Mapping and Assessing Critical Habitats for the Pacific Humphead Wrasse (Cheilinus undulatus)


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ABSTRACT

Underwater visual census is the most widely used method to determine fish abundance. However, this method ignores the basic assumptions of animal detectability. This study quantifies detectability in reef fishes and estimates population abundance as a function of species-specific detection probability. We apply a double observer approach to a roving snorkel survey to estimate detection probabilities and calculate population abundance of the rare coral reef fish, the Pacific humphead wrasse Cheilinus undulatus, on the reef flats of Tutuila Island in American Samoa. This approach allows for the calculation of observer-specific detection probabilities and the estimation of population abundance by incorporating detection probabilities. Factors that influence detection such as observer bias, species-specific detectability, and species-group characteristics were incorporated in the model. Multiple regression was used to determine relationship of other factors such as distance of fish from observers, horizontal visibility and wideness of reef flats (as a function of sheltering from wave action) with the detection probability and population estimates. A total of 58 surveys estimated a detection probability of around $p = 0.61$ for juvenile humphead wrasse. This suggests that on reef flat habitats an observer has a 61% chance of detecting the individual at any given survey. The ‘corrected’ population size was 359 ± 25 individuals from counts of 218 individuals. Juvenile humphead wrasses were mostly observed in wide sheltered reef flats with small patches of sand bordered with branching corals. This juvenile habitat comprises only 1.6% of the shallow reef habitat and suggests that Tutuila Island coral reef system can potentially support only a ‘small’ population size. These results suggest that the perceived low abundance of this coral reef fish species can be explained by the limited distribution of the juvenile stage’s preferred habitat. Finally, this study provides a methodological perspective on the survey of a rare and threatened coral reef fish and provides a mechanism to correct estimates of its population abundance. More importantly, the results have implications on how we view the status of a naturally rare reef fish and the perceived impacts of threats such as overfishing.

Keywords: Cheilinus undulatus, detection probability, double observer, population abundance, American Samoa

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INTRODUCTION

Underwater visual census survey methods such as belt transects (English and others 1994), stationary point counts (Bohnsack and Bannerot 1986), roving diver surveys (Schmitt and others 2002), and towed-diver surveys (Brainard and others 2008), etc., have been commonly used to estimate the abundance and biomass of coral reef fishes. In a highly dynamic environment like coral reefs, numerous physical factors such as habitat complexity, water clarity, environmental conditions and survey period, interact with intrinsic factors such as observer experience and fish behavior to influence these population estimates. Therefore, a "count" of a certain fish represents only a proportion all the individuals found in the area (e.g. Lancia and others 1994) and true abundances are rarely known. Chances are some of the fish that have been missed and are not likely included resulting in the underestimation of the population abundance. Traditional statistics have normally used variance to estimate likely statistical distribution. However, this situation can also be mathematically represented by a Bayesian approach using the equation

Eq. 1. $E(Ci) = Ni\ pi$

where the expected value of the counts made during the survey is a function of the actual number of individuals, N, present in the area and the probability of detecting (p) the species given the array of conditions affecting the ability to "detect" the individuals in time or location i (see Barker and Sauer 1992, Nichols 1992, Lancia and others 1994). Although this estimation of detection probability is widely used in avian population research and monitoring, it has been underutilized in coral reef fish ecology. This oversight is surprising since coral reef fish ecology has its deep theoretical roots in terrestrial bird studies.

In order to properly estimate population size/abundance, the count data has to be collected in a manner that permits estimation of the detection probability. Equation 1 can be rewritten as:

Eq. 2. $Ni' = Ci / pi'$

where the prime denotes the estimates. This would allow the population estimates to accommodate changes in abundance in a spatial and temporal manner. If the detection probabilities are the same at different time and locations, then the count statistics can be used to draw inferences about the difference in abundance.

Currently, the incorporation of detection probabilities has not been considered in underwater census surveys of reef fish populations. This study incorporates estimation of detection probabilities using double observer method (Nichols and others 2000) on the population of a rare coral reef fish species, the Pacific humphead wrasse Cheilinus undulatus. In a global scale, humphead wrasse has been listed as endangered on the IUCN (World Conservation Union) Red List (Russell 2004) based on perceived decline in abundance in many areas along its distribution and an increase in demand in the live reef food fish trade (Sadovy and others 2003). In the United States, it was proposed to be listed as a threatened species under the Section 6 of the Endangered Species Act. Despite the perceived high threat on this species, Sadovy and others

(2003) showed that the humphead wrasses also display low abundance even in undisturbed areas. This rarity was also evident for the population in the west coast of India (Sluka and Lazarus 2005). This low abundance even on areas unperturbed can be indirectly explained by the demography of the species wherein they display rapid indeterminate growth rate coupled with short life span resulting high species population turn over (Choat and others 2006). Given the inverse relationship between size and abundance (Dulvy and others 2003), the rarity of humphead wrasse rarity in many highly-fished areas cannot be explained by fishing pressure alone.

