A TEST FOR BIAS ATTRIBUTABLE TO SEABIRD AVOIDANCE OF SHIPS DURING SURVEYS CONDUCTED IN THE TROPICAL PACIFIC

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SUMMARY

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We present an analysis of the degree to which seabird species respond to ships, thereby affecting the results of at-sea strip transect surveys (continuous, snapshot) undertaken to quantify community patterns of tropical seabirds. Two survey methods for counting seabirds were employed simultaneously and independently on research cruises in the eastern tropical Pacific Ocean: (1) a 600-m strip quadrant was surveyed on one side of the bow using 8×40 binoculars (strip transect), and (2) birds were surveyed from the bow to the horizon on both sides of the ship using 25×150 mounted binoculars ("big-eyes"). Data collected using each method were compared to determine potential biases of the strip transect method, with particular attention paid to seabird ship avoidance. Seabird species were assigned to six categories to control for detection biases resulting from differences in body size and flight behavior, and comparisons between methods were made within each of these categories. Our results indicate that frigatebirds *Fregata* spp., Sooty Terns *Sterna fuscata* and White Terns *Gygis alba* may avoid ships, and therefore, unless compensatory procedures are taken, estimates of density and abundance of these species using strip transects may be negatively biased.

Key words: Seabirds, survey methods, strip transect, biases, ship avoidance

INTRODUCTION

The strip transect method, which includes both continuous and snapshot surveys, is the most widely accepted technique by which quantitative data on at-sea distribution and abundance of seabirds are collected (reviewed by Tasker *et al.* 1984, Spear *et al.* 2004). A number of assumptions are critical to the method, yet these assumptions are difficult to test. Among them is the assumption that all birds entering the survey area are detected. Tasker *et al.* (1984) pointed out the fallacy of this assumption, and Van der Meer & Camphuysen (1995) attempted quantification by comparing counts from different observer teams. They found that up to 90% of individuals for a given species could be missed. Spear *et al.* (2004) conducted a similar study by comparing single and multiple observer teams. They also found that number of undetected birds was species-specific, and that a single observer missed about 26% of the birds present. They concluded that at least two observers on watch simultaneously are required to obtain a detection rate of 95%.

A second assumption of strip-transect methods had been that birds are stationary objects (e.g. Wiens *et al.* 1978). However, several methods were developed to account for bias caused by the movement of birds relative to ships (Tasker *et al.* 1984, Gaston *et al.* 1987, Spear *et al.* 1992, van Franeker 1994, Spear *et al.* 2004).

A third assumption of strip transect methods is that birds do not react to ships, although it is well known that some species are attracted to ships and others avoid them (reviewed in Spear *et al.* 2004). As a result, survey counts will be artificially inflated or deflated, respectively. The identity of species that are attracted to ships is fairly well known, and to counter this, various correction methods have been proposed (Powers 1982, Hyrenbach 2001, Clarke *et al.* 2003, Spear *et al.* 2004).

The problem of ship avoidance has been recognized (Bailey & Bourne 1972, Wiens *et al.* 1978, Griffiths 1981, Tasker *et al.* 1984, van Franeker 1994, Spear *et al.* 2004), but specific investigations to identify the species involved and the extent to which the behavior occurs are limited. In fact, the only ship-avoiders specifically recognized in the literature are the Soft-plumaged Petrel *Pterodroma mollis* (Griffith 1981), Waved Albatross *Phoebastria irrorata* (Clarke *et al.* 2003), and seaducks and divers (Camphuysen *et al.* 2002)—although Spear *et al.* (2004) noted that, in their particular study, ship avoiders included "some albatrosses, shearwaters, terns, and jaegers" (some of which are known to be attracted to ships in certain oceanic regions). And additional experience has also shown the same to be true for small alcids and diving petrels (DGA, unpubl. obs.). To avoid undercounting these birds, observers should watch well ahead of the vessel to identify and count birds that would have passed within the strip transect had they not avoided the ship.

The goal of the present study was to identify species that are undercounted because they avoid ships during seabird surveys in the eastern tropical Pacific. We conducted our study by comparing data collected simultaneously using two methods that differed dramatically in extent of area surveyed beyond the survey platform. The first was a typical strip transect having a fixed strip-width; the second used an unfixed strip-width extending to the horizon.

