether a species is threatened or endangered in a significant portion of its range. Conserv. Biol. 21:964-974. This paper applies a simple test to determine whether the areas of the species range where it is currently at risk amount to a "significant portion" for evaluating listing under the Endangered Species Act. SPOIR is defined as "significant portion of its range". Significant portion is defined as a geographic area(s) that contains a population unit(s) that, if lost, would cause that entire species to be in danger of extinction or likely to be come so in the foreseeable future. The test involves determining, if the species were to extirpated from all areas where it is currently at risk, would the entire species then be at risk? If the answer is yes, then these areas represent a significant portion of the species' range. The paper goes on to give hypothetical and real world examples, including stating whether or not the scenario represented an SPOIR.

Wessel, P., and W. Smith.
1991. Free software helps map and display data. EOS Transactions 72:441. This paper presents a freeware software package developed at the University of Hawaii for mapping and graphing complex data.

Wood, C., J. Bickham, R. Nelson, C. Foote, and J. Patton.
2008. Recurrent evolution of life history ecotypes in sockeye salmon: implications for conservation and future evolution. Evolutionary Applications 1:207-221. This paper looks at the evolutionary history and future of three basic ecotypes of the sockeye salmon.

Wright, A., and A. Richards.
1985. A multispecies fishery associated with coral reefs in the Tigak Islands, Papua New Guinea. Asian Mar. Biol. 2:69-84. Here, the species composition and catch rates for the fishery in the Tigak Islands, Papua New Guinea are discussed. Data is given over a 13-month period starting in November 1980. Spearfishing was dominated by bolbo.

Zgliczynski, B., S. Sandin, I. Williams, R. Schroeder, M. Nadon, and B. Richards.
In prep. Status of International Union for Conservation of Nature (IUCN) red listed species in the U.S. Pacific Islands. J. Fish. Biol., Mar. Ecol. Prog. Ser., or Conserv. Biol. This paper is a summary of biennial surveys of IUCN Red listed species in 53 US Pacific Islands from 2000 to 2009. These data were collected from belt transects, stationary point counts and towed-diver surveys. Forty-four Red Listed species were observed including BHP. The probability of encountering a BHP in American Samoa, Hawaii and the Mariana Islands was zero, while in the Pacific Remote Island Areas (PRIAs) it was 0.12. BHP was listed by the IUCN as vulnerable status with decreasing trend.

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7. APPENDIX: GLOBAL ESTIMATION OF POPULATION

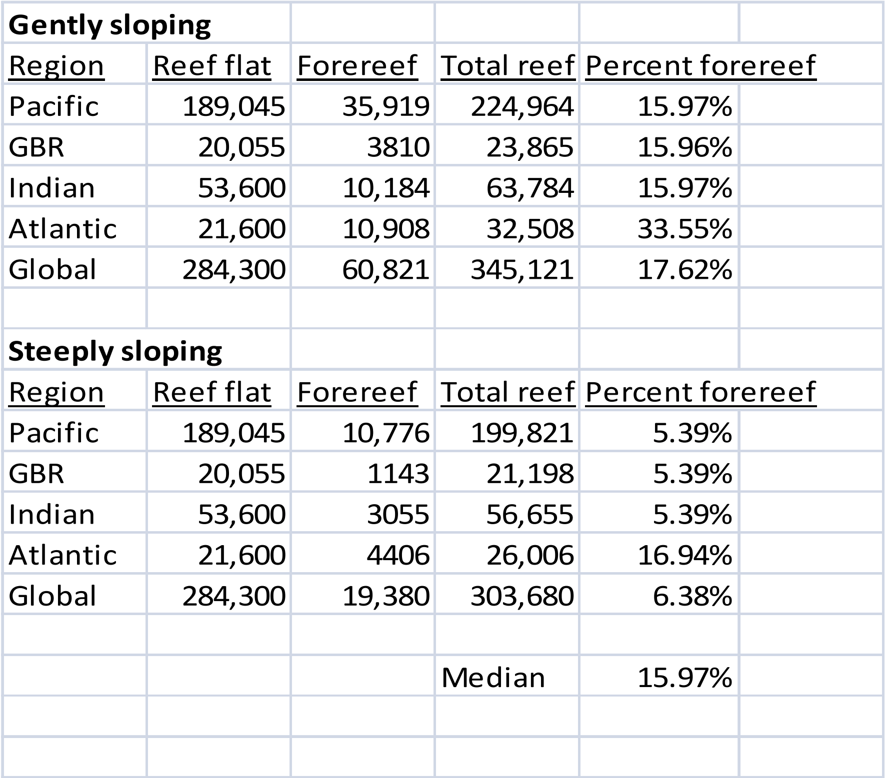
Geographic strata for bumphead parrotfish were gleaned from published and unpublished references that discuss the geographic range of bumphead parrotfish. This was supplemented by oral interviews of experts on Pacific and Indian Ocean and Red Sea fish biogeography. In all, 59 strata were identified which were primarily specific countries. It should be noted that other geographic strata located in or near the overall range polygon, but not known to have bumphead parrotfish presently or historically (e.g., Cook Islands, Tokelau, Nauru, British Indian Ocean Territory, etc.), were ignored in this exercise.

