8534

REACTION OF DOLPHINS TO A SURVEY VESSEL: EFFECTS ON CENSUS DATA

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ABSTRACT

A field experiment is described in which a helicopter was used to observe the efficiency of shipboard line-transect sampling of dolphin populations in the eastern tropical Pacific Ocean. Nineteen dolphin schools were tracked; 13 of these were detected by observers aboard the ship and 5 of these reacted to the approach of the ship by altering the direction and/or the speed of their movement; however, only 1 school reacted prior to shipboard detection. The results suggest that dolphin schools only occasionally react to the approach of a survey vessel prior to their detection by shipboard observers and that the use of a monotonically decreasing detection function is adequate to minimize bias. Aerial and shipboard estimates of school size and species composition for six schools compared favorably.

The Marine Mammal Protection Act of 1972 prohibits the harvest of marine mammals and specifies that the Federal Government may issue permits for their take only under special circumstances. One such circumstance involves the incidental kill of dolphins associated with the yellowfin tuna fishery in the eastern tropical Pacific Ocean. Before issuing the permits, the government must first certify the viability of the affected dolphin populations. To meet this requirement, scientists at the Southwest Fisheries Center define stocks and monitor their population demography, reproductive output, and abundance.

The vital statistics are derived primarily from specimens obtained from the tuna fishery. However, to estimate abundance, surveys are conducted using ships and aircraft independently of the fishery. The surveys, using line-transect methods (Burnham et al. 1980), have yielded estimates of the density of dolphins in the eastern tropical Pacific Ocean (Holt and Powers 1982). A critical assumption in the application of the method is that the animals do not move, in reaction to the observer, prior to their detection. In practice, a detection function, which is relatively insensitive to nonrandom movement, is used to describe the probability of observing a school of dolphins given its position relative to the observer's transect. A field experiment was designed with the following objective:

1) Test the assumption that the animals do not alter their movement in reaction to the approach of a survey vessel *prior* to shipboard detection.

During a survey the unit of observation is a school of dolphins. In addition, species composition and the number of individual animals in a school (school size) are estimated. Surveys routinely collect information to determine the precision of these estimates by recording independent observations of several observers; however, determining their accuracy is more difficult and attempted less often (Holt and Powers 1982). Six schools were closely approached and observed from both an aircraft and a ship with the following objective:

2) Compare shipboard and aerial estimates of school size and species composition.

Although not an absolute determination of accuracy, the comparison yielded estimates from two very different viewpoints (high-altitude plan view versus low-altitude profile view).

A similar experiment was conducted using the NOAA Ship *Surveyor* and a ship-supported helicopter in 1977 (Au and Perryman 1982). They observed the reaction of eight dolphin schools to the approach of a ship; all eight schools swam away from the projected trackline of the ship. Au and Perryman also suggested that, in some cases, avoidance began beyond the visual range of shipboard observers. The present study was intended to collect additional data under a wider variety of conditions.

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METHODS

The experiment was designed to observe the efficiency of shipboard survey operations by using a helicopter to track dolphin schools before, during, and after shipboard detection. This approach was an enhancement of the design employed by Au and Perryman (1982) which focused only on the behavior of the dolphins. A simulated survey operation was included in the experiment for the following reasons:

1) It was not reasonable to assume that movement of a dolphin school and the probability of detecting it are unrelated (i.e., it may be easier to see a school in full flight than one at rest). Therefore, associated data on movement and shipboard detection were collected for each school.
2) It was necessary to separate random movement from directed movement toward or away from the survey vessel. To do so unambiguously, the ship could not be directed toward a school detected by the helicopter, but rather had to continue searching along a predetermined transect.

From the experience gained on the 1982 survey (Holt 1983), we expected 80% of the sighting cues to be within 3 nmi of the transect line and <5 nmi ahead of the vessel. Furthermore, the Au and Perryman observations on eight schools suggested that dolphins may react to a ship 6 nmi away. With these considerations and prior experience in mind, the following field procedure was employed.

The ship proceeded at 12 kn in a direction selected so as to minimize glare from the sea surface. Two observers maintained constant watch through 25 power binoculars, mounted on the port and starboard sides of the flying bridge (11 m above the water); search patterns extended from the bow to the beam of the ship on each side. Records were kept of searching effort and sighting details. With the exception of selecting the transect direction, these are the same methods employed during previous dolphin surveys (e.g., Holt and Powers 1982). The helicopter searched a distance of 8 to 12 nmi ahead of the ship and 2 nmi to either side of the transect line, at right angles to the direction of the ship's travel (Fig. 1). Search altitude was 1,200 ft and speed was 60 kn. When a school was sighted by the helicopter, shipboard radar tracking began. The observers on the flying bridge were not aware of a track in progress until its termination. Schools were tracked for about an hour's time until one of three events occurred: 1) the school passed abeam of the ship; 2) the school passed beyond the visual range of shipboard observers; or 3) the aerial observers lost sight of the school and had to terminate the track prematurely; in all of the latter cases the presence of the animals was obscured by deteriorating sea state.

During a track, the helicopter was positioned over the school at a minimum altitude of 1,200 ft (370 m); the radar range and bearing to the helicopter were determined from the approaching survey vessel about every 4 min (an interval sufficient to record the appropriate navigational data and still provide continuity in the track). A transponder, mounted on the aircraft, facilitated accurate radar measurements. In addition, OMEGA navigation positions were recorded from dual systems aboard the helicopter and the ship. As the track progressed, field notes were taken on visual observations of school behavior and associated birds and fish. The tracking altitude appeared to

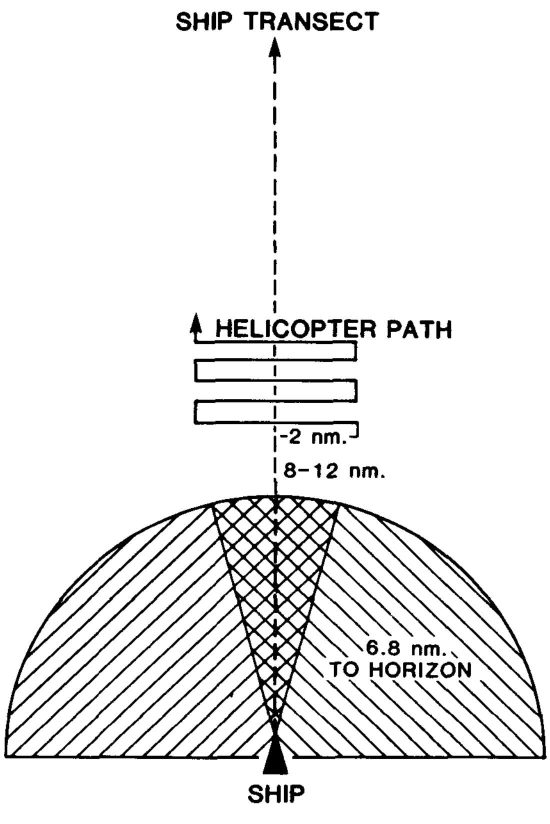

FIGURE 1.—Port and starboard search patterns (shaded areas) and path of helicopter (solid line) during transect (dashed line) surveys for dolphins.

be sufficient so as not to elicit a response from the animals. The dolphins appeared to be swimming calmly throughout the tracking; similar experience was reported by Au and Perryman (1982). It also placed the helicopter above the shipboard observers' vertical field of vision and therefore did not prematurely cue them on a school. Two oil drums were released and tracked at the beginning of the cruise to test the procedure: The resolution of radar measurements was 1-2° in bearing and 0.1 nmi in range; at 1,200 ft (370 m) altitude we were able to maintain visual contact with a 1 m object; and the shipboard observers were not aware of the helicopter until it was within 1 nmi of the ship, where the noise signaled its presence. Shipboard observers were questioned periodically throughout the experiment as to their cognizance of the helicopter; answers were always in the negative except when the binoculars were purposefully directed above the searching field. Observers were aware that looking for the helicopter would compromise the experiment and did not do so.

At the finish of a track, the helicopter descended to a lower altitude for additional photography and to estimate school size and species composition. The ship approached a limited number of schools to enable close-range shipboard estimates of the same school parameters. After school size and species composition were determined, normal survey operation resumed, with the helicopter searching ahead of the vessel and the shipboard observers actively scanning and recording search effort.