METHODS

Data collection

Our survey data were collected during three cruises in the eastern tropical Pacific Ocean on 84- and 92-m National Oceanic & Atmospheric Administration (NOAA) research vessels. The cruises occurred during 9 October–4 November 1984, 19 April–15 May 1985, and 22 September–7 December 1985. Two seabird survey methods were conducted simultaneously by two observers. All observations were made from the flying bridge at 14 m to 15 m above sea level, depending on the survey vessel. One observer used the unaided eye and handheld 8×42 binoculars in an attempt to count and identify all birds occurring within a 600-m strip quadrant off the side of the vessel having the best viewing conditions. Hereafter, we refer to data collected in this way as "ST," denoting the strip transect method. The second observer attempted to identify and record birds that occurred on both sides of the ship from the observation platform to the horizon (*c.* 15 km), using 25×150 mounted binoculars ("big-eyes"). We refer to data collected in this way as "BE," denoting the big-eye method. Both observers surveyed simultaneously for most of the time. Each recorded data independently and did not cue the other regarding birds they observed. Both observers recorded number of birds of each species (referred to as "counts" in this paper); ship speed (average: 14 knots), course and noon position; and weather and visibility conditions in half-hour intervals. Seabirds could not always be identified to species level, and in those cases, they were identified to the lowest possible taxon.

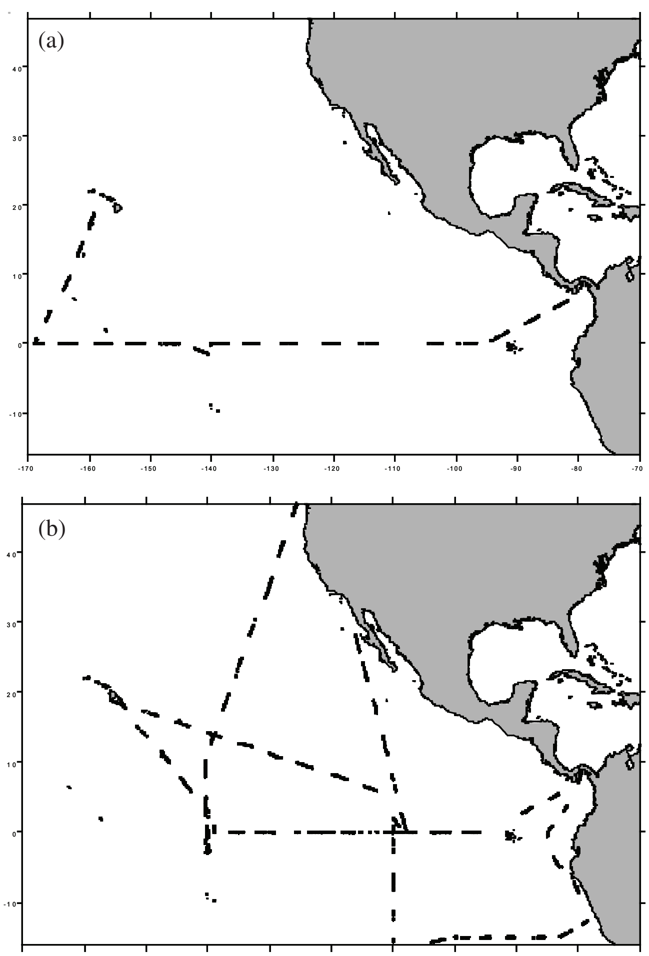

Fig. 1. Cruise tracks from days on which both observers surveyed seabirds in the eastern tropical Pacific Ocean during (a) the 1984 survey, and (b) the 1985 surveys.

Survey tracklines during 1984 and 1985 cruises differed substantially (Fig. 1). Approximately 75% of the search effort occurred in 1985.

Data analysis

Analyses included only days on which both ST and BE effort occurred, resulting in 99 observation days for the three cruises in total. The ST method was used during an average of 4.9 ± 0.2 h (standard error) daily (range : 1.0–10.0 h daily), and the BE method during an average of 5.3 ± 0.2 h daily (range: 0.5–8.5 h daily). To account for this slight variation in time searched, we used count rates in our analyses, calculated as the total birds counted when using a given method, divided by total hours surveyed using that method (birds/hour).

