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LETTER

Integrating Satellite-Tagged Seabird and Fishery-Dependent Data: A Case Study of Great Shearwaters (*Puffinus gravis*) and the U.S. New England Sink Gillnet Fishery

Joshua M. Hatch[1], David Wiley[2], Kimberly T. Murray[3], & Linda Welch[4]

[1] Integrated Statistics, Inc., 172 Shearwater Way, Falmouth, MA 02540, USA
[2] Stellwagen Bank National Marine Sanctuary, 175 Edward Foster Road, Scituate, MA 01938, USA
[3] NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA
[4] U.S. Fish & Wildlife Service, Maine Coast Islands National Wildlife Refuge, P.O. Box 279, Milbridge, ME 04658, USA

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Correspondence
Joshua M. Hatch, 166 Water Street, Woods Hole, MA 02543, USA.
Tel: 508-495-2259; fax: 508-495-2066
E-mail: joshua.hatch@noaa.gov

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Abstract

Identifying the overlap of commercial fishing grounds and seabird habitat can suggest areas of high bycatch risk and inform management and mitigation measures. We used Bayesian state space modeling to describe the movements of 10 satellite-tagged Great Shearwaters and a bivariate kernel density technique to investigate spatial overlap with commercial fishing effort to predict areas of high bycatch in the Gulf of Maine. We then used contemporaneous fishery observer data to test the validity of our predictions, highlighting an area constituting 1% of the Gulf of Maine as having the highest bycatch risk that accounted for 50% of observed takes. Fishery observer data also provided insights into characteristics of the seabird-fishery interactions. Our results indicate that a relatively small number of satellite-tagged seabirds, when combined with fishery-dependent data, can lead to identifying high-bycatch areas, particular fishing practices that might increase risk, and fishing communities that could be targeted for education/mitigation.

Introduction

Fisheries-related bycatch mortality has been linked to population declines of numerous long-lived seabird species and is of global concern (Tuck *et al.* 2011; Croxall *et al.* 2012; Regular *et al.* 2013). Adverse population effects from incidental takes are compounded by uncertainties imposed by climate change and other chronic, human-induced pressures that can be difficult to evaluate (Genovart *et al.* 2013; Moreno *et al.* 2013), making bycatch mitigation of even greater conservation importance. For seabird species that are known or suspected of being vulnerable to bycatch, quantifying overlap between habitat use and commercial fishing grounds can suggest areas where it would be prudent to test and implement mitigation measures or increase monitoring efforts. However, the scale at which overlap between commercial fishing grounds and seabird habitat is assessed can be contentious (Croxall *et al.* 2013, Torres *et al.* 2013a, b). For instance, broad-scale assessments often fail to discriminate between the key issues of overlap (i.e., ecological association) versus interaction (i.e., bycatch) (Croxall *et al.* 2013, Torres *et al.* 2013a, b; Votier *et al.* 2013).

One way to differentiate between overlap and interaction is by integrating bycatch data from onboard observers monitoring commercial fishing vessels with tracks from satellite-tagged seabirds to assess concurrence and subsequent interaction with culpable fisheries. Areas where vessels and seabirds co-occur could reflect spatial and temporal overlap rather than interaction (Torres *et al.* 2013a). Sampling these fisheries for seabird bycatch could validate whether times and areas of overlap result in seabird-fishery interactions, and investigating the characteristics of these events might further identify priority areas and/or practices for mitigation.

Great Shearwaters (*Puffinus gravis)* are subject to one of the highest levels of bycatch in the Atlantic Ocean (ICES 2013), and in our Gulf of Maine study area (US National

Marine Fisheries Service, unpublished data). Here we provide an integrated assessment of the spatial intersection between foraging Great Shearwaters and commercial gillnetters fishing in the Gulf of Maine from June to December of 2013. We then validated areas of overlap using fishery observer data, collected in times and areas where tagged seabirds and commercial fishers co-occurred. The fishery observer data were also used to identify characteristics of the fishing fleet that might contribute to shearwater bycatch and the fishing ports that might be the focus of education and outreach programs. While our assessment of broad-scale interactions is a partial description of the total incidental mortality sustained by Great Shearwaters, it is an essential first step in characterizing bycatch and how it might be selectively mitigated.

Materials and methods

All analyses were conducted in the R programming language and software environment (R Development Core Team 2013). Additionally, maps were generated using the shoreline and bathymetry data sets provided by Wessel & Smith (1996) and GEBCO One Minute Grid (n.d.), respectively.

