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Influence of Hook Size in the Hawaiian Deep-sea Handline Fishery

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RALSTON, S. 1982. Influence of hook size in the Hawaiian deep-sea handline fishery. Can. J. Fish. Aquat. Sci. 39: 1297 – 1302.

Experimental bottom fishing trials were conducted in the Northwestern Hawaiian Islands where four different hook sizes (Nos. 28, 30, 34, and 38) were fished simultaneously. Within this series the biggest hook is about 71% larger than the smallest hook. Alterations in gear within this range have no substantive effect on the catch of bottom fish. In all cases examined, variation in catch statistics associated with differing replications (days and sites) greatly exceeded any effect attributable to different hook sizes. It is concluded that for medium- and large-sized fish, the catch is reasonably representative of those fish which strike the hooks and that a sigmoid selection curve most accurately describes the selective properties of the gear in this fishery.

Key words: gear selection, hook size, bottom fish, replications

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Des pêches expérimentales sur le fond ont été pratiquées dans le nord-ouest des îles Hawaii avec quatre grandeurs d'hameçons différentes (n^{os} 28, 30, 34 et 38) utilisées simultanément. L'hameçon le plus gros de la série est environ 71 % plus gros que le plus petit. Entre ces extrêmes, des modifications à l'engin n'ont pas d'effet notable sur les prises de poissons de fond. Dans tous les cas étudiés, la variation des prises dans divers essais se répliquant (quant aux jours et aux sites) dépasse de beaucoup tout effet attribuable à différentes grandeurs d'hameçons. Nous concluons que, dans le cas de poissons de taille moyenne et grande, les prises sont assez représentatives des poissons qui mordent aux hameçons et qu'une courbe de sélection sigmoïde est celle qui décrit avec le plus de précision les propriétés sélectives de l'engin utilisé dans cette pêche.

Received December 30, 1981
Accepted June 4, 1982

Reçu le 30 décembre 1981
Accepté le 4 juin 1982

MUCH is known of the selective properties of both trawls and gill nets (e.g. ICNAF 1963), and Gulland (1969) describes briefly some methods for evaluating selection by these kinds of gear. In contrast, very little information concerning selection by hook-and-line fishing gear is available. The results of these few studies are somewhat contradictory, and currently it is difficult to generalize concerning the type and extent of bias likely to be present in samples obtained by this method of fishing.

A number of investigators have reported substantial bias in length–frequency samples derived from angling. For example, Fry (1949) found that hook-and-line fishing gear exhibited a dome-shaped selectivity curve for lake trout (*Salvelinus namaycush*), similar to that classically obtained from gill nets. Also, Fraser (1955) reported that smallmouth bass (*Micropterus dolomieui*) are increasingly susceptible to capture by hooks as fish size increases. Both of these authors concluded that size selection by hook and line is relatively severe and strongly dependent upon the size-classes sampled. Similarly, Brock (1962) found that length–frequency distributions of yellowfin tuna (*Thunnus albacares*) summarized from longline catches were quite different from those obtained from the purse-seine and live-bait fisheries. He found that small fish were poorly represented in the former fishery, whereas few large fish were sampled in the latter. Japanese researchers (Koike et al. 1968; Kanda et al. 1978; Koike and Kanda 1978) have suggested that samples of spiny goby (*Acanthogobius flavimanus*), mackerel (*Scomber japonicus*), and pond smelt (*Hypomesus olidus*) collected with hook and line demonstrate a bias towards an optimum catchable length which is in turn dependent upon hook size.

Other researchers have come to somewhat different conclusions. Chatwin (1958) reported that the hook-and-line selectivity curve of lingcod (*Ophiodon elongatus*) is sigmoidal and constant above a certain minimal size, analogous to selection curves obtained from trawl fisheries (Gulland 1969). Both McCracken (1963) and Saetersdal (1963) reported similar findings while studying Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). In addition, these authors found that variation in hook size tended to shift the

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Printed in Canada (J6761)
Imprimé au Canada (J6761)

minimum size of capture but did not affect the catch of large fish. Moreover, Allen (1963) concluded that samples of New Zealand trout obtained by fly-fishing were unbiased. Similarly, Leclerc and Power (1980) found fly-fishing to be the least selective of three different methods of sampling for brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*).

This study began as an attempt to evaluate the type and extent of size bias present in the catch of bottom fish landed in the Hawaiian deep-sea handline fishery (Hawaii Department of Land and Natural Resources 1979; Ralston 1981; Ralston and Polovina 1982). Because of the conflicting nature of previous work on this topic, it became necessary to investigate the process of gear selection in this particular fishery. A selection curve can be calculated by comparing independent, unbiased samples with hook-and-line catch statistics. At present there are no similar data concerning stocks of bottom fish in Hawaii and it is not possible to calculate selection curves for this fishery. However, by examining the effect of hook size variation on the catch of bottom fish, one can infer much about the selective properties of fishing hooks.

Methods

Fishing trials were conducted during four research cruises to the Northwestern Hawaiian Islands on the 23-m, 109 gross ton R/V *Easy Rider*. This vessel is capable of multiple fishing activities and is typical of the larger, more powerful craft which have recently entered the offshore handline fishery in Hawaii.

The boat was equipped with three deep-sea bottom fishing rigs composed of Charlin hydraulic motors, Pacific King fishing reels, and ~ 400 m of 150-kg test, braided prestretched Dacron line. Standard equipment on each rig included four #34 Tankichi ulua hooks attached to 75-kg test monofilament leaders and a 2-kg welded reinforcement-bar weight.

The effect of variation in hook size on the catch of bottom fish was studied by simultaneous fishing with hooks of different sizes (Fig. 1). Each of the three fishing reels was rigged with one each of the four differently sized hooks (Nos. 28, 30, 34, and 38) to control for line and fisherman effects. To control for a possible position effect, the locations of the four hooks on each line were determined at random. During experimental trials each fishing line was monitored individually. All hooks were baited with equivalent pieces of cut frozen squid and released to the bottom. The fate of each hook was recorded upon retrieval to the surface. When fish were landed the species and the fork length (FL) or total length (TL) in centimetres were noted, as were loss of bait and broken hooks when appropriate.

Data were summarized according to each day of fishing trials ($n = 17$), which individually were treated as experimental replications. Fishing took place at Necker Island, French Frigate Shoals, Maro Reef, and Midway and Kure Atolls during March and October 1979, and November 1980. Catch statistics included the number and size composition of each species landed on the four different sizes of hooks. These data were analyzed as randomized complete blocks in parametric two-way analyses of variance (ANOVA) when samples were sufficiently abundant, although for two species the size composition data were sparse. In these situations the data were pooled across replications and a simple one-way parametric ANOVA was performed (hook size as treatment effect). Similarly, for the same two species the Friedman test, a nonparametric two-way analysis (Tate and Clelland 1957; Conover 1980), was applied to the number of individuals landed per day because the data matrix contained many zeros.

Results

A total of 1110 fish were landed and measured during the four research cruises. The catch was composed mainly of opakapaka (*Pristipomoides filamentosus*), which alone accounted for 50% of the total. This snapper (Lutjanidae), the target species, is usually found in waters 100–200 m deep. Lesser numbers of other species were also taken: the hapuupuu (*Epinephelus quernus*), a grouper (Serranidae), and the pig ulua (*Pseudocaranx dentex*), a jack (Carangidae). These two species comprised 17 and 21%, respectively, of the catch. Analyses of gear selection in each of these three species were conducted independently.

Number of Opakapaka

Adequate samples of opakapaka were taken on 12 of the 17 possible trial days. The data were square-root transformed ($\sqrt{x}$) because some cell entries were small whole numbers leading to heterogeneous variances. Application of Tukey's test showed no evidence of non-additivity after transformation ($P \simeq 0.20$, Snedecor and Cochran 1967). The ANOVA showed that the four different sizes of hooks did not catch significantly different numbers of opakapaka per day, although the F statistic was only marginally insignificant ($0.10 > P > 0.05$). Based upon examination of the treatment means there was the suggestion that hook size may affect the number of opakapaka caught in a day, the three smaller hooks being more effective. The data were subsequently analyzed as a one-way χ^2 test under the null hypothesis that the total number of opakapaka caught on each of the four different hook sizes, pooled across all replications, should be equal. This analysis is appropriate because all hooks were always fished simultaneously and the experiment was therefore completely randomized, with catch per hook following the multinomial distribution. Furthermore, a two-way χ^2 analysis of the data showed no interaction between replications and hooks in their joint effect on catch per day ($P \simeq 0.80$). The one-way calculation yielded a significant value ($P \simeq 0.03$), however, demonstrating that smaller hooks are more effective than size No. 38 hooks in catching opakapaka.