The BE data do not meet the assumptions of ST methods because it is impossible for a single observer to detect all birds out to the horizon on both sides of the ship. Consequently, we have no way of calculating density (as is possible when using the ST method). We therefore compared species-specific count rates relative to each other, between the two methods. All analyses were performed using data from all three cruises combined.

Controlling for detection differences

The BE data were affected by at least two biases: the fact that distant birds are more difficult to identify than are closer birds, and biases attributable to species-specific detection probability. We dealt with these biases as follows:

- Distant birds are more difficult to identify than are close birds are. Consequently, a greater proportion of the birds observed during the ST surveys, as compared with the BE surveys, were identified to species level. To control for this difference, we combined taxonomically similar species into groups (Table 1). We will refer to these groups as taxa regardless of the number of species, genera or families that have been combined.
- Detection probability of different seabird species varies primarily as a result of body mass and flight altitude (Spear *et al.* 2004). Specifically, large birds that fly high are easier to detect than small birds that fly low. To control for this difference, we defined six species groups according to detection probability based on size and flight altitude characteristics of each group (see Spear *et al.* 2004): (1) storm-petrels and phalaropes; (2) small petrels; (3) large petrels; (4) shearwaters; (5) Charadriiformes; and (6) Pelecaniformes (Table 2). Hereafter, we refer to these groups as detectability categories. Additionally, we made a correction to account for the large wing span and high flight of frigatebirds (which potentially allows them to be detected in the BE data over the horizon) by excluding from both datasets all frigatebirds that were not identified to species level.

Statistics

We used two different analytical tools to assess the possibility of ship avoidance by each of the seabird taxa. Our approach was to look for patterns and outliers in the data rather than to focus on statistical significance. For each of the analyses, we excluded rare (<10 individuals observed by each method) and non-oceanic taxa (those restricted to the continental shelf).

TABLE 1
Common and scientific names of all seabird species included in the analyses