High habitat preference and limited home range can also explain for the low abundance of C. undulatus. Sadovy and others (2003), in a review of its ecology, showed that smaller individuals were mostly found in shallow coral reefs with gradual transitions to deeper habitats with size and age. Earlier studies in the Indian Ocean showed that adult C. undulatus was more prevalent in outer areas of an atoll (Sluka 2000) with specific preference for channels (Sluka 2005). In some islands in the Western Indian Ocean, juvenile humphead wrasses were mostly found on seagrass beds whereas adults were mostly found on coral reefs (Dorenbosch and others 2006). However, generalizations on a large scale may be misleading if there is small scale variability in the distribution of preferred habitats (Tupper 2006). Tupper (2007) showed microhabitat specificity in juvenile humpheads with high association with branching corals with macroalgae. The home range, at least for juvenile humphead wrasses, tends to be around less than 100m radius based on tagging results (Tupper 2007). With a strong affinity for a specific habitat type, the distribution of such habitat would seem to be a limiting factor for population abundance. Small home range and specificity to microhabitats have a profound effect on the ability to detect the abundance of species and estimate of population size.

The population status of C. undulatus in American Samoa is unknown. It is not a highly targeted species and only appears in the fishery catches as incidental catch from bottomfishing. There are also occasional catch from the nearshore spear fishery of juveniles on the reef flats but rarely of adults. Belt transect surveys conducted by the NOAA Pacific Islands Fishery Science Center, Coral Reef Ecosystem Division showed higher sighting of humphead wrasse in highly populated island of Tutuila than the remote islands of Manua and two other atolls (Brainard and others 2008). There is a significant concern of the presumed decline of the humphead wrasse due to low abundance and sighting frequency attributed to high fishing pressure in Tutuila Island, American Samoa. The main objective of this study was to estimate the detection probability of the juvenile humphead wrasse, a rare reef fish, and to estimate the total juvenile abundance on the shallow coral reef habitat. The results can provide insights on the roles of habitat availability and of the detectability of juveniles on population size.

METHODS

Study Area

American Samoa is an unincorporated territory of the United States south of the equator (14° S 170° W) in the South Pacific (Figure 1). It is comprised of four highly-eroded volcanic islands (Tutuila, Ofu, Olosega, Tau) and two atolls (Swains and Rose). This study focused on the reef flats of the main island of Tutuila. Tutuila reef flats are narrow and are more extensive on the south facing shores of the island. The north side of Tutuila is mostly volcanic cliffs with deep pavement benthic substrate. The true reef flats are concentrated only on embayments. The surveys were conducted in 39 villages from February to October 2010.

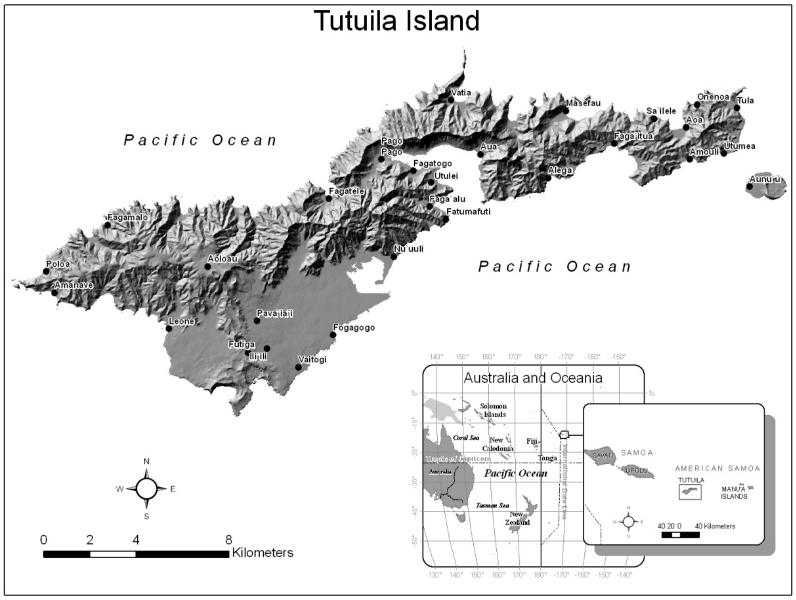


Figure 1 Location map of Tutuila, American Samoa.