Seabird tracking

To identify Great Shearwater habitat use in the Gulf of Maine (Figure 1a), we placed 12-gram platform transmitter terminals (PTTs; Microwave Technology, Fremont, CA, USA) on 10 Great Shearwaters captured in the Great South Channel off the coast of Cape Cod, Massachusetts, USA (Figure 1a). Movement of tagged shearwaters was tracked using the Argos satellite system for approximately 4 months, from July to October of 2013, a partial timeframe when shearwaters overwinter in the region. Great Shearwaters primarily utilize U.S. Northwest Atlantic waters as a migratory staging ground, arriving in early May and subsequently departing in December en route to breeding grounds in the South Atlantic (Powers 1983).

Seabird paths were recorded at irregular time intervals and some tracks were abbreviated, possibly a consequence of battery failure, mortality, or tag detachment. As such, Argos data were filtered, interpolated, and regularized at 3-hour intervals using Bayesian state-space models (SSMs) (Plummer 2003; Jonsen *et al.* 2005). SSMs work by simultaneously estimating the "true," unobserved locations of seabirds' paths and the measurement errors imposed on observations through satellite transmissions. Argos assigns each calculated position to a location class (i.e., 3, 2, 1, 0, B, A, Z) based on theoretical estimates of location error and the number of messages received by satellites from the PTTs (Boyd & Brightsmith 2013). We used all location classes, except for Z (representing an "invalid location"), to estimate Great Shearwater tracks and removed locations that plotted on land.

Commercial fishing records

Commercial fishing grounds were identified through vessel trip reports (VTRs), which are logbook records of fishers participating in federally managed fisheries. All federally permitted vessels in the U.S. Northeast region, with the exception of vessels solely permitted to catch American lobster, must submit a VTR on a trip-by-trip basis. Commercial fishers are instructed to record the fishing location "where most of your fishing effort occurred", as well as catch and gear particulars. Fishing permit applications were also used to obtain vessel home ports, and were linked back to VTRs by means of unique identifiers. In order to validate self-reported locations, comparison was made between the average latitude and longitude of all gear deployments (i.e., sets) recorded by fishery observers and the spatial coordinates documented by the VTR for the same fishing trip. VTRs from fishers participating in the New England sink gillnet (NESG) fishery were used to assess seabird bycatch risk, as this fishery accounts for the majority of observed shearwater bycatch in the U.S. Northwest Atlantic (US National Marine Fisheries Service, unpublished data). Additionally, only VTRs from June to December of 2013 were used, as these months are when Great Shearwaters occupy the Gulf of Maine (Powers 1983).

Spatial intersection

In order to identify areas of use by Great Shearwaters and commercial gillnetters, we computed bivariate kernel densities for each using the estimated locations of tagged seabirds (i.e., posterior average) and the self-reported positions of commercial fishers from submitted VTRs, respectively (Venables & Ripley 2002). We then separately calculated the contour levels that included 50%, 75%, and 95% of the shearwater and fishing activities. Estimated bivariate kernel densities were then spatially intersected to obtain areas of overlap (Bivand & Rundel 2013), which may predict seabird bycatch. High-risk areas included the intersection of 50% contours, medium-risk areas included the intersection of 75% contours and included the high-risk areas, and low-risk areas included the intersection of 95% contours and included the high- and medium-risk areas. Intersected areas of overlap were then superimposed with observed locations of Great Shearwater bycatch from the NESG fishery operating from June to December of 2013. Areas (km^2) of risk

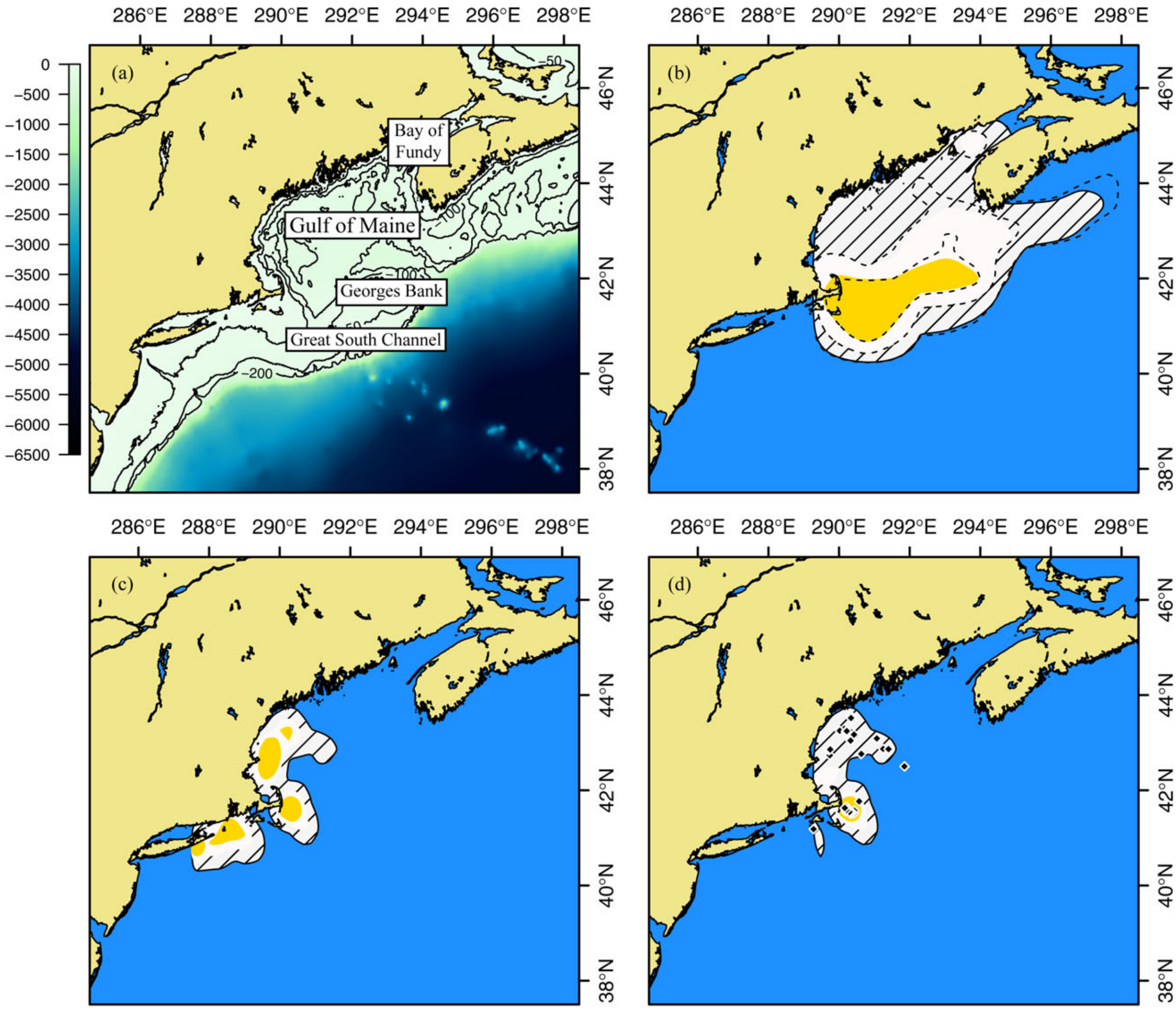

Figure 1 The study region (a) along with associated bathymetry (GEBCO One Minute Grid n.d.). Great Shearwater habitat use (b) and commercial fishing grounds for gillnetters (c) obtained from bivariate kernel densities of estimated locations and self-reported positions, respectively, for June to December of 2013. The intersection of (b) and (c) is depicted in (d), which is overlaid with observed incidental takes from fishery observers. Gold denotes 50% contours, white denotes 75% contours, and white with hatching denotes 95% contours. Dashed lines in (b) indicate changes to contours when using a time-weighted estimation scheme for bivariate kernel densities.

contours were calculated assuming a North American Albers Equal Area Conic projection (Bivand *et al.* 2014).

The influence of truncated seabird tracks on estimating foraging grounds was assessed by comparing bivariate kernel density estimates using weighted versus non-weighted estimation schemes (Maxwell *et al.* 2013). A basic time-weighted estimation scheme was used, whereby weights were calculated as the inverse of the total number of seabirds that had location estimates at each 3-hour interval (Maxwell *et al.* 2013). In this way, positions with more seabird locations contribute less to area demarcation, allowing tagged individuals with longer tracks to contribute more to the estimation process, in the hopes of reflecting a more representative spatial range (Maxwell *et al.* 2013).

Fisheries observer data

In 2013, two fisheries observer programs were tasked with monitoring fishing vessels that participated in federally managed fisheries within U.S. Northwest Atlantic waters: the Northeast Fisheries Observer Program and the Northeast Fisheries At-sea Monitoring Program. Both fisheries observer programs were responsible for the collection of biological information from commercial fishing trips, including characteristics pertaining to the vessel and individual gear deployments/retrievals (e.g., time, area, catch, discard, and protected species bycatch—marine mammals, sea turtles, and seabