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COMMENT

Recommendations for improving the estimation of the number of seabirds potentially sustained by fisheries discards

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Seabirds feed extensively on fisheries waste (discards and offal), and quantifying the degree of utilisation is an important and politically sensitive area of research (Furness 1992, Garthe & Hüppop 1994, Oro & Ruiz 1997). Studies on the feeding ecology of seabirds offer insights into issues like the energy flow in marine ecosystems and the ecological impacts of fishing activities. Recently, consumption experiments have been combined with published data on fisheries discards and bird bioenergetics to estimate the number of seabirds sustained by feeding exclusively on fisheries waste (Garthe et al. 1996, Walter & Becker 1997). Here, I point out some of the estimation problems faced in such studies and recommend ways for improving the data analysis. In particular, I demonstrate how the Delta method (Seber 1982) can provide estimates of precision, thus allowing more informed decision-making by conservation and fisheries managers.

Consumption of fisheries waste by seabirds is usually estimated by experiments conducted on board research vessels. In these experiments, items normally found in the discarded component of the commercial catch are discharged individually, and their fate is recorded. The realism of this design has been questioned for some time, mainly because experimental discarding cannot reproduce the conditions during commercial fishing (Garthe & Hüppop 1994). For example, Garthe & Hüppop (1998) recently showed that discarding up to 50 items simultaneously resulted in significantly lower estimates of consumption rates than those obtained from single release experiments. Data from the Scottish discard sampling programme (Stratoudakis 1997, Stratoudakis et al. 1998) suggest that multiple releases are closer to commercial discarding practices, where large quantities of fish are processed per haul (median of 1200 fish discarded per haul in the Scottish demersal fisheries).

Despite these deficiencies, the results of feeding experiments are used to quantify the total consumption of fisheries waste by seabirds in a fishery. Estimates of the number of seabirds (N) potentially sustained by feeding on fisheries waste are usually obtained by:

(1) multiplying estimates of total discards (D) for a fishery by an average estimate of consumption rate (CR) to get the total biomass potentially available to seabirds;
(2) multiplying this biomass by a calorific value (CAL) to obtain an energetic equivalent;
(3) multiplying the energetic equivalent by the assimilation efficiency (AE) to get the potentially utilised part of this food source; and
(4) dividing the potentially utilised energy by the average annual energetic requirement (ER) of a typical bird in the studied community:

$$N = (D \times CR \times CAL \times AE)/ER \quad (1)$$

Estimation is usually performed separately for groups of fishery waste assumed to have similar calorific values and consumption rates (roundfish, flatfish, etc.), while spatial variation in discards may also be taken into account (Garthe et al. 1996).

An issue often ignored in seabird studies that use the above estimation protocol is that the precision of N (which depends on the precision of the estimated input variables) should also be estimated. Reliable discard data are difficult to collect and annual estimates of total discards are usually based on small and variable samples. For example, annual estimates of biomass for the main commercial gadoids discarded by Scottish demersal vessels in the North Sea and the West of Scotland have coefficients of variation around 30 to

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40% (Stratoudakis et al. unpubl.), although the Scottish discards sampling programme is among the most extensive applied worldwide. Published estimates of the remaining parameters suggest similar elements of systematic and random variation. The calorific value of fish that form prey of seabirds in the North Sea varies between seasons and fish lengths (Hislop et al. 1991). Pooling estimates of calorific values across several years give coefficients of variation (CVs) of 5 to 10% at length, which roughly translate to 15 to 20% when length stratification is also ignored. Consumption rates vary among areas, seasons, and type and size of discarded material (Garthe et al. 1996, Garthe & Hüppop 1998). Using arcsine transformations of the consumption rates tabulated in Garthe et al. (1996), I roughly estimated CVs of 10 to 20% for roundfish and 35 to 40% for flatfish. Furness (1978) used simulated data to estimate CVs close to 30% for the annual energetic requirements of 2 of the most abundant seabirds in the Shetland area.

When estimating a variable as a function of several input variables, analytic variance estimation may be difficult or impossible. In such cases, the Delta method (Seber 1982) can offer an approximate numerical solution by means of a Taylor expansion (e.g. Prager & MacCall 1988, Borchers et al. 1997). In the case of Eq. (1), where the output variable is a simple product (or quotient) of uncorrelated input variables, the Delta method reduces the coefficient of variation (CV) of the estimated number of seabirds to:

$$CV^2(N) = CV^2(D) + CV^2(CR) + CV^2(CAL) + CV^2(AE) + CV^2(ER) \quad (2)$$

In a hypothetical example, I consider CVs of 30 to 40% for the total discards, 20 to 30% for consumption rate, 15 to 20% for calorific values and 25 to 35% for annual energetic requirements. Assimilation efficiency generally varies less than the remaining parameters (ICES 1994), and was therefore assumed to be measured without error. Under this scenario, CV for the estimated number of seabirds ranges between 46 and 64%.

The above approximate estimate of CV demonstrates that the currently available point estimates of the number of seabirds potentially sustained by fisheries waste should only be seen as order of magnitude indicators. For example, Walter & Becker (1997) estimated that approximately 60000 seabirds could be sustained for a year by exclusively feeding on the waste produced by beam trawlers targeting brown shrimp *Crangon crangon* off Lower Saxony, Germany. Similarly, Garthe et al. (1996) estimated that the entire North Sea fisheries waste could sustain 5.9 million seabirds throughout the year, although this estimate refers to an absolute maximum (i.e. assuming a consumption rate of 100%). If the levels of precision calculated in the above hypothetical example applied to these studies, the estimated standard error could be around 30000 for the waters off Lower Saxony and around 3 million birds for the entire North Sea. Assuming a multiplicative error, the 95% confidence interval would range between 22000 and 163000 birds in Lower Saxony and between 2.2 and 16.3 million birds in the North Sea.

Application of the Delta method also helps to identify the input variables with the largest contribution to the variance of the output variable (e.g Borchers et al. 1997). According to the precision estimates available here, the precision of the seabird estimates would benefit most by improvements in the estimation of total discards. Discard estimation from sampling programmes on board commercial vessels is currently an area of active research, with alternative design and model based estimators being tested (Stratoudakis et al. unpubl., M. McCracken, Department of Mathematics and Statistics, University of St. Andrews, Scotland, pers. comm.). Another input variable that probably contributes considerably to the variance of the overall estimate is consumption rate, a variable for which within-study variation is currently ignored. It is also possible that modelling the fate of offered fish as a function of fish length or number of seabirds present (see Garthe & Hüppop 1998 for rationale) could improve the estimation of consumption rate.

In conclusion, although there is no doubt that seabirds feed extensively on fisheries waste, the estimates that have been provided up to date are biased and imprecise. Garthe & Hüppop (1998) offer a way to deal with one of the major sources of bias, the single-item release in experimental discarding. Here, I have shown how the application of the Delta method can provide approximate estimates of precision and confidence limits for the estimated number of seabirds. Despite its approximate nature, application of the Delta method may prevent point estimates of seabirds sustained on fisheries waste from being used out of context in debates related to conservation and fisheries management. It also helps to identify the research areas that would allow more precise estimates of seabirds to become available to decision makers.

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