Survey Design

The reef flats were classified into two categories based on the suitability of the habitat to support humphead wrasse population. The criteria used were: (1) presence of sandy substrate with coral fringing the periphery; (2) low water motion; and (3) distance from the reef crest as a function of wave action.

Double Observer Survey

We utilized an independent double observer survey method (Nichols and others 2000; Alldredge and others 2006) with roving snorkels keeping a constant approximate distance of 5 meters from each other. The roving snorkeling transect length ranged from 165 m to 2500 m depending on the expanse of the reef flat on each coral reef site. One observer was equipped with a GPS unit set to log coordinate at every 30 seconds. The time in the GPS unit was synchronized with the dive watches used by the observers. Both observers recorded sightings of humphead wrasses by recording the time of sighting, counts, estimated size (total length) in centimeters, distance of the fish to the observer, and the type of bottom substrate in the fish was sighted. The time of sighting was matched with the corresponding time in the GPS in order to determine the approximate location of the fish around the island. The fish survey data was overlaid as a layer on the bathymetric map and compared with the habitat map generated by NOAA National Center for Coastal and Oceanographic Services (NCCOS 2005) using ArcGIS (Environmental Systems Research Institute 2008). In order to minimize observer infused bias, one observer was designated as the primary observer and the other as the secondary observer during the first half of the survey and the roles switched during the second half of the survey.

Detection Probability and Population Estimation

Any underwater visual census survey is limited by the detectability of target individuals or species due to the complexity of the reef environment, environmental variables affecting visibility and ability of the diver as well as the behavior of the fish. All these affect the ability to detect the target survey organism resulting to biased estimates. In order to correct for bias, non-detection of the individuals should be quantified to account for present but undetected individuals. Estimation of the detection probability, p, is based on the detection history from the independent double observers. The mathematical equation is as follows:

Eq. 3. $pi' = 1 - (1 - p'1)(1 - p'2)$

where pi' is the combined detection probability for both observers; (1 – p'1) is the detection probability for the first observer; and (1 – p'2) is the detection probability for the second observer.

Given that two independent observers were used on the survey, the detection probability for observer 1 and 2 can be computed as:

Eq. 4. $p'1 = x11 / (x11 + x01)$; and $p'2 = x11 / (x11 + x10)$

where p'1 is the detection probability for the first observer; p'2 is the detection probability for the second observer; x11 are the humphead wrasse counts recorded by both observers; x10 and x01 are the counts recorded independently by the first and second observer, respectively.

In order to estimate the population size from count estimates, detection probabilities are incorporated from multiple observers taking into account the detection history which can be expressed as:

Eq. 5.a $N' = (x11 + x10) + (x11 + x01) / x11$

which is the same as:

Eq. 5.b.$N' = x01 + x10 + x11 / 1 - (1-p'1)(1-p'2)$

where the denominator is equation 3 and is the same denominator for equation 2.

This study used the DobServ Program developed by the Patuxent Wildlife Research Center (Nichols and others 2000) to test model assumptions, accommodate model selection and estimate detection probabilities and population abundance utilizing Program SURVIV (White 1983) as a base platform to run a series of product-binomial model. The six models which incorporate possible combination of sources of variations in the detection probabilities are: (1) detection probabilities are similar for all species and all observers [P(. , .)]; (2) dependence of detection probabilities on observer identity [P(. , i)] and not by species; (3) detection probabilities differ by species but within species is similar for each observer [P(s , .)]; (4) dependence of detection on both species and observer identity similar to an interaction term where one observer may be proficient in detecting a species but not in others [P(s , i)]; (5) [P(g , i)] retains different detection probabilities for both observers but imposes a different detection of the different species; and (6) different detection probabilities for the a priori defined groups [P(g , .)]. The survey also included other species of interest that tend to grow to large sizes and were detected during the survey along with C. undulatus to simulate possible group-infused and species level variability. Other species included were: (1) Carcharhinus melanopterus, black tip shark; (2) Carcharhinus amblyrhinchos, gray reef shark; (3) Aetobatis narinari, spotted eagle ray; (4) Himantura fai, brown sting ray; (5) Sphyraena barracuda, great barracuda; (6) Plectropomus laevis, saddleback grouper; and (7) Eretmochelys imbricata, hawksbill turtle. Species 1 to 4 were assigned to one group, the group of cartilaginous group marine fish while species 5 and 6 were grouped with C. undulatus as the reef fishes group. E. imbricata belonged to the third group under sea turtles. The groupings were used with the assumption that each group has varying detectability due to differences in mobility and affinity to the habitats being surveyed. Species that have low sightings used the detection probability of species within the group that have enough data in order to estimate the population size. The cut-off threshold was set to x = 10.

