CPUE as an index of relative abundance for nearshore reef fishes

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This is the accepted manuscript of a paper originally published in Fisheries Research. You may find the final, formatted version at [10.1016/j.fishres.2006.05.015](https://doi.org/10.1016/j.fishres.2006.05.015).

Abstract

Using density measurements derived by SCUBA diving, we have verified that research angling catch per unit of effort (CPUE) is a useful measurement of the relative abundance of nearshore reef species when the appropriate habitat is targeted. We found a strictly proportional relationship between lingcod and copper rockfish CPUE and density using a ranged major axis regression. This relationship did not hold for quillback rockfish since this study did not target their preferred depth range; nor for kelp greenling. Researchers must be aware of such limitations when using CPUE as a measure of relative abundance.

Introduction

The use of catch per unit effort (CPUE) as a measure of relative fish abundance is a common index used in stock assessment, whether calculated from commercial or recreational fisheries data or from research survey data. CPUE is often considered to be biased and not strictly proportional to abundance (Harley et al., 2001). Catch rates may remain high even if abundance decreases, a situation termed hyperstability, because of increases in fishing efficiency (catchability), changes in the behaviour of fishers (Gillis and Peterman, 1998; Cox et al., 2002), or due to fish behaviours such as hyperaggregation (Rose and Kulka, 1999) and habitat selection (Fréon et al., 1993). Commercial and recreational fishery data will often have bias due to fishing efficiency and fisher behaviour. These factors can, to some degree, be controlled in research data by applying standardized methods that include pre-determined fishing durations, locations and gear.

One of the difficulties in investigating the relationship between abundance and CPUE is obtaining a measure of abundance that does not rely on fishing data. Richards and Schnute (1986) explored the relationship between nearshore reef fish abundance and CPUE using fish counts made with a submersible research vessel and catch and effort data from a research angling survey. They found a strictly proportional relationship between fish density and CPUE for quillback rockfish (*Sebastes maliger*), the most abundant species in their survey. However, less abundant species such as lingcod (*Ophiodon elongatus*) and copper rockfish (*S. caurinus*), were too scarce to permit the nature of the relationship between density and CPUE to be determined. In their study, the submersible could only adequately sample depths greater than 40 m (Richards and Schnute, 1986). Previous research shows that lingcod and copper rockfish catch rates are higher for depths less than 25 m than for depths from 26 to 50 m (Haggarty and King, 2004, 2005). Richards and Cass (1987) also found that catch rates of these species decreased below 40 m; therefore, the submersible survey by Richards and Schnute (1986) likely did not target these species' preferred depth range.

We revisit the topic of the relationship between CPUE and nearshore reef fish abundance using fish counts based on SCUBA dive surveys and research angling survey catch and effort data. Dive survey density estimates may provide a better estimate of fish abundance than those made with submersible research vessels or remotely operated vehicles (ROV) because divers have the ability to search crevices and among boulders to detect fish. Views into crevices and under rocks are not possible with submersible research vessels or ROVs and it is likely that fish counts using these methods underestimate actual fish abundance. In addition, our survey focuses on shallower depths than [Richards and Schnute \(1986\)](#) in order to sample habitat preferred by lingcod and copper rockfish. We compared the CPUE of lingcod, copper rockfish, quillback rockfish and kelp greenling (*Hexagrammos decagrammus*) from the research angling to the density of these species obtained by visual counts using SCUBA divers. We assume density estimates from the dive survey to be indicative of the true abundance of these species.

Methods

This study took place between 27 September and 15 October 2004. All diving and fishing activities were conducted off a 7 m aluminium boat equipped with a depth sounder, global positioning system (GPS) and laptop computer with the navigational software Nobeltech[®]. Eight study sites were selected in the Strait of Georgia (Fig. 1) based on their reef fish catch rates in previous research angling surveys with the intent of sampling sites that represented a range from low to high catch rates ([Haggarty and King, 2004, 2005](#)).

Fig. 1. Location of sampling sites in the Strait of Georgia, BC, Canada.