Common name	Scientific name	Common name	Scientific name
White-chinned Petrel	*Procellaria aequinoctialis*	White-throated Storm-Petrel[f]	*Nesofregatta albigularis*
Parkinson's Petrel	*Procellaria parkinsoni*	Wedge-rumped Storm-Petrel[f]	*Oceanodroma tethys*
Parkinson's/Shoemaker Petrel	*Procellaria parkinsoni/ aequinoctialis*	Harcourt's Storm Petrel[f]	*Oceanodroma castro*
Townsend's Shearwater	*Puffinus auricularis*	Markham's Storm-Petrel[f]	*Oceanodroma markhami*
Buller's Shearwater	*Puffinus bulleri*	Hornby's Storm-Petrel[f]	*Oceanodroma hornbyi*
Flesh-footed Shearwater	*Puffinus carneipes*	Fork-tailed Storm-Petrel[f]	*Oceanodroma furcata*
Pink-footed Shearwater	*Puffinus creatopus*	Black Storm-Petrel[f]	*Oceanodroma melania*
Sooty Shearwater	*Puffinus griseus*	Least Storm-Petrel[f]	*Oceanodroma microsoma*
Audubon's Shearwater	*Puffinus lherminieri*	White-rumped Leach's Storm-Petrel[f]	*Oceanodroma leucorhoa*
Christmas Island Shearwater	*Puffinus nativitatis*	Dark-rumped Leach's Storm-Petrel[f]	*Oceanodroma leucorhoa*
Black-vented Shearwater	*Puffinus opisthomelas*	Black/Markham's Storm-Petrel[f]	*Oceanodroma melania/ markhami*
Wedge-tailed Shearwater	*Puffinus pacificus*	Leach's/Harcourt's Storm-Petrel[f]	*Oceanodroma leucorhoa/castro*
Newell's Shearwater	*Puffinus newelli*	Unidentified tropicbird[e]	*Phaethon* spp.
Slender-billed Shearwater	*Puffinus tenuirostris*	Red-billed Tropicbird[e]	*Phaethon aethereus*
Dark morph Wedge-tailed Shearwater	*Puffinus pacificus*	Red-tailed Tropicbird[e]	*Phaethon rubricauda*
Light morph Wedge-tailed Shearwater	*Puffinus pacificus*	White-tailed Tropicbird[e]	*Phaethon lepturus*
Manx-type Shearwater	*Puffinus* spp.	Unidentified booby	*Sula* spp.
Sooty/Slender-billed Shearwater	*Puffinus griseus/tenuirostris*	Masked Booby	*Sula dactylatra*
Solander's/Murphy's Petrel	*Pterodroma solandri/ultima*	Red-footed Booby	*Sula sula*
Stejneger's/Cook's Petrel[a]	*Pterodroma longirostris/cookii*	Brown Booby	*Sula leucogaster*
Stejneger's/White-winged Petrel[a]	*Pterodroma longirostris/ leucoptera*	Nazca Booby	*Sula granti*
Kermadec/Herald Petrel	*Pterodroma neglecta/heraldica*	Magnificent Frigatebird[b]	*Fregata magnificens*
Phoenix Petrel	*Pterodroma alba*	Great Frigatebird[b]	*Fregata minor*
Collared Petrel	*Pterodroma brevipes*	Unidentified phalarope[g]	*Phalaropus lobatus/fulicarius*
Bermuda Petrel	*Pterodroma cahow*	Red-necked Phalarope[g]	*Phalaropus lobatus*
White-necked Petrel	*Pterodroma externa cervicalis*	Red Phalarope[g]	*Phalaropus fulicarius*
Cook's Petrel[a]	*Pterodroma cookii*	Wilson's Phalarope[g]	*Steganopus tricolor*
Juan Fernandez Petrel	*Pterodroma externa*	Unidentified skua[d]	*Catharacta* spp.
Herald Petrel	*Pterodroma heraldica*	South Polar Skua[d]	*Catharacta maccormicki*
Mottled Petrel	*Pterodroma inexpectata*	Unidentified jaeger[c]	*Stercorarius* spp.
White-winged Petrel[a]	*Pterodroma leucoptera*	Pomarine Jaeger[c]	*Stercorarius pomarinus*
Stejneger's Petrel[a]	*Pterodroma longirostris*	Parasitic Jaeger[c]	*Stercorarius parasiticus*
Black-winged Petrel	*Pterodroma nigripennis*	Long-tailed Jaeger[c]	*Stercorarius longicaudus*
Dark-rumped Petrel	*Pterodroma phaeopygia*	Parasitic/Long-tailed Jaeger[c]	*Stercorarius parasiticus/ longicaudus*
Kermadec Petrel	*Pterodroma neglecta*	Unidentified tern	*Sterna* spp.
Cook's/Pycroft's Petrel[a]	*Pterodroma cookii/pycrofti*	Black Tern	*Chlidonias niger*
Tahiti Petrel	*Pseudobulweria rostrata*	Common Tern	*Sterna hirundo*
Solander's Petrel	*Pterodroma solandri*	Arctic Tern	*Sterna paradisaea*
Murphy's Petrel	*Pterodroma ultima*	Gray-backed Tern	*Sterna lunata*
Juan Fernandez/White-necked Petrel	*Pterodroma externa/e. cervicalis*	Bridled Tern	*Sterna anaethetus*
Unidentified Cookilaria[a]	*Pterodroma* spp.	Sooty Tern	*Sterna fuscata*
Tahiti/Phoenix Petrel	*Pterodroma rostrata/alba*	Least Tern	*Sterna antillarum*
Bulwer's Petrel	*Bulweria bulwerii*	Royal Tern	*Sterna maxima*
MacGillivray's Petrel	*Bulweria macgillivrayi*	Elegant Tern	*Sterna elegans*
Unidentified storm-petrel[f]	*Oceanodroma sp.*	Inca Tern	*Larosterna inca*
Wilson's Storm-Petrel[f]	*Oceanites oceanicus*	White Tern	*Gygis alba*
White-vented Storm-Petrel[f]	*Oceanites gracilis*	Arctic/Common Tern	*Sterna paradisaea/hirundo*
White-bellied Storm-Petrel[f]	*Fregetta grallaria*	Little Tern	*Sterna albifrons*

[a–g] All species within the marked genera were combined for analyses, as noted by the superscripts assigned: (a) Cookilaria spp., (b) frigatebird spp., (c) jaeger spp., (d) skua spp., and (e) tropicbird spp. Additionally, all storm-petrels were combined into (f) storm-petrel spp., and all phalaropes into (g) phalarope spp.

TABLE 2
Total number of seabirds recorded during the 1984 and 1985 surveys using strip transect methods (ST) and big eye methods (BE, see "Methods"), in descending order of ST counts

Taxa	ST	BE
Storm-petrel spp.[a]	2 397	5 988
Sooty Tern[e]	952	12 980
Juan Fernandez/White-necked Petrel[c]	695	3 325
Phalarope spp.[a]	530	829
Wedge-tailed Shearwater[d]	391	1 880
Cookilaria spp.[b]	386	1 474
Black-winged Petrel[b]	217	510
Jaeger spp.[e]	152	428
Sooty/Slender-billed Shearwater[d]	135	566
Red-footed Booby[f]	108	357
Tahiti/Phoenix Petrel[c]	105	361
Masked Booby[f]	92	559
Newell's/Townsend's/Manx Shearwater[d]	57	154
Tropicbird spp.[f]	53	136
Black Tern[e]	49	132
Mottled Petrel[c]	47	243
Frigatebird spp.[f]	42	1 171
Brown Booby[f]	37	137
Kermadec/Herald Petrel[c]	29	87
Murphy's/Solander's Petrel[c]	27	35
Audubon's Shearwater[d]	25	152
Arctic/Common Tern[e]	23	126
Bulwer's Petrel[b]	21	29
Dark-rumped Petrel[c]	20	34
Pink-footed Shearwater[d]	19	54
White Tern[e]	15	320
Christmas Island Shearwater[d]	11	32
Parkinson's/Shoemaker's Petrel[c]	10	15
Buller's Shearwater[d]	9	9
Bridled Tern[e]	7	30
Elegant Tern[e]	7	7
Flesh-footed Shearwater[d]	6	2
Black-vented Shearwater[d]	5	15
Gray-backed Tern[e]	5	2
Skua spp.[e]	4	9
Bermuda Petrel[b]	3	0
MacGillivray's Petrel[b]	3	0
Royal Tern[e]	2	2
Collared Petrel[b]	1	6
Inca Tern[e]	1	0
Least Tern[e]	1	0
Nazca Booby[f]	0	1
Unidentified booby[f]	0	2
Little Tern[e]	0	2
Unidentified tern[e]	0	9
TOTAL	6 699	32 210

[a–f] For analysis, each species was placed into one of six detectability categories: (a) storm-petrels and phalaropes; (b) Small petrels; (c) Large petrels; (d) Shearwaters; (e) Charadriiformes (jaegers, skuas and terns); and (f) Pelecaniformes (boobies, frigatebirds and tropicbirds).

First, for each taxon we compared the normalized differences in count rate between the ST and BE methods, calculated as

$$(\text{birds/h}_{BE} - \text{birds/h}_{ST}) / (\text{birds/h}_{BE} + \text{birds/h}_{ST}).$$

Because count rates were always higher in the BE data, these normalized differences ranged from 0 to 1. Low values were indicative of taxa with high count rates by the ST method relative to count rates by the BE method; high values were indicative of taxa with relatively low count rates by the ST method. We plotted these normalized differences to visually assess patterns for taxa within each of the six detectability categories and for all taxa together.

Second, we regressed ST counts on BE counts using linear regression and 95% confidence bands to look for outliers amongst all 28 taxa (Neter *et al.* 1996). We used total count rates for the entire dataset rather than daily count rates so that each taxon would provide one data point only, thus equally weighting the regression. We calculated the residuals and Cook's distance measure to quantify the influence of each taxon on the regression (Neter *et al.* 1996). Then, to investigate the resultant regression without extreme outliers, we re-ran the regression after removing the taxa with the strongest influence on the line.

RESULTS

In total, 6699 seabirds were recorded in 486 hours by the ST method; and 32 210 seabirds were recorded in 527 hours by the BE method (Table 2). As expected, because the area searched using the BE method was so much greater than that searched using the ST method, all taxa had higher BE than ST count rates.