The 59 geographic strata were georeferenced using EEZ polygons (shape files) from the Flanders Marine Institute at http://www.vliz.be/vmdcdata/marbound/download.php which were extracted to files in ASCII format using the freeware software utility *shp2text*. Individual closed polygons were reconstructed either manually or by automated polygon identification in the R programming language using the subroutine *ashape*.

A global coral grid at 4-km resolution was downloaded from the World Resources Institute Reefs at Risk website http://www.wri.org/publication/reefs-at-risk#data. These global data were extracted to ASCII using the freeware utility *shp2text* and regridded into 0.03 degree latitude/longitude grids using the software Generic Mapping Tools (GMT; (Wessel and Smith, 1991). A variety of gridding increments were attempted; the 0.3 degree latitude/longitude increment was optimal with respect to minimizing both the number of duplicate and missing nodes. Assignment of coral pixel locations to EEZs was accomplished using a ray casting subroutine written in QuickBASIC v4.5. Area of each coral pixel was calculated using cubic polynomial conversion functions derived from tabled values of longitude and latitude distances as a function of latitude (Strahler, 1969).

The nominal area of coral derived from using this approach closely matched an early estimate (Smith, 1978) of global coral reef area. However, this is probably an overestimate of actual coral cover (Rohmann et al., 2005; Spalding and Grenfell, 1997) or habitable coral reef area for bumphead parrotfish. Therefore, the coral data were adjusted in 3 steps prior to using them in a bumphead parrotfish population estimate. First, the areal data were standardized to an average correction factor (56.85%) based on measurements from the Maldives (Naseer and Hatcher, 2004), Hawaii (Spalding et al., 2001), and American Samoa (Hunter, 1995). This procedural step scales the global grid to a better estimate of actual coral cover. Second, the areal data were adjusted for the amount of forereef habitat using the median scaling data (15.97%, Table 15) from reef surveys (Vecsei, 2004). The reason for this scaling is that the forereef area is the preferred microhabitat region of the coral reef area for adult bumphead parrotfish. Third, to account for biogeographic patterns, trends in fish abundance, and patchiness, the areal forereef habitat estimates were scaled by 50%, assuming that half of the forereef habitat in the geographic strata was not suitable habitat for bumphead parrotfish. This 50% scaling factor is loosely based on general observations of patchiness and also on bumphead parrotfish abundance patterns on the Great Barrier Reef, where there is an apparent natural trend of decreasing abundance from north to south, and possibly similar patterns in French Polynesia. Other regions also exhibit trends in abundance or patchy distributions, even after accounting for such things as forereef habitat. One such notable example is the apparent lack of bumphead parrotfish at Ningaloo Reef off northwestern Australia, the longest barrier reef in the world. The reasons for this differential occupancy are unclear, but the 50% scaling factor is assumed to adequately account for these processes. This scaling factor is clearly worthy of more study.

Table 15. Summary of forereef habitat breakdown in km^2 (Vecsei, 2004).



Gently sloping				
Region	Reef flat	Forereef	Total reef	Percent forereef
Pacific	189,045	35,919	224,964	15.97%
GBR	20,055	3810	23,865	15.96%
Indian	53,600	10,184	63,784	15.97%
Atlantic	21,600	10,908	32,508	33.55%
Global	284,300	60,821	345,121	17.62%
Steeply sloping				
Region	Reef flat	Forereef	Total reef	Percent forereef
Pacific	189,045	10,776	199,821	5.39%
GBR	20,055	1143	21,198	5.39%
Indian	53,600	3055	56,655	5.39%
Atlantic	21,600	4406	26,006	16.94%
Global	284,300	19,380	303,680	6.38%
			Median	15.97%

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E. M. JENKINSON
(July 2011)