Density estimates

SCUBA divers counted all large reef fishes encountered within a circular plot with a radius of 10 m. This plot method is also during lingcod egg mass surveys which is also used to estimate the density of large

reef fishes (Haggarty et al., 2005). We completed five plots per sampling site with the exception one site, Neck Reef, which was too small to accommodate more than two plots. The mean depth at the center of the plots was 12 m and the minimum and maximum depth of the plots ranged between 5 and 20 m (Table 1). Given that catch rates for lingcod, kelp greenling and copper rockfish decline below 25 m, we are confident that we covered an appropriate depth range. The percent coverage of algae (*Agarum* sp. plus *Nereocystis luetkeana*) in each plot was recorded (Table 1) and was not dense enough to obstruct the movement of the 10 m plot line. The centre of each plot was marked with a cannon ball attached to a line and dive float, and was mapped using GPS and Nobeltech®. Plots were selected for suitable rocky reef habitat using the depth sounder to assess relief and hardness of the bottom, and were orientated along the same depth contour. One diver controlled the 10 m plot line which was attached to the center cannon ball while the other diver searched consecutive wedges of the plot. Divers used lights to search for fishes in crevices and cracks and among flora. Divers compared the size of the copper rockfish and quillback rockfish to a 15 cm mark on their slates in order to classify rockfish as less than or greater than 15 cm in length. Previous research showed that only rockfish greater than 15 cm are caught on the research angling gear (Haggarty and King, 2005). For each site, the density of lingcod, kelp greenling, copper rockfish and quillback rockfish greater than 15 cm was calculated as the total number of fish counted in all plots divided by the total area searched.

CPUE from research angling

Table 1
The sampling date for SCUBA fish density estimates by site

Site	Date	N	Depth	Algae, % cover	Fish density (fish per 100 m ²)			
			Mean (range)	Mean (S.D.)	Lingcod Mean (S.D.)	Copper Mean (S.D.)	Quillback Mean (S.D.)	Kelp greenling Mean (S.D.)
Copper	2004-10-04	5	12.1 (8–15)	2.0 (2.7)	2.4 (1.7)	1.9 (1.7)	7.1 (1.2)	1.6 (1.1)
Discovery	2004-10-03	5	13.3 (10–17)	2.4 (5.4)	2.1 (0.5)	9.2 (4.8)	2.6 (0.9)	1.5 (1.0)
Maud	2004-10-03	5	9.8 (7–14)	26.0 (32.3)	1.3 (0.4)	1.8 (1.9)	2.2 (1.5)	1.1 (0.9)
Douglas	2004-09-27	5	11.1 (9–14)	1.0 (2.2)	0.2 (0.2)	1.7 (2.2)	2.7 (1.3)	1.2 (0.8)
Entrance	2004-10-01	5	13.4 (11–15)	9.0 (14.7)	0.5 (0.5)	2.6 (2.9)	0.0 (–)	1.0 (0.4)
Round	2004-09-28	5	10.7 (10–13)	33.0 (19.2)	0.0 (–)	1.3 (0.8)	1.0 (0.7)	0.6 (0.6)
Snake	2004-09-30	5	12.9 (12–15)	32.0 (25.9)	0.5 (0.6)	2.9 (2.5)	1.0 (1.0)	1.3 (0.8)
Neck	2004-10-15	2	15.0 (10–19)	77.5 (3.5)	0.5 (0.7)	5.3 (1.6)	4.5 (1.4)	1.1 (0.7)

Information for each site includes: the number of plots surveyed (N); the mean depth (m) and range surveyed; the estimated mean (and standard deviation) proportion (%) of the area surveyed by divers that was covered by macroalgae (*Agarum* sp. and *Nereocystis leutkeana*); and the mean (and standard deviations) fish density (fish per 100 m²) from SCUBA observations for the N plots at each site.

All fishing was conducted using trolling rods and reels using 12 cm frozen herring as bait, and occurred after fish counts by divers were completed. Similar angling methodology to Richards and Schnute (1986) was used to derive CPUE and is outlined in detail in Haggarty and King (2005). Briefly, each person fished at each site for a designated amount of time and recorded all fish caught. Fishing time was halted when a fish was caught or whenever the gear was reeled in or hooked to the bottom. We were able to fish directly over each dive plot, since the center of each plot was mapped with navigational software. Three people fished at once for an accumulated fishing time of 60–75 min per site, except at the Neck Reef, which was only fished for 30 min (Table 2). The boat operator used a depth sounder and navigational software to ensure that fishing occurred at the same depth range as each dive plot and ensured that equal fishing time (approximately 12 min) was spent above each plot. Fishing was halted when the boat floated outside the target range of the plot. A catch was recorded if a fish was brought to the surface and could be identified to species. Fork or total lengths of all fishes landed were measured to the nearest millimeter. CPUE (fish per hour) for lingcod, kelp greenling, copper rockfish and quillback rockfish greater than 15 cm was calculated for each site as the total number of fish caught by all anglers divided by the total fishing time of all anglers.

Table 2

Catch per unit effort (CPUE) (fish per hour) for lingcod, copper rockfish, quillback rockfish and kelp greenling for each site presented with the date fished; the time fishing commenced; the total time fished (time summed for all three fishers); the sea state (1: calm, 2: ripple); and the minimum, maximum and modal fishing depth (m)

Site	Date	Start time	Total time (min)	Sea state	Depth (m)			CPUE (fish per hour)			
					Minimum	Maximum	Modal	Lingcod	Copper	Quillback	Kelp greenling
Copper	2004-10-06	15:38	75	1	5	12	19	3.2	0.8	0.0	2.4
Discovery	2004-10-06	13:36	60	1	8	20	12	13.2	12.2	2.0	3.1
Maud	2004-10-06	11:48	75	1	5	20	12	2.4	3.2	1.6	0.8
Douglas	2004-10-12	09:50	62	1	5	17	11	1.0	0.0	0.0	1.9
Entrance	2004-10-12	12:05	60	1	5	13	8	3.0	0.0	0.0	3.9
Round	2004-10-13	09:28	61	1	5	16	11	0.0	2.0	0.0	0.0
Snake	2004-10-12	13:21	62	1	5	16	8	2.9	2.9	0.0	0.0
Neck	2004-10-14	09:03	30	2	14	20	18	2.0	10.0	46.0	4.0

Regression analyses

Because both the dependent variable, CPUE (fish per hour) and the independent variable, density (fish per 100 m²), have associated variability, we used a Model II regression to determine the relationship between CPUE and fish density totalled for all dive plots per site (Ricker, 1973; Laws and Archie, 1981). Since the fishing was conducted by drifting overtop of all dive plots, site density was calculated as total number of fish counted by total area searched summed across plots for each site. Prior to regression analysis, we used the Shapiro–Wilk test to examine whether the data con- formed to a normal distribution and then used a square root transformation to meet the assumptions of normal distribution and homogenous variance (Sokal and Rohlf, 1995). We applied the square-root transformation to both variables in order to preserve the relationship between the y and x variables (Carroll and Ruppert, 1988). In order to make the two variables dimensionally homogenous we ranged the data and performed a ranged major axis regression (RMA) (Legendre and Legendre, 1998). We calculated 95% confidence intervals around the RMA slope to examine significance (Sokal and Rohlf, 1995). Legendre and Legendre (1998) state that confidence intervals can be used to compare the slope to hypothetical values of interest such as 1 or 0. We also provide the ordinary least squares (OLS) regression F statistic and probability for comparison. OLS regression and Shapiro–Wilk test were performed with Statistix 7.0 (Analytical Software, 2000).

Results

Lingcod, copper rockfish and quillback rockfish densities varied by site (Table 1), but there was no difference among sites in kelp greenling density (Table 1). Lingcod and copper rockfish catch rates were highest at Discovery but Neck Reef also had high rockfish catch rates. There were no significant differences among sites in the size of any species caught during fishing. The length of fish observed while diving was not estimated. The mean length (and standard deviation) of lingcod, copper rockfish, quillback rockfish and kelp green- ling caught was 45.9 cm (10.2), 30.5 cm (4.4), 29.3 cm (4.1) and 37.5 cm (8.5), respectively. The minimum size of copper rockfish (21.0 cm) and quillback rockfish (17.8 cm) caught on hook and line was greater than the 15 cm size category we used in the visual survey. Numerous copper rockfish and quillback rockfish in the less than 15 cm category were counted during the dive survey. The OLS regression of CPUE on fish density showed significant regression lines for both lingcod and copper rockfish (Table 3). The slope of the ranged major axis regression was, in both cases, close to 1 with relatively tight 95% confidence intervals; however the confidence interval around the slope was greater for copper rockfish than it was for lingcod (Table 3). The y -intercept of the RMA slope for these two species was also close to zero. Consequently, the data from these two species agrees with a model of strict

proportionality. Although quillback rockfish CPUE and density had a RMA slope of 1.5, the confidence interval around the slope was large, and the OLS regression was not statistically significant (Table 3). Kelp greenling CPUE and density had the worst fitting RMA line with a slope of 1.9 and a wide confidence interval (0.8–17.4) (Table 3).

Table 3

The slope (b_{RMA}), 95% confidence intervals and the equation of the line of the ranged major axis (RMA) regression between CPUE and density

Species	b_{RMA}	95% CI		Equation of line	F	OLS, P level
		Lower	Upper			
Lingcod	0.8	0.2	2.4	$y = 0.8x + 0.02$	10.48	0.02*
Copper	1.1	0.4	4.90	$y = 1.1x + 0.1$	9.09	0.02*
Quillback	1.5	0.5	8.4	$y = 1.5x - 0.6$	0.94	0.37
Kelp greenling	1.9	0.8	17.4	$y = 1.9x - 0.6$	1.26	0.30

The F statistic and probability from the ordinary least squares (OLS) regression are also provided.

*Significant at 0.05 level.

Discussion

Using SCUBA density measurements, we have verified that research angling CPUE is a useful measurement of the relative abundance of nearshore reef species when targeting appropriate depth and habitat. We assume that the density measurements made by SCUBA divers in this study provide a good estimate of the true abundance of nearshore reef fish species. Richards and Schnute (1986) remark that since submersibles do not have the ability to examine cracks and crevices unless they pass directly over them, fish density estimates from submersible surveys should be considered minimum estimates. Conversely, we made a concerted effort to search for fish in cracks and crevices and recorded the position of the fish at sighting. SCUBA surveys are also known to underestimate fish counts but bias tends to be greatest for cryptic species and highly abundant fishes (Sale and Douglas, 1981; Brock, 1982). The four fish species considered here are relatively large and visible, but do not usually aggregate in large groups; therefore, we have confidence that our observed fish density provides a reasonable abundance estimate for these species.

Richards and Schnute (1986) compared catch rates from the research angling surveys to density data collected on submersible dives and modeled the relationship between density and CPUE. They discuss various cases their model is able to describe, including strict proportionality, no relationship, and modifications of proportionality at low and high density (Richards and Schnute, 1986). They found that quillback rockfish, the dominant species observed by the submersible and most frequently caught while angling over the 41–70 m depth interval, demonstrated a strictly proportional relationship between CPUE and density. Copper rockfish and lingcod observations from the submersible were too low and variable to model separately, so they combined them using a general fish category and were not able to find a significant fit to their model (Richards and Schnute, 1986).

Using SCUBA diving rather than submersible counts allowed us to sample the shallower depth distribution of lingcod and copper rockfish. We found a strictly proportional relationship between catch rates and density for lingcod and copper rockfish over the depth range sampled. Both lingcod and copper rockfish CPUE and density had a significant linear relationship using the ranged major axis regression which allows for variation around both variables (Legendre and Legendre, 1998). Conversely, the SCUBA survey and shallow depth interval fished did not adequately sample the depth range of quillback rockfish (subtidal to 274 m) (Love et al., 2002). Therefore, the strictly proportional relationship found by Richards

and Schnute (1986) for quillback rockfish was not reproduced here. There was no correlation observed between kelp greenling density and CPUE, perhaps because kelp greenling are less susceptible to the bait used in the research angling. Kelp greenling have smaller mouths than the other species and tend to nibble at the bait rather than swallowing it whole.

Our research, coupled with Richards and Schnute (1986), indicates that CPUE derived from standardized surveys can be used to measure relative abundance. Although they can- not be easily translated into a fish density, they can be used to monitor, in a relative sense, if a fish population is increasing, decreasing or remaining constant. Researchers need to be aware of limitations such as susceptibility to gear, here illustrated by the lack of correspondence between kelp greenling density and CPUE; or targeted habitat, here illustrated by the difference in our results for quillback rockfish, lingcod and copper rockfish from Richards and Schnute's (1986) results when a different depth range is targeted.

As a research tool, hook and line surveys are probably a cost effective and simple way to obtain a relative abundance measure for certain species, such as copper rockfish and lingcod and quillback rockfish in deeper water (Richards and Schnute, 1986). Biological samples (length, weight, sex, maturity, stomach contents) can also be collected using this method. SCUBA surveys, or other visual survey techniques such as remotely operated vehicles and submersible surveys, are more time consuming and expensive but do offer the advantages of monitoring species and life history stages that are not susceptible to hook and line gear, and have the ability to also collect additional data on behaviour and habitat use. Visual surveys may not be as susceptible to environmental variables (i.e. time of day, tide, weather) or behaviour (competition or satiation) that may affect catch rates. Visual surveys are also non-lethal, which is can be an advantage in areas where there are conservation concerns and for species, such as rockfishes, that do not have high survival rates after being released.

Acknowledgements

Thank you to V. Hodes, P. Winchell, K. Mathias, L. Mac- Dougall and J. Martin for their assistance in the field.

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