Relative motion radar plots were maintained. Apparent change in the relative direction of dolphin school movement was used as an indication of avoidance; field notes of aerial observations of behavior supplemented this information. The criteria defining reaction was a change of 30° or more in the direction of relative motion that was sustained over 2 or more subsequent fixes (Fig. 2).

The experimental design was opportunistic and only specifically designed to compare between a steam-powered survey vessel (NOAA Ship *Surveyor*) and a diesel-powered survey vessel (NOAA Ship *David Starr Jordan*). The experiment was conducted within a 100 square nmi area to the north and east of Clipperton Island (lat. 10°N, long. 110°W) during March and April 1983.[2] Observations were conducted with the *Surveyor* from 10 March through 17 March; the ship then ported at Manzanillo, Mexico, to take on fuel and subsequently met the *David Starr Jordan*, which had just completed a marine mammal survey[3] on 26 March at Clipperton Island. Observations were conducted in the same area with the *David Starr Jordan* until 7 April.

RESULTS

Avoidance

Tracks were started on a total of 26 dolphin schools, 5 in front of the *Surveyor* and 21 in front of

[2]Cruise Report NOAA Ship *Surveyor* Cruise RP-12-SU-83 dated May 24, 1983, on file at the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038.

[3]Cruise Report NOAA Ship *David Starr Jordan* Cruise DS-83-01 dated May 6, 1983, on file at the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038.

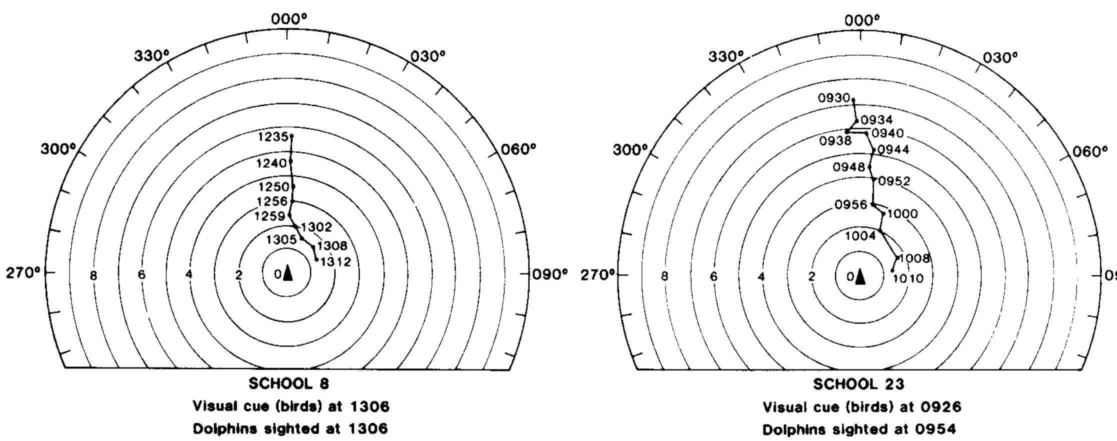

FIGURE 2.—Relative motion plots of dolphin school #8 and school #23. School #8 appeared to react to the approach of the ship; the sighting cue was reported after the dolphins' initial reaction. School #23 did not appear to react to the survey vessel.

the *David Starr Jordan;* a summary of the observations is listed in Table 1. Seven of the tracks were terminated prematurely, and of the remaining 19, 6 schools passed undetected by shipboard observers. These 6 schools did not appear to adjust their direction of movement in reaction to the survey vessel.

Of the 13 schools sighted by ship, 1 school altered its direction of movement in reaction to the approaching ship, prior to the detection of a sighting cue by the shipboard observers, and 12 schools did not appear to react before detection by the ship. One of the 12 schools was composed of rough toothed dolphins, *Steno bredanensis,* which are not a target of abundance surveys. Thus, from the results of this experiment, it is expected that 8% (1/12) of the target schools encountered on a survey will have moved (in reaction to the observer) prior to detection. This does not imply a corresponding degree of survey bias. Nonrandom movement, prior to detection, will alter the distribution of sighting distances and the detection function fit to the distribution; the survey will be biased to the extent that the functional form is sensitive to the data (see Discussion). Survey bias may also exist as a result of schools that react to the ship and are subsequently never seen by shipboard observers; if these schools would have been observed (the expectation is certain if they are on the transect line, less certain if they are off the line), then the bias is proportional to the fraction of schools that escaped detection. As stated above, no schools were observed to react to the ship and avoid detection.