Akaike's Information Criteria (AIC) are used to make decisions on the most appropriate model to estimate detection and population abundance. It is a theoretical measure used to evaluate the most parsimonious model to explain the variation in the survey data using the fewest parameters possible (Burnham and Anderson 1998). Since our sample size was smaller than the number of parameters used we utilized the AICc values for model selection. AICc is a second order AIC that adjusts for smaller sample sizes (Burnham and Anderson 2002). Only the detection probability and population abundance of C. undulatus are reported in this study.

Effects of Co-Variates on Abundance Estimates

Several factors can affect abundance estimates. They can be categorized into survey-specific and environmental factors. Survey-specific variables include: (1) distance of target survey to observer; (2) size of the target; and (3) length of transect. Environmental factors include: (1) horizontal visibility as a function of turbidity; and (2) perpendicular distance of the reef crest to the coastline as a function of wave action. Horizontal visibility was quantified during surveys by estimated the distance of the farthest object visible to the naked eye. The perpendicular distance of the crest was taken from satellite imagery and measured from the coastline to the reef crest in each site where the surveys was conducted. A forward step-wise multiple regression was used to determine significant relationship in the patterns and trend of abundance and detectability relative to the factors mentioned.

RESULTS

Fifty-eight roving snorkel surveys were conducted in 39 coral reef sites around Tutuila Island. Only 22 surveys had sightings of C. undulatus and other species listed. Habitat characteristic of site surveyed ranged from a bare limestone pavement with occasional encrusting coral to a highly diverse coral community with high percentage live coral cover. Bare limestone pavement habitats are usually found on reef flats that are narrow < 150 m from crest to coastline. There were several lagoon areas that were surveyed specifically, the dredged deep water pool beside the airport runway and Alofau village. There were deep crevices filled with sand within coral communities on the reef flats of Faga'alu, Nuu'uli, Utulei, Gataivai, Fagaitua, and Laulii. Each habitat encompasses a range of perturbation impacting the various sites. Other villages surveyed had coral rubble and basalt boulders as primary substrate.

Spatial Distribution of Cheilinus Undulatus Habitat

The Pacific humphead wrasse exhibited preference in terms of habitat occupancy. In a total of 46 kilometers of survey track, this species appeared only on 21 kilometers of reef track. Figure 2 shows a track plot of sites where humphead wrasses were detected. Humphead wrasses were found only in the villages of Faga'alu, Fatumafuti, Gataivai, Nuu'uli, Utulei, Fagaitua, Alofau, Laulii, and the back reef lagoon beside the airport runway (hereafter called Airport Lagoon). All these sites are characterized by sandy bottom habitats as patches within branching coral communities. The corals found in Gatavai, Faga'alu, Fatumafuti, Utulei and Alofau were mostly Porites cylindrica while Fagaitua, Nuu'uli, Laulii and the Airport Lagoon reefs were dominated by Acropora muricata, A. pulchra, and A. nobilis. The size of humphead wrasses found within the branches and the base of these corals ranged from 5 cm to 23 cm. The largest recorded individual on the shallow reef flat survey was 45 cm at the Airport Lagoon. The larger sized individuals that ranged from 30 to 45 cm were found predominantly at the Airport Lagoon and the reef flats of Nuu'uli and Laulii. Based on the track plots, it appears that the humphead wrasses were found on a habitat characterized by a sandy bottom patch with branching corals in the periphery.

Remote sensed data from IKONOS imagery with ground truthing information showed that these specific humphead wrasse habitats are limited around the island of Tutuila (Figure 3). The area of sandy substrate reef flats bordered by patch or aggregated reef types was extracted from the GIS layers (NCCOS, 2005) and was estimated to be 73,478 m2 on Tutuila and adjacent island of Aunu'u. This comprises 34% of the total sandy substrate area (218,981 m2) consistent with juvenile humphead wrasse habitat features. Furthermore, the humphead habitat features is further limited at merely 1.07% relative to the total area of the reef flat (6,880,229 m2).