A highly significant replication effect is evident in these data (ANOVA, $P << 0.005$), implying that the number of opakapaka caught among differing days and sites is highly variable. The total catch, pooled across hooks, ranged from a high of 58 to a low of 3 individual opakapaka landed per day.

Size of Opakapaka

The effect of hook size variation on the size (FL, cm) of

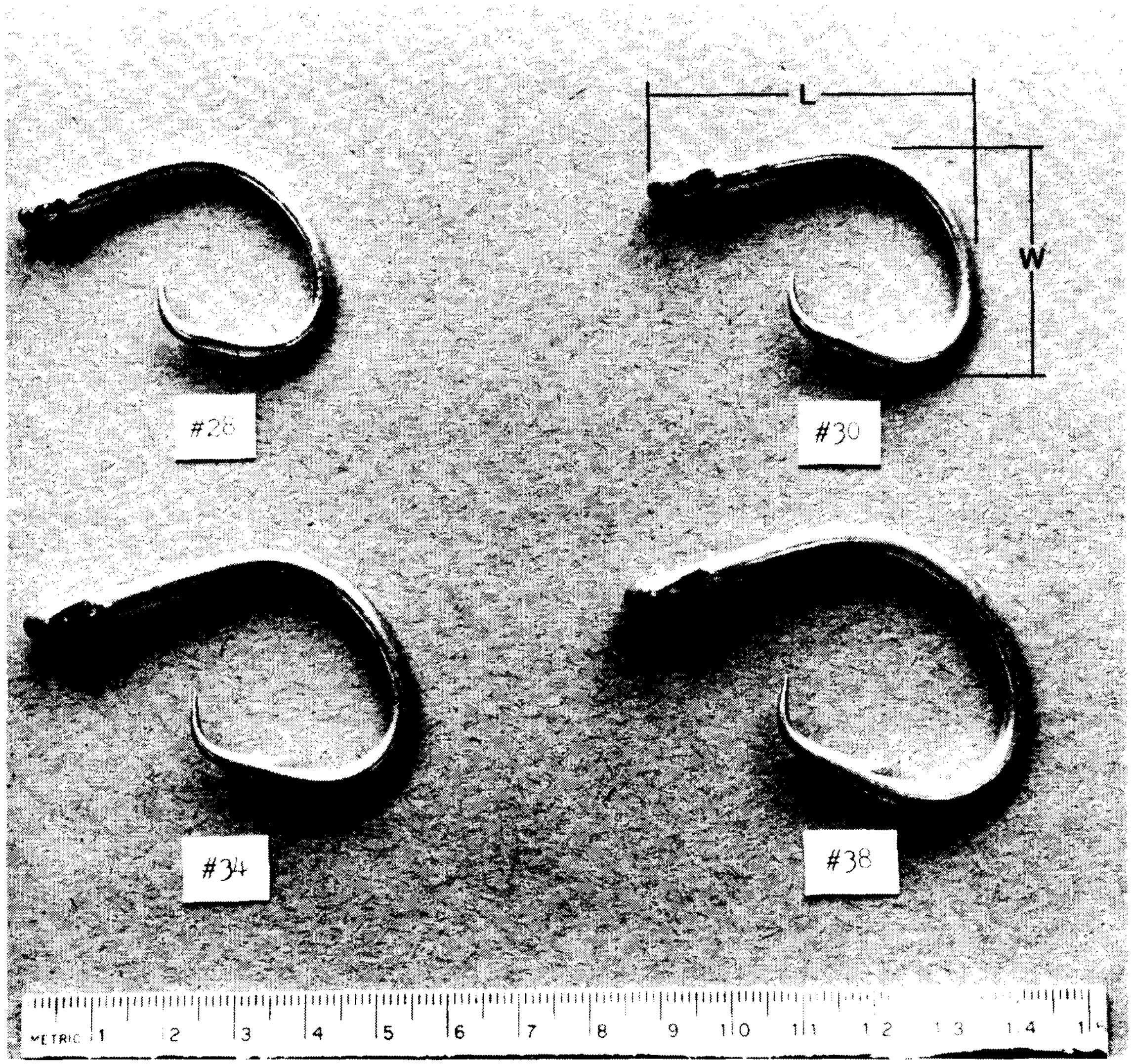

FIG. 1. Four sizes of Tankichi ulua hooks used in experimental fishing trials. The absolute size of a hook was calculated as the product of its length (L) and width (W).

opakapaka landed was examined by means of a two-way ANOVA with repeated observations of unequal sample size (Dixon 1977, program BMDP2V). The analysis was treated as a mixed model with hooks as fixed effects and days as random effects.

Over the size range of hooks tested (Nos. 28–38) there is no indication of a treatment effect. Large hooks appear to be as successful as small ones in catching small fish and vice versa (ANOVA, $P \approx 0.25$). In comparison, the day of fishing (replication) very strongly affected the size of opakapaka landed ($P << 0.005$). The mean size of opakapaka caught among different days ranged from 37 to 61 cm FL. Most of this variation can be attributed to differences between French Frigate Shoals and Maro Reef in the average size of fish they yield. Furthermore, the analysis suggests that there is no interaction between hook and day effects.

NUMBER OF HAPUUPUU

Sufficient numbers of hapuupuu for analysis were landed on 15 of the 17 possible experimental fishing days. Variable hook size had no discernible effect on the number of hapuupuu landed (Friedman test, $P >> 0.05$) whereas the day fished had a profound effect on this statistic ($P << 0.01$). This is evidenced by the fact that the numbers of hapuupuu caught on the different hooks, pooled across days, ranged from 24 to 35 whereas the numbers caught on different days ranged from 1 to 24. A χ^2 test examining the total numbers of hapuupuu landed, pooled across all replications, was insignificant ($P \simeq 0.55$).

SIZE OF HAPUUPUU

Variation in hook size had no detectable effect on the size of hapuupuu landed, although the F statistic was but marginally insignificant (one-way ANOVA, $P \simeq 0.10$). Because variation attributable to different days of fishing could not be factored out, a more thorough sampling program might demonstrate significant hook effects (larger hooks tending to catch, on average, larger fish).

NUMBER OF PIG ULUA

Sufficient numbers of pig ulua for analysis were taken on 10 of the 17 experimental fishing days. Hook size did not significantly affect the number of pig ulua caught (Friedman test, $0.10 > P > 0.05$). The borderline condition of the test statistic could well be due to sampling error (type I) because no trend was evident in the success of the various hook sizes in capturing this species. Hooks of intermediate size (Nos. 30 and 34) seemed to perform slightly better than the extremes (Nos. 28 and 38). Furthermore, a χ^2 test of the treatment totals, pooled across all replications, showed no difference due to hooks ($P \simeq 0.18$). In contrast, the day of fishing (replications) exerted a strong effect on the numbers landed (Friedman test, $P << 0.01$). The numbers of pig ulua landed on different days ranged from 1 to 47. As with the opakapaka, differences in catch rates of pig ulua between the study sites at French Frigate Shoals and Maro Reef probably account for the preponderance of this effect.

SIZE OF PIG ULUA

All pig ulua data were simply classified according to the size of hook the sample was landed with because the numbers caught were limited. Variation in hook size (Nos. 28–38) had no effect on the size of pig ulua landed (one-way ANOVA, $P >> 0.05$). The mean sizes of fish caught, in ascending order of hook size, were 65.3, 65.1, 65.7, and 65.4 cm FL.

TOTAL NUMBERS OF FISH

To assess whether variation in hook size affects total catch of bottom fish I included the three species already treated, and the incidental catch of kahala (*Seriola dumerili*), ehu (*Etelis carbunculus*), gindai (*Pristipomoides zonatus*), and other species. Catch rate was measured on a daily basis as the mean number of fish caught per drift of the vessel. Drifts generally ranged between 10 and 40 min duration. The computations include all 17 of the experimental fishing days and the analysis performed was a two-way ANOVA.

Variable hook size had no detectable effect on the mean number of fish caught per drift ($P >> 0.10$). In ascending order of hook size, the treatment means for hooks were 0.99, 0.97, 0.92, and 0.86 individuals per hook per drift. Similarly, when the total catch of all species is pooled across all replications, a χ^2 test of the treatment totals is insignificant ($P \simeq 0.22$). In contrast, the day fished (replication) exhibited a strong effect on total catch rate ($P << 0.005$), with replication means ranging from 0.15 to 2.35 individuals per hook per drift. These results indicate that variation in hook size from No. 28 to No. 38 has no appreciable effect on bottom fish catch rate.

TABLE 1. Summary of all analyses performed in assessment of gear selection. Probabilities (P) refer to the chance of obtaining a test statistic under the null hypothesis of no difference due to treatment or replication. N.S. = not significant.

Variable examined	Treatment (hooks)	Replication (d)
Number of opakapaka	$P < 0.05$	$P << 0.005$
Size of opakapaka	N.S.	$P << 0.005$
Number of hapuupuu	N.S.	$P << 0.005$
Size of hapuupuu	$P \simeq 0.10$	—
Number of pig ulua	$0.10 > P > 0.05$	$P << 0.005$
Size of pig ulua	N.S.	—
Total numbers of fish	N.S.	$P << 0.005$
Bait loss	N.S.	$P << 0.005$

BAIT LOSS

The effectiveness of different sizes of hooks at retaining bait provides another means of ascertaining selection. If one hook size loses bait more often than another, it might be concluded that the two hooks draw different samples from the population, assuming strike rate is unaffected by hook size.

Eleven of the 17 possible trial days were used in this analysis, which shows that variation in hook size had no appreciable effect on the mean number of baits lost per drift whereas the day fished had a highly significant effect on this quantity (two-way ANOVA, $P \simeq 0.20$ and $P < 0.005$, respectively). The mean numbers of baits lost per hook per drift among the four hooks, in ascending order of hook size, were 1.65, 1.50, 1.43, and 1.42 whereas among the days fished these figures ranged from 0.82 to 2.11.

Discussion

This simple attempt at analyzing the nature of gear selection in the Hawaiian deep-sea handline fishery demonstrates two basic points. In all six situations examined, the day fished had a highly significant effect on the variables measured, whereas in only one case out of eight was a significant effect due to hook size demonstrated (Table 1). It is important to realize that the range of hook sizes used here is fairly typical of those in the fishery although hooks smaller than this series are occasionally employed.

Based on these facts it is reasonable to conclude that alterations in gear within this range of sizes have very little effect on the outcome of bottom fishing in Hawaii. It is readily apparent that variation in both catch rates and species size composition within this fishery are caused predominantly by differences between fishing banks, months, and days (replications). This variation is more than enough to mask any real hook effects at the present level of sampling, although in one situation (number of opakapaka) a significant effect due to hooks was revealed.