The data suggest that dolphin schools may alter their direction of movement in reaction to the approach of a survey vessel. Thirty-eight percent (5/13) of the schools which were tracked by helicop-

TABLE 1.—Summary of dolphin school tracking data.

Vessel	School number	Beaufort sea state	Species composition		Number of individuals	Closest point of approach (nmi)	Reaction distance (nmi)	Radial sighting distance (nmi)	Relative bearing	Sighting cue	Interpolated radar position at time of sighting (range/bearing)
Surveyor	1	1	*Steno bredanensis*	100%	9	1.3	F[1]	2.5	317°	animals	1.8/335°
	2	1	*Stenella attenuata*	50%	175	7.0	F[1]	F[2]			
			S. longirostris	50%							
	3	3	*S. attenuata*	100%	53	2.5	F[1]	F[2]			
	4	5	Unidentified dolphins	100%	100	2.0	F[1]	2.0	030°	splashes	4.0/032°
	5	5	Unidentified dolphins	100%	15	F[3]					
Jordan	6	4	Unidentified dolphins	100%	22	F[3]					
	7	4	Unidentified dolphins	100%	35	F[3]					
	8	4	*S. attenuata*	25%	300	1.5	2.5	1.5	024°	birds	1.6/030°
			S. longirostris	5%							
			Unidentified dolphins	70%							
	9	4	Unidentified dolphins	100%	25	F[3]					
	10	4	*S. attenuata*	20%	150	0.5	1.7	6.0	003°	birds	6.3/002°
			S. longirostris	80%							
	11	4	*S. attenuata*	100%	25	5.0	F[1]	6.8[4]	023°	birds	7.2/019°
	12	4	*S. attenuata*	15%	65	7.0	F[1]	F[2]			
			S. longirostris	85%							
	13	4	*S. attenuata*	65%	175	1.3	2.2	6.8	356°	birds	6.2/357°
			S. longirostris	35%							
	14	4	*S. attenuata*	90%	50	2.5	F[1]	6.8[4]	000°	birds	8.1/354°
			S. longirostris	10%							
	15	4	*Stenella* spp.	100%	150	F[3]					
	16	4	*S. attenuata*	100%	35	1.2	1.5	6.0	357°	birds	7.0/359°
	17	3	Unidentified dolphins	100%	40	F[3]					
	18	3	*S. coeruleoalba*	100%	160	F[3]					
	19	3	*S. attenuata*	100%	45	3.0	F[1]	F[2]			
	20	0	*S. attenuata*	15%	260	1.7	F[1]	6.8[4]	355°	birds	6.7/353°
			S. longirostris	85%							
	21	2	*S. attenuata*	91%	230	6.4	F[1]	F[2]			
			S. longirostris	9%							
	22	1	*S. attenuata*	50%	180	2.1	2.1	6.8[4]	340°	birds	6.7/336°
			S. longirostris	50%							
	23	1	*S. attenuata*	50%	155	1.5	F[1]	6.8[4]	004°	birds	8.0/357°
			S. longirostris	50%							
	24	1	*S. coeruleoalba*	100%	29	0.1	F[1]	1.8	020°	animals	1.8/018°
	25	1	*S. attenuata*	40%	410	2.0	F[1]	4.0	015°	birds	5.0/010°
			S. longirostris	60%							
	26	1	*S. attenuata*	100%	85	3.0	F[1]	F[2]			

[1]School did not appear to react to the approach of the survey vessel.
[2]School passed undetected by shipboard observers.
[3]Track prematurely terminated.
[4]Cue observed on the horizon.

ter and detected by shipboard observers appeared to react to the ship. Spotted dolphins, *Stenella attenuata,* and spinner dolphin, *S. longirostris,* reacted at a distance of 0.5 to 2.5 nmi and were able to maintain a separation of 0.5 to 2.0 nmi from the ship; one school of striped dolphins, *S. coeruleoalba,* was successfully tracked and these animals stayed on a collision course with the ship until they were only a few hundred meters away. In all cases but one (school 8), the schools were detected by shipboard observers at distances far greater than the reaction distance.