By overlaying the track plot with humpheads occurrence on the habitat maps, it is shown that C. undulatus only occurs on mentioned specific habitat features

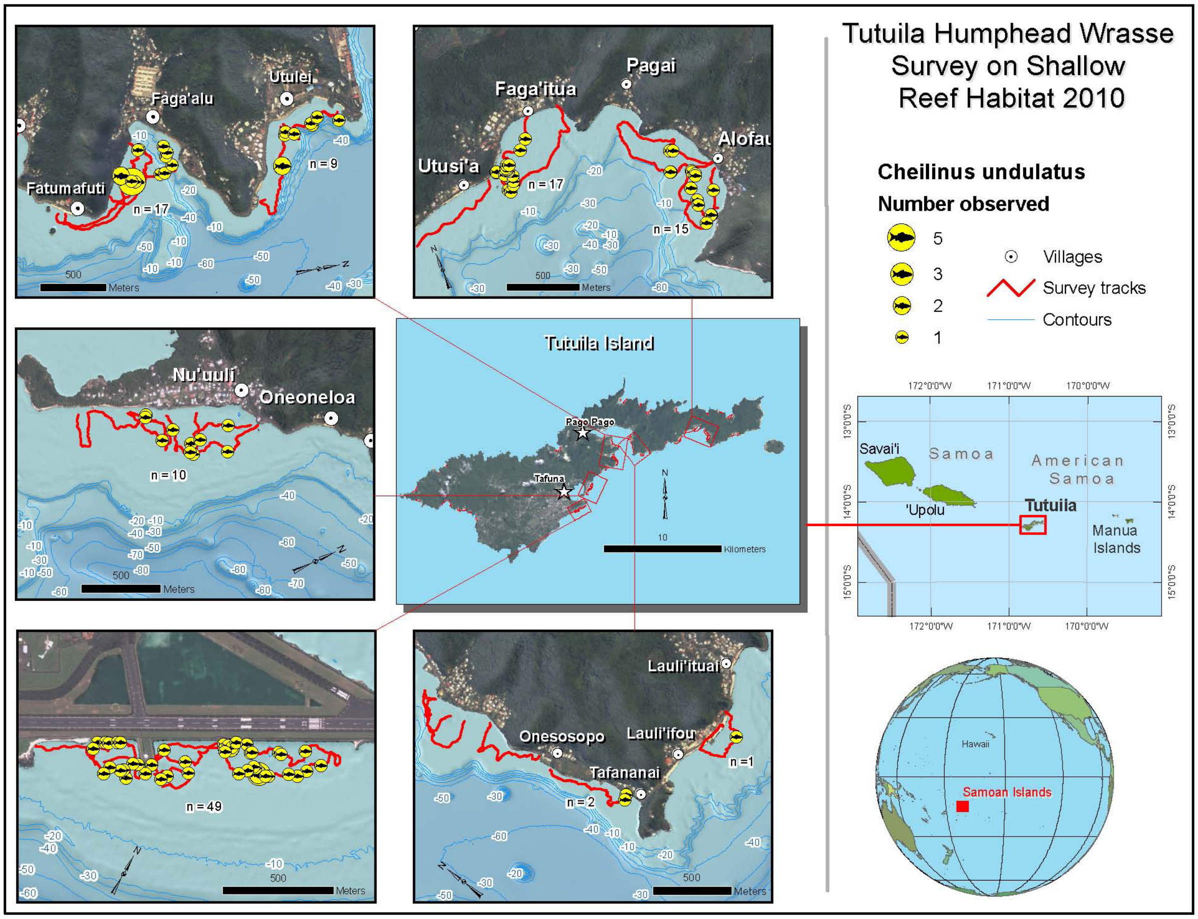


Figure 2 Track plot of the roving double observer survey on sites where Cheilinus undulatus was sighted. Tracks from other sites are shown on the island map but no C. unulatus were detected by both observers.