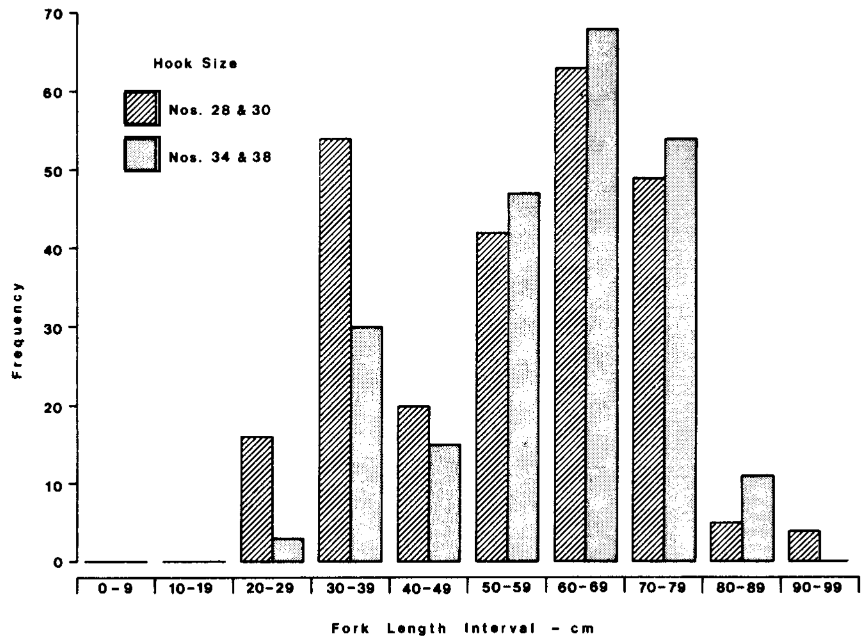

FIG. 2. Combined length−frequency distributions of opakapaka, hapuupuu, and pig ulua which are pooled according to capture on small hooks (Nos. 28 and 30) or large hooks (Nos. 34 and 38).

That the hook-and-line fishery is relatively insensitive to moderate changes in gear is contrary to expectation if the selection curve for hooks were dome shaped. Thus, it is reasonable to presume that in this fishery, selection by hooks is better described by a trawl type or sigmoidal selection curve, with little differential sampling of the larger individuals in the population (e.g. Chatwin 1958; McCracken 1963; Saetersdal 1963). This presumption is supported by the data presented in Fig. 2. Here the combined catches of opakapaka, hapuupuu, and pig ulua have been pooled into two groups: those fish caught on large hooks (Nos. 34 and 38) and those caught on small hooks (Nos. 28 and 30). The histograms suggest that for medium- and large-sized fish (≥45 cm FL) the large and small hooks draw more or less equivalent samples. However, the small hooks appear to have been more effective in capturing small fish (<45 cm FL). These results are compatible with the hypothesis that the selection curve for hooks is sigmoidal. For these reasons it is reasonable to conclude that the catch of bottom fish ≥45 cm FL is likely to be representative of the population sampled.

If a sigmoidal selection curve is postulated for this hook-and-line gear, there should exist a minimum size of capture. That the mean size landed for each species, when treated individually, was insensitive to changes in hook size (Table 1) is contrary to the findings of both McCracken (1963) and Saetersdal (1963). This discrepancy could be due to constraints imposed on the sampling process by the behavior of the fish (see for example Allen 1963). A more likely explanation is insufficient sampling.

Furthermore, the range of hook sizes which were utilized in these experiments (Fig. 1) was not broad. If hooks spanning a greater size range had been employed, it is more likely that a treatment effect on mean size of capture would have been conclusively demonstrated for each species. For example, it is possible to compute an index which measures the size range of hooks used by forming the ratio of the absolute sizes of the largest hook used to the smallest. Hook size is calculated as the product of the length and width of a hook (Fig. 1). In this study the largest hook used (No. 38) was 71% greater in size than the smallest hook (No. 28). In contrast, Koike et al. (1968) and Kanda et al. (1978) used series of hooks in which the largest sizes were 215 and 111%, respectively, larger than the smallest of sizes. Both studies reported shifts in the size composition of the catch depending upon the size of hooks used. Clearly, if hook sizes are highly dissimilar the size composition of the catch must ultimately vary. In spite of this, the hook sizes I used are typically those in use by the fishermen. Moreover, Saetersdal (1963) reported a change in the selective characteristics of fishing hooks which differed in size by only 76%. Consequently, it may be concluded that within the context of the Hawaiian deep-sea handline fishery, little size bias attributable to hook-and-line gear manifests itself in the catch of bottom fish.

Acknowledgments

This research was sponsored in part by the University of Hawaii Sea Grant College Program under Institutional Grant No. NA79AA-D-00085 from NOAA Office of Sea Grant, Department of Commerce. It is a product of the "Snapper and Grouper Management" project (NI/R-7) and constitutes journal contribution UNIHI-SEAGRANT-JC-82-14. Additional support was provided by the University of Washington Sea Grant College Program under Grant No. NA79AA-D-00054. I thank Captain G. Naftel and crew members R. Dahleen, L. Raabe, and C. Fogg of the *Easy Rider* for their good humor and full cooperation, and T. Otsu for translating several papers from the Japanese. Comments provided by J. J. Polovina, J. Stimson, W. Walsh, J. A. Wetherall, H. O. Yoshida, and an anonymous reviewer helped improve the manuscript.

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