None of the four dolphin schools successfully tracked in front of the *Surveyor* appeared to react to the approach of the ship. Five out of 15 schools appeared to react to the approach of the *David Starr Jordan.*

Estimates of School Size and Species Composition

Six schools were approached at close range by the *David Starr Jordan* so that shipboard observers could make estimates of school size and species composition using the same techniques that were used on previous abundance surveys. Estimates of school size and species composition were made independently by four to six shipboard observers and averaged, giving each an equal weight. These estimates compared favorably with estimates made by a single aerial observer stationed in the helicopter (Table 2). Shipboard estimates of school size ranged from 65 to 134% of the aerial estimates and averaged 101% (mean difference = 1.167; Pr = 0.713, paired t test of mean difference = 0); shipboard and aerial observers agreed on the species composition for all six schools compared, although there was some variation in the proportion assigned to each species.

DISCUSSION

The density estimator used in line-transect applications, formally derived by Burnham and Anderson (1976), and used to estimate the density of dolphin schools by Smith (1981) and Holt and Powers (1982), is:

$$\hat{D} = \frac{N\hat{f}(0)}{2L}$$

where $\hat{D}$ is the estimated density of dolphin schools in the survey area based on the number of schools observed, N, over transect length L. The function $f(x)$ is a probability density function fit to the observed perpendicular sighting distances and estimating its value at zero distance, $\hat{f}(0)$, is the critical concern in the application of line-transect methods (Burnham et al. 1980).

The frequency distribution of observed perpendicular sighting distances reflects both the detection abilities of the observer and the reactions of the observed (Burnham et al. 1980). Dolphin schools are more difficult to see with distance from the track line and avoidance, prior to detection, may cause fewer schools to be seen close to the track line and more schools to be seen further from the track line. The school that did move away from the transect line before shipboard detection (#8) would have been sighted at 0.1 nmi off the transect line if it had not altered the direction of its movement. Instead it was detected at 1.0 nmi off the transect line. If the sample size was larger, such information could be used to dissect the frequency distribution of perpendicular sighting distances into that component which is the result of decreasing visibility with distance from the transect line and that component which is the result of dolphin schools adjusting their natural spatial disposition

TABLE 2.—Comparison of shipboard and aerial estimates of dolphin school size and species composition.

	Vessel estimate				Helicopter estimate			
School number	Number of observers	Estimated number of individuals (standard error)	Species proportions (range)		Number of observers	Estimated number of individuals	Species proportions	
20	5	248 (24)	*S. attenuata*	0.14 (0.05-0.20)	1	260	*S. attenuata*	0.15
			S. longirostris	0.86 (0.80-0.95)			*S. longirostris*	0.85
22	4	241 (40)	*S. attenuata*	0.96 (0.90-1.00)	1	180	*S. attenuata*	0.50
			S. longirostris	0.04 (0.00-0.10)			*S. longirostris*	0.50
23	4	139 (20)	*S. attenuata*	0.62 (0.50-0.73)	1	155	*S. attenuata*	0.50
			S. longirostris	0.35 (0.22-0.50)			*S. longirostris*	0.50
			Unidentified	0.03 (0.00-0.12)				
24	6	36 (6)	*S. coeruleoalba*	1.00 (1.00-1.00)	1	29	*S. coeruleoalba*	1.00
25	5	393 (61)	*S. attenuata*	0.55 (0.40-0.70)	1	410	*S. attenuata*	0.40
			S. longirostris	0.39 (0.30-0.60)			*S. longirostris*	0.60
			Unidentified	0.06 (0.00-0.30)				
26[1]	5	55 (9)	*S. attenuata*	1.00 (1.00-1.00)	1	85	*S. attenuata*	1.00

[1]Not detected by shipboard observers while in survey mode; ship was directed to school by aerial observer.

in response to the ship. There are, however, other factors (such as glare and sea state) which are seldom constant long enough to allow for accumulation of a reasonably precise frequency distribution, such that the effects due to school movement would not be overwhelmed by the effects due to sighting conditions.

The results of this experiment suggest that 1) dolphin schools occasionally react to the approach of a survey vessel prior to their detection by shipboard observers and 2) the expected rarity of the event implies that a considerable amount of additional data would be required to quantify its effect.