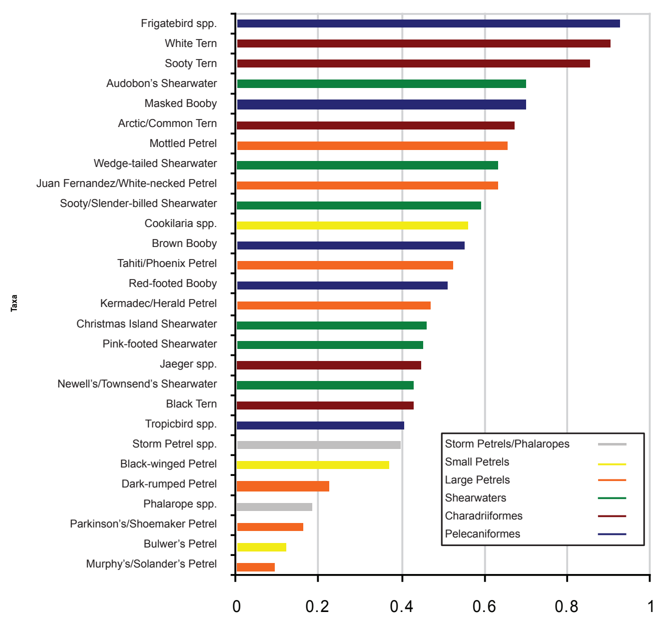

Fig. 2. Normalized differences in count rates (birds/hour) of seabird taxa using two survey methods. Low values are taxa with higher strip transect (ST) count rates as compared with "big-eyes" (BE) count rates; high values are taxa with low ST count rates as compared with BE count rates (see "Methods"). Detectability categories are denoted by different bar colors (see key, or see Table 2 for category description).

The normalized differences in count rates for the ST and BE methods varied greatly among taxa within each detectability category (Fig. 2). When all 28 taxa were considered together, three had notably high ratios (greater than 0.8): White Terns *Gygis alba,* Sooty Terns *Sterna fuscata,* and frigatebird spp.. Another five had notably low ratios (less than 0.3): Murphy's/Solander's Petrels *Pterodroma ultima/solandri,* Bulwer's Petrels *Bulweria bulwerii,* Parkinson's/Shoemaker Petrels *Procellaria parkinsoni/aequinoctialis,* phalarope spp., and Dark-rumped Petrels *Pterodroma phaeopygia* (Fig. 2).

The linear regression performed with all 28 taxa revealed four outliers (taxa outside of the 95% confidence bands): storm-petrel spp. and phalarope spp. had high ST count rates relative to those for BE data, and Sooty Terns and frigatebird spp. had high BE count rates relative to those for ST data (Fig. 3). The plotted residuals with the proportional influence of Cook's distance measure clearly indicate that Sooty Terns and, to a lesser extent, storm-petrel spp. had a strong influence on the regression (Fig. 4).

Re-running the regression without Sooty Terns and storm-petrel spp. resulted in a slightly steeper slope, tighter confidence bands, and six outliers (taxa outside of the 95% confidence bands, Fig. 5). Again, phalarope spp. had high ST count rates relative to those for BE data and frigatebird spp. had high BE count rates relative to those for ST data [Fig. 5(a)]. In addition, Black-winged Petrels *Pterodroma nigripennis*—and to a lesser extent, Cookilaria spp. (see Table 1 for species included in this taxon)—were slight outliers above the upper confidence band; White Terns, and to a lesser extent Sooty/Slender-billed Shearwaters *Puffinus griseus/tenuirostris,* were slight outliers below the lower confidence band [Fig. 5(b)].

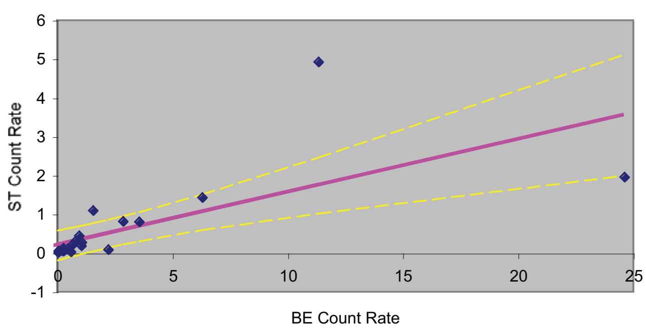

Fig 3. Linear regression of "big-eyes" (BE) versus strip transect (ST) count rates for all 28 taxa (r^2 = 0.473, P = 0.217). Also shown are 95% confidence bands.

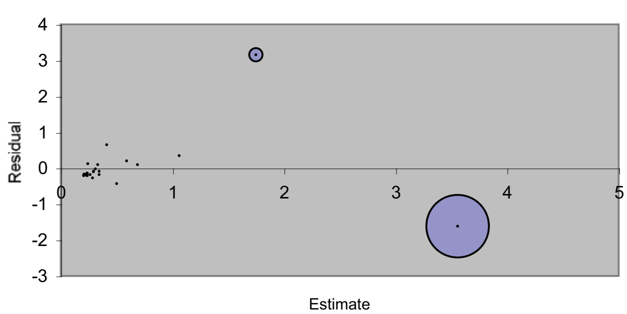

Fig. 4. Proportional influence plot of regression residuals weighted by Cook's Distance Measure. High residuals (both positive and negative) and large circles indicate taxa with the strongest influence on the regression.

DISCUSSION

Controlling for bias in detection

The variability of normalized differences for taxa within each of the six detectability categories indicates that they do not reflect categorical differences in detectability between the BE and ST methods (Fig. 2). This finding is perhaps understandable, because the effect of an increase in the number of observers on detectability, quantified by Spear *et al.* (2004) and leading to the categories we used in this paper, may not be the same as the effect of increased distance on detectability. We interpret our results, then, relative to all 28 taxa as a group.

Ship-avoiding species

Frigatebirds, Sooty Terns and White Terns were outliers in both of the analytical methods we used, with all three having high count rates in the BE data as compared with the ST data (White Terns were slight outliers in the regression analysis once Sooty Terns and storm-petrels were removed). One possible explanation for these patterns is that, with BE survey methods, a positive bias exists for these three taxa. In other words, frigatebirds and Sooty and White terns may be prevalent in the BE data because, relative to other taxa, these three are more easily detected at great distances because of their flight behavior or some other factor. Indeed, all three typically fly high above the water except when actively feeding (R. Pitman & L. Ballance, unpubl. data), a flight pattern which may enhance detectability at great distances. However, not all species with flight behavior that enhances detectability were identified in our analysis. For example, a number of large *Pterodroma* petrels and shearwaters use the wind to fly by dynamic soaring. This flight is characterized by rapid changes in altitude and alternating dorsal and ventral exposures to windward, a flight pattern that enhances detectability, even at great distances. For this reason, we believe that a more likely explanation is that the use of ST methods creates a negative bias for these three taxa—in other words, they are ship-avoiding species.

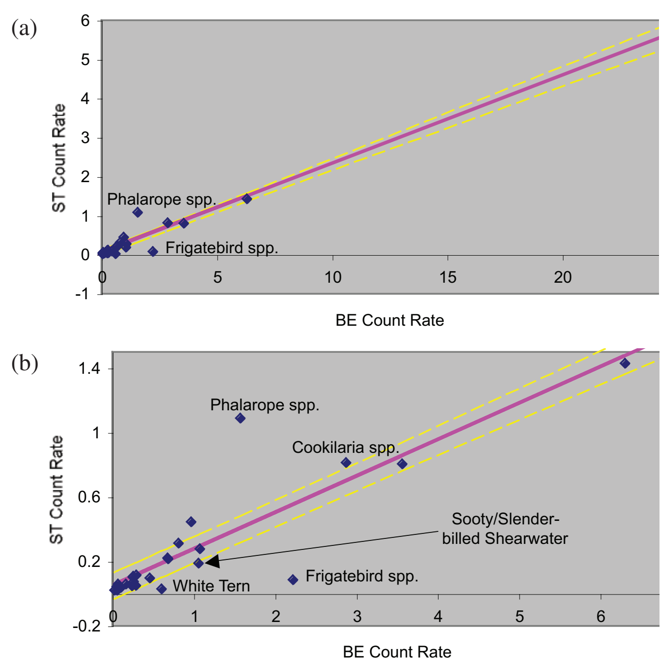

Fig. 5. (a) Linear regression of "big-eyes" (BE) versus strip transect (ST) count rates after removing Sooty Terns and storm-petrel spp., as per Fig. 4 (r^2 = 0.763, P = 0.319). Also shown are 95% confidence bands. (b) The same regression with enlarged x- and y-axis scales.

Frigatebirds and Sooty and White terns share two ecologic characteristics that may offer insight into why they are ship avoiders. All three feed in multi-species seabird flocks in association with tunas and dolphins (Au & Pitman 1986, 1988; Ballance *et al.* 1997), and all three are proficient fliers relative to other tropical species (see references below). The significance of this behavior is as follows. When ships approach schools of tunas and dolphins with which flocking seabirds associate, the subsurface predators tend to stop feeding, scatter and move away from the ship, even at distances of several miles (R. Pitman & L. Ballance, unpubl. data). The birds then typically do one of two things: they either sit down on the water or remain airborne. Both strategies achieve the same goal, to wait for the school to once again coalesce and begin to feed. The strategy a bird follows depends upon its flight proficiency. Birds with relatively high energetic flight costs will sit on the water; those with relatively low energetic flight costs will remain in the air. Sooty Terns rarely sit on the water (Haney 1985), and they have extremely low flight costs (Flint & Nagy 1984). Frigatebirds have the lowest wing loading of any seabird. They are unable to sit on the water, and they use oceanic thermals to remain in flight, presumably at very low energetic costs (Orta 1992, Weimerskirch *et al.* 2004). Because White Terns rarely sit on the water (R. Pitman & L. Ballance, unpubl. data), we expect that they too are on the proficient end of the energetic flight-cost scale.

For the purposes of this paper, the relevance of this behavior is that, when a ship approaches a seabird flock feeding in association with tunas and dolphins, the subsurface predators avoid the ship, and some seabirds sit to wait while others remain in the air at higher altitude to stay with the subsurface predators. Frigatebirds and Sooty and White Terns remain in the air. We believe that this latter behavior results in ship avoidance.

Ship-attracted species?

Phalaropes were outliers in both of the analytical methods we used, having high ST count rates relative to BE count rates. It is possible that this pattern resulted from ship-attraction; however, we believe that phalaropes were underrepresented in the BE data simply because their small size makes them difficult to detect at greater distances.

Four taxa had notably low normalized count rates, indicating a positive bias with ST methods. One of these four, Parkinson's/Shoemaker Petrel, is known to be a ship-follower (Pitman & Ballance 1992). A second, Bulwer's Petrel, is small and difficult to detect at distance; we suspect its low normalized count rate indicates the detectability problem rather than ship-attraction. We have no explanation as to why the two other taxa, Murphy's/Solander's and Dark-rumped Petrels, had such low normalized count rates.

Finally, storm-petrels were a strong outlier in the regression, with higher count rates in ST data as compared with BE data. We suspect that this finding is explained mainly by their small size and low flight, resulting in low detectability at distance, rather than in ship-attraction behavior.

CONCLUSIONS

Because our BE data were collected without specifying a strip width *a priori,* our results are qualitative. However, these data suggest that ship avoidance can be a bias in ST methods, possibly resulting (unless compensation is made) in an underestimate of density and abundance of flocking species with proficient flight. In our experience, at least some compensation can be made for frigatebird and tern avoidance by searching in front of the survey zone to estimate the number of birds that would have occurred in that zone had the ship not passed through. Such compensation is particularly important for areas in which feeding flocks occur. However, it is difficult for a single observer to both scan ahead of the survey zone and search within the zone to meet the strict assumptions of strip transect methods (all birds detected). Financial and berthing constraints often preclude a team of multiple observers, with one scanning ahead of the vessel while the other surveys the strip width. We therefore suggest a future study to test our hypothesis and calculate correction factors for seabirds that avoid ships. Such a study could use a methodologically similar approach to that used in our study (simultaneous use of big-eyes and handheld binoculars), but could apply standard ST methods in both cases, using a very large strip width for data collected with big-eyes.

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