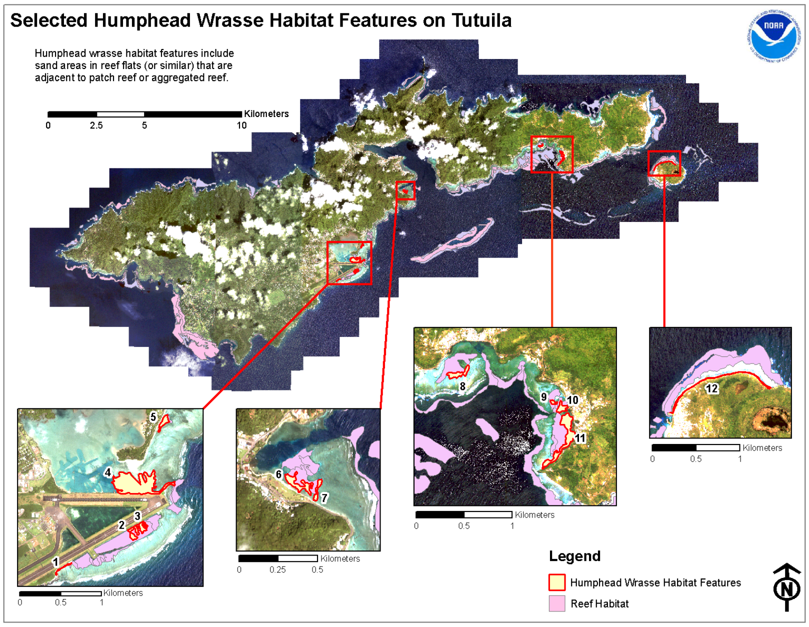


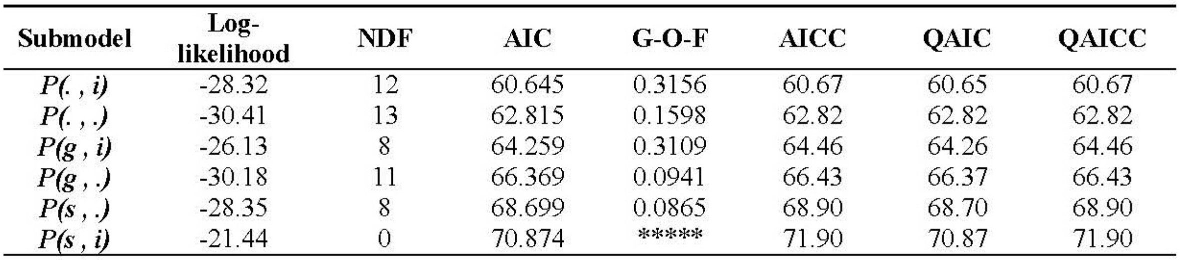
Figure 3 Shallow water benthic habitats in Tutuila Island showing habitat features of Cheilinus undulatus. Twelve potential C. undulatus habitats were identified characterized by sand substrate on reef flats with adjacent patch or aggregated reefs.

Population Estimation and Detection Probability

Ideally, the double observer analysis is done on a per survey level in order to compare the models and test for sources variations (observer, grouping, and species). However, it was not possible to run the analysis on this detailed level due to low sighting frequency. Majority of the surveys (62%) yielded zero sightings on all species surveyed. Therefore, the viable data sets available are those only with sightings.

Comparisons of model assumptions based on AICc values showed that P(. , i) was more appropriate with the data available (Table 1). It generated the lowest AICc among all models being tested. Simply, it indicated that there were significant differences in the detection probabilities between the two observers. The estimated detection probabilities for the first and second observer were p1 = 0.399 ± 0.031 and p2 = 0.346 ± 0.028, respectively.

Table 1 Summary of the model selection based on ranking of parsimony as estimated by the Akaike's Information Criterion.



Submodel	Log-likelihood	NDF	AIC	G-O-F	AICC	QAIC	QAICC
P(. , i)	-28.32	12	60.645	0.3156	60.67	60.65	60.67
P(. , .)	-30.41	13	62.815	0.1598	62.82	62.82	62.82
P(g , i)	-26.13	8	64.259	0.3109	64.46	64.26	64.46
P(g , .)	-30.18	11	66.369	0.0941	66.43	66.37	66.43
P(s , .)	-28.35	8	68.699	0.0865	68.90	68.70	68.90
P(s , i)	-21.44	0	70.874	*****	71.90	70.87	71.90

The detection probability used to estimate population abundance of C. undulatus was computed at pi = 0.6073 ± 0.034. This is not equivalent to the observer specific detection probabilities shown above upon which the model was based. The analysis suggests that an individual observer has a 61% chance in detecting the fish at any given survey on habitats that C. undulatus is present. Conversely, a single observer also has a 39% chance of not detecting the fish. Raw counts of C. undulatus yield 218 individuals. Incorporating detection probabilities yielded a population abundance estimate of 359 ± 25 individuals found in the preferred habitats with 141individuals not detected.

