APPENDIX 1

Most seabird surveys at sea adopt a 300 m strip transect for detecting resting birds, along with snapshot sampling within 300 × 300 m blocks at fixed intervals for flying birds. The use of a fixed strip width accounts for decreased detectability at greater distance, while snapshot sampling is designed to minimize bias introduced by animal movement.

However, seabird densities in Taiwan's waters are generally low — except near breeding colonies — so the fixed-width and snapshot-based methods risk omitting a significant proportion of detections. To address this, the Ocean Conservation Administration of Taiwan recommended a survey protocol based on continuous observation without predefined strip width (Yuan & Ding 2021).

Bai and Lien (2024) set out to develop a method for estimating bird densities under this protocol. Their approach builds on previous work by Spear et al. (1992) and Glennie et al. (2015). Spear et al. (1992) proposed a geometric framework to quantify bias introduced by bird movement in strip transect surveys. They demonstrated that the degree of bias is linked to the ratio of bird flight speed to vessel speed, and introduced a correction factor to adjust density estimates. Glennie et al. (2015) used simulations to explore the effects of animal movement on density estimation in line transect surveys. However, their simulations only covered scenarios where animals moved at up to twice the observer's speed — insufficient for seabird surveys, where bird speed relative to vessel speed is usually higher.

In the study of Bai & Lien (2024), the authors (1) used simulations to assess how bird movement (at 2 to 4 times of the vessel speed) affects density estimates, and derive the relationship between the correction factor and the speed ratio; (2) derived the effective strip width (ESW) for various bird taxa following the distance sampling protocol, using empirical data from the Taiwan Strait; (3) calculated taxon-specific correction factors and combined them with ESW values to produce corrected ESW (ESW_{cor}) values for future use in density estimation.

In the simulations, adapted from Glennie et al. (2015), birds were assumed to fly in straight lines at constant speed in random directions, without responsive movement toward the vessel. The observer was assumed to survey continuously in all directions around the vessel without a predefined strip width, in line with the protocol proposed by Yuan & Ding (2021). Detection probability was modeled as a monotonically decreasing function with respect to distance, and several function shapes were tested. Bird flight speeds were obtained from the literature, and a vessel speed of 5 m/s (approximately 10 knots, per Yuan & Ding's recommendation) was used to derive the correction factor for each taxon. Following Spear et al. (1992), a parameter K was defined as the ratio of estimated to actual density ($K = D' / D_0$), and K^{-1} was the correction factor. Based on distance sampling, the estimated density is:

$$D' = N / (2 \times L \times ESW)$$

Thus, the actual density can be derived by:

$$D_0 = D' \times K^{-1} = N / (2 \times L \times ESW \times K) = N / (2 \times L \times ESW_{cor})$$

Where N is the number of birds detected, L is the transect length, and ESW_{cor} is defined as ESW × K, enabling users to plug the corrected value into standard distance sampling formulas.

Simulation results (summarized in Fig. A1) confirmed that bird movement leads to density overestimation, and the magnitude of bias increases with the bird-to-vessel speed ratio (V_b/V_s). Within the simulated range, K can be approximated by the regression:

$$K = D'/ D_0 = 1.136 \times (V_b/V_s) + 0.032$$

The shape of the detection function had minimal influence on this relationship. The estimates of K, ESW, and ESW_{cor} of each taxon are presented in Table A1.