Any directed movement prior to detection biases the frequency distribution of perpendicular distances and may bias the function, $f(x)$, fit to these data. In the absence of information regarding movement, Burnham et al. (1980) suggested choosing a function which is relatively insensitive to data contaminated by movement, i.e., a function that monotonically decreases with distance from the transect line. Their simulations suggest that in situations where "undetected movement is relatively minor, then use of an estimator based on a monotonically decreasing function will minimize bias in $\hat{D}$," (Burnham et al. 1980:130). The small sample size of the present experiment was sufficient to qualify undetected movement as relatively minor but not sufficient to quantify its effect on the distribution of perpendicular distances.

Although the work reported here was conducted in the same geographic area (Clipperton Island, lat. 10°N, long. 110°W) as the Au and Perryman (1982) observations, the two experiments are not strictly comparable. Au and Perryman used the ship and helicopter to search for schools and collected data on their reaction to the ship without regard to the effect on survey operations; in four of the eight schools they studied, the ship was turned toward the school during tracking. They were interested in describing the behavior of dolphin schools and combining the description with a search model to quantify survey bias. The present experiment did not assume that the two processes (reaction and detection) were independent and was less ambitious because there was no intention to generalize dolphin behavior. Indeed, the results presented here may only be relevant to this area and for these sighting conditions. Both the reaction distance and the sighting distance may be affected by environmental conditions and may vary between geographic areas with the degree of animal naivete.

The comparisons of aerial and shipboard results suggest that school-size estimates may be more reliable than those of species composition. Although neither observation platform can be considered to yield estimates without error, they do provide unique vantage points with very different views of the dolphin school. All shipboard observers, after exposure to observation conditions in the helicopter, agreed that they could more confidently estimate school size from the air than from a vessel. The helicopter provides an opportunity to observe the entire school over an extended period of time, making it easier to estimate that portion of the school which is submerged and not completely visible. Species proportions are more difficult to estimate and it is not clear which platform is better; indeed, in the case of school 22, all four shipboard observers reported similar proportions which were quite different than that estimated from the air. One explanation may be that it is more difficult to identify animals in plan view than in profile view; alternately, the fluid character of school structure may combine with the limited view of the school from a ship to preclude accurate estimates of species proportions; a third possibility is that both are inaccurate because of species-specific behaviors which make the animals less visible from above and/or the side.

Estimates of the density of dolphin schools are multiplied by the area of the survey, the average school size and the species proportions to estimate species abundances (Holt and Powers 1982). Because they affect the abundance estimates directly, biases in the latter two parameters may be more serious than the effect of school movement prior to detection. As an example, consider the six schools compared during this experiment: the average number of *S. attenuata* per school, estimated by shipboard observers, was 27% greater than that estimated from the helicopter data, the shipboard estimate of *S. longirostris* was 34% less than the helicopter estimates, and the estimate of *S. coeruleoalba* was the same for both platforms (Table 3). Although these differences should only be considered as variability between two estimates, they illustrate the direct dependence of abundance estimates on accurate estimates of species proportions. Avoidance affects density estimates less dramatically; its affect on $\hat{f}(0)$ may be somewhat offset by using a function that is relatively insensitive to predetection movement.

The application of line-transect methods requires that along the transect line all schools are seen with certainty. Any departures from the assumption of perfect detection, either because of

TABLE 3.—Average dolphin school composition.

	Vessel	Helicopter
Average school size (number of individuals)	185.3	186.5
Average species proportions		
S. attenuata	0.545	0.425
S. longirostris	0.273	0.408
S. coeruleoalba	0.167	0.167
Unidentified dolphin	0.015	
Average school composition[1]		
S. attenuata	102.5	79.3
S. longirostris	51.3	76.1
S. coeruleoalba	31.5	31.1

[1]Unidentified dolphins distributed proportionately among identified dolphins following Holt and Powers (1982).

movement or visibility effects, will introduce a negative bias in the density estimate that is proportional to the decrease in apparent density along the transect line (Smith 1979). The sample size was insufficient to test this assumption rigorously; only one school was observed on the transect line (school 14) and it was detected well beyond any of the reaction distances observed.

It is recommended that future fieldwork include additional comparisons of estimates of school size and species proportions. In addition, the assumption of certain detection along the transect line should be tested. Biases in school composition and detection on the transect line affect the abundance estimates directly and present a greater potential for inaccuracy than the degree of directed movement prior to detection observed during this experiment.

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