Co-Variates Affecting Abundance and Detection

Forward step-wise multiple regression analysis showed significant relationship between abundance estimates and distance of fish to observer as well as transect length (r2 = 0.729; F(3,51) = 45.664; p<0.000) (Table 2). This can be interpreted as longer transects increase the chances of bisecting preferred habitat areas where the animals can be detected. The distance of the animal to observer may have an inverse relationship with abundance and detectability. The assumption is that there is higher detectability on animals closer to observers and decreases with increasing distance (Buckland and others 2001). Our results have shown significant positive relationship between distances of animal sighting with abundance.

DISCUSSION

The double observer method was useful to determine differences in the detection probabilities and incorporated these probabilities in estimating the total population of a rare species such as Cheilinus undulatus. This method also enabled estimation of individual observer's probability of detection by utilizing both observer's data (Nichols and others 2000). Although used mostly on avian population survey, we have demonstrated its utility in assessing a rare fish of interest especially for conservation purposes. Reef independent double observer method relies mostly on visual counts which is prone to violating the "independence" of the observation in situations where one observer will get visual cue from the other observer when a species of interest is being detected (Nichols and others 2000, Alldredge and others 2006) (i.e. writing data on the slate or getting angle reading on the fish location). This can be minimized by simply agreeing a priori that when one observer was seen writing and detected the fish thereafter will not log that sighting event. Various methods that addresses minimizing and correcting sampling biases and errors such as distance (Buckland and others 2001), double-observer (Nichols and others 2000), double-sampling (Anderson 2001, Bart and Earnst 2002), and removal method (Farnsworth and others 2002) have various limitations. What is critical is that the sampling design is appropriate for each method’s assumptions and that conclusions be drawn are within the bounds of these assumptions. Estimating detection probabilities has not been previously applied in coral reef fish surveys. We have demonstrated that C. undulatus may have some detection and habitat related issues resulting in a general perceived low abundance and sighting frequency.

Table 2 Forward step-wise multiple regression of survey specific and environmental factor that affect abundance estimation of C. undulatus.

Dependent variable	Independent variable	Beta	t(51)	p-level
Abundance	Intercept		-1.879	0.066
	Sighting$_{\text{distance}}$	**0.765**	**7.459**	**0.000**
	Length$_{\text{transect}}$	**0.255**	**2.704**	**0.009**
	Wave action	-0.126	-1.244	0.219

Our results have shown that C. undulatus has a low detection probability and is limited by habitat availability in Tutuila Island, American Samoa. Based on the double observer results, a single observer has 61% chance of detecting an individual humphead wrasse present in the area. In addition, observer-specific detection probabilities yield very low values indicating that observer-based factors such as survey experience and physical ability to sight individuals influences species detectability. The overall detection level can be considered as low and therefore may have led to low sightings even in an undisturbed environment. The double observer method estimates detectability relative to the observers themselves. The ‘true’ abundance might be more than what is estimated from this method since their combined ability to detect is 61% of an unknown portion of the 100%, not 61% of the 100%.

The length of transect and the distance of fish relative to the observer were significant survey-specific and environmental factors tested for its effects on the abundance estimates. Width of reef flat that provided wave shelter allowing for the formation of preferred habitats and horizontal visibility had no significant effect on abundance. Length of transect had a significant positive relationship with abundance. The longer the survey tracks possibly increased the odds of bisecting a preferred habitat of C. undulatus. Sighting distance of fish to observer was also significantly related to the trends in abundance. The results seemed to be counter-intuitive where upon the more distant fish had greater detectability resulting in higher counts. Normally, survey targets closer to the observer will have higher detection rates (Buckland and others 2001). However, it was generally observed that the humphead wrasse by behavior kept a distance from the observer. Majority of the reef fishes are known to swim with a distance from divers (Chapman and others 1974) and the extent of behavior varies depending for instance on level of fishing (Kulbicki 1998, Friendlander and DeMartini 2002). It is also entirely possible that the effective distance of detection of C. undulatus by virtue of aversion is far less than the effect of horizontal visibility on the ability to detect the fish. Any sighting distance will be the same as long as it is within that range of detection and beyond which it can no longer be detected effectively.

The spatial distribution of the shallow water humphead wrasse population around the island was shown to be highly concentrated in areas with sand substrates bordered by a patch or aggregate reef typically composed of branching corals with macroalgal community. Remote sensing data have shown that these habitat features are very limited on Tutuila Island and comprised merely 1.07% of the shallow reef flat habitat. Within this preferred habitat, there was an estimated 359 individuals of C. undulatus. Work by Tupper (2007) on the humphead wrasse population on nursery habitats in Palau showed strong affinity of smaller size classes to its microhabitat characterized by branching corals with macroalgae consistent with this study. The scale of our results was an order of magnitude larger than the microhabitat scale of Tupper (2007) and smaller than the general habitat scale described by Dorenbosch and others (2006) suggesting that proper scaling of the survey is critical in trying to determine the population abundance of C. undulatus.

Newly settled C. undulatus individuals tend to remain near their settlement sites even up to 6 months after settlement (Tupper 2007). This will have a significant effect on the succeeding life history stages. Studies done by Choat and others (2006) provided clues on the life-history strategy of humphead wrasse where it exhibited indeterminate rapid growth and a short life span. There are no mortality estimates for C. undulatus for American Samoa. Given that this species is not highly targeted in any of the fishery coupled with low fishing effort (Sabater and Carroll 2009, Sabater and Tulafono 2010), one can assume the total mortality would be a proxy of mortality rates. Based on the northeastern Australia population, C. undulatus has an annual total mortality range from 0.10 to 0.14 indicating that only a small portion of the population lived more than 30 years old (roughly 75 and 396 cm for female and male individuals, respectively) (Choat and others 2006). This strong site affinity, life-history characteristics and our findings of limited juvenile habitat availability suggest that the coral reef of Tutuila Island cannot support a large population of C. undulatus thus possibly resulting in low abundance especially for the adult population. These factors combined with the low detectability make this a rare coral reef fish.

The results have management implications for the conservation of the humphead wrasse which is now listed as an endangered species under IUCN Red List (Russell 2004). Given that C. undulatus has low detectability, low abundance, and has limited distribution, extracting abundance data from multiple species surveys from methods like belt transect and stationary point count might lead to underestimating its abundance. On the other hand, expanding the counts to a larger spatial scale would result in overestimation if one does not take into consideration habitat specificity of the species in question. It was initially assumed that C. undulatus are found generally on reef flats where branching corals are abundant. Our survey showed that even in areas with 100% live branching coral cover, no humphead wrasses were sighted. One has to be careful in expanding data sets to larger scale if: 1) the count data is not reliable; and 2) the species exhibit strong habitat specificity. Unqualified upscaling can lead to biased estimates and can be misleading when used as scientific basis for management and conservation. A more robust method would be to use probability of detection approaches and to concentrate on areas where the target surveys are known to be found.

Using Marine Protected Areas as a tool to conserve this species could be useful if designed properly. The critical nursery habitat of C. undulatus has been mapped and studies showed their strong site affinity which may have some implication of their home range. Although C. undulatus is known to undergo stage-dependent, ontogenetic habitat shift, it is critical to keep the nursery habitats intact and protected from land based sources of impacts given that these critical habitats are found nearshore. Unfortunately, in the case of C. undulatus, its critical shallow water habitats are located near villages with high population density. Aside from the Airport Lagoon, the reef flat of Faga'alu, Alofau and Nuu'uli are critical nursery grounds and at the same time major watersheds identified by the American Samoa Environmental Protection Agency being impacted by sedimentation, nutrient and bacterial loading (Pedersen 2000a, 200b). These land-based threats although indirect to the C. undulatus population itself have direct impact on its habitat and perhaps have greater impact than the fishery.

The effectiveness of banning the take of C. undulatus at any phase of its life history would depend on the level of fishery threat as well as the capability to enforce such regulation if such management measure is be established. It is a balance between the logistics involved in managing this species and biological benefit to the species. If the system naturally does not support a huge population of a certain fish species then management strategy should focus more on enhancing the viability of the population. Banning the fishery assumes that the population would increase over what the coral reef system can naturally support especially for a habitat-limited species. An outright ban on the harvest will be ineffective in an area where takes on C. undulatus only occurs as incidental catches. Fishery manager should explore bait and hook options for the bottomfish fishery that can maximize or maintain the catchability of the targeted species (i.e. deep red snappers) and that minimizes the incidental hooking of humphead wrasse. This way incidental mortality can be controlled rather than imposing a ban that cannot account for incidental mortality which would result in wasted biomass.

This study has demonstrated the potential of estimating population abundance by incorporating detection probabilities in underwater visual surveys especially for a normally rare coral reef fish. The double observer method utilized in this study estimated the probability of sighting C. undulatus and provided some insights and explanations on its low sighting frequency and abundance in Tutuila Is., American Samoa. The low abundance of C. undulatus is partly explained by its low detectability and the low abundance constrained by low habitat availability. Low abundance does not necessarily imply high fishing pressure. Management should focus on protecting critical habitats for this species in order to sustain the population. Further studies addressing home range and habitat mapping of the off-shore reef are critical to fully understand the population dynamics for this species.

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