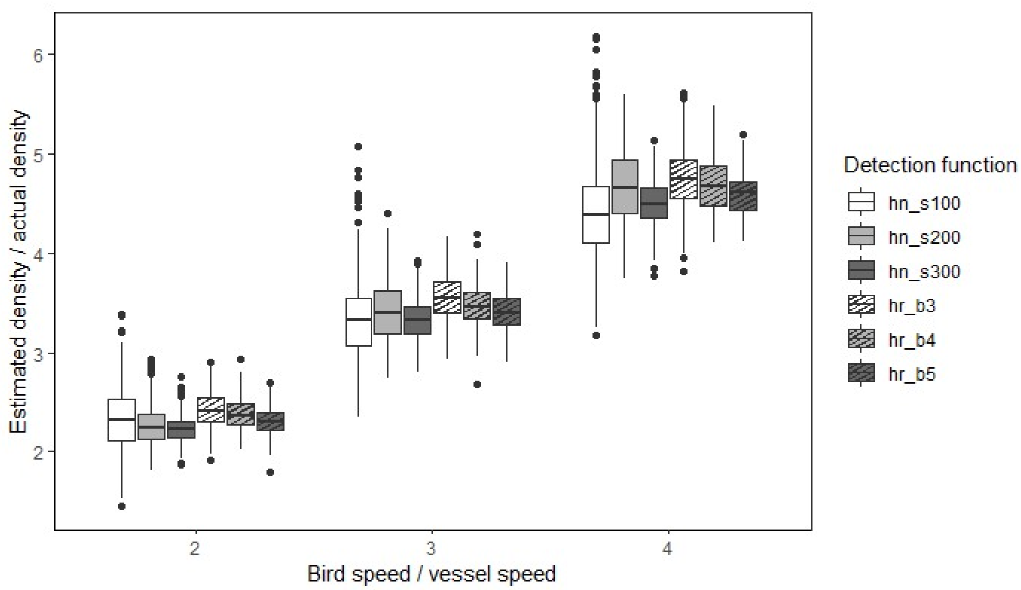

Fig. A1. The relationship between the ratio of estimated bird density to actual bird density and the ratio of bird flight speed to vessel speed. hn and hr denote the half-normal distribution and the hazard rate distribution, respectively. s denotes the parameter σ in the half-normal distribution. b denotes the parameter β in the hazard rate distribution.

TABLE A1 Flight speed of birds (V_b, in m/s), the inverse of the correction factor (K), the effective strip width (ESW, in meter), and the ESW after flight speed correction (ESW_{cor}, in meter) for each taxon.

Taxon	V_b	ESW	K	ESW_{cor}
Waterfowl	17.0	243	3.89	946
Phalaropes	13.1	130	3.01	392
Waders, small	10.9	138	2.51	347
Waders, large	13.1	239	3.01	720
Jaegers	15.1	246	3.47	854
Gulls, small	13.9	199	3.19	634
Gulls, large	12.6	261	2.89	754
Little Tern	10.9	169	2.51	423
Common Tern	12.1	178	2.78	494
Bridled Tern	12.1	183	2.78	509
Great Crested Tern	13.7	216	3.14	680
Terns, other	12.4	178	2.85	507
Storm Petrels	11.1	195	2.55	499
Petrels	11.9	199	2.74	544
Shearwaters	14.1	233	3.24	754
Boobies	16.4	307	3.76	1153
Egrets, Herons and Spoonbills	14.7	488	3.37	1643
Raptors	16.0	354	3.67	1298
Passerines	10.6	75	2.43	183

REFERENCES

BAI, M.-L. & LIEN, Y.-Y. 2024. Estimating density of birds at sea with vessel line-transect in Taiwan waters. *Taiwan Journal of Biodiversity* 26: 9-30. (in Chinese)

GLENNIE, R., BUCKLAND, S.T. & THOMAS, L. 2015. The effect of animal movement on line transect estimates of abundance. PLoS ONE 10: e0121333. doi:10.1371/journal.pone.0121333

SPEAR, L., NUR, N. & AINLEY, D.G. 1992. Estimating absolute densities of flying seabirds using analyses of relative movement. The Auk 109: 385-389. doi:10.2307/4088211

YUAN, H.-W. & DING, T.-S. 2021. Assessment of Impact Mitigation Measures for Protected Seabirds in Taiwan. Ocean Conservation Administration, Ocean Affairs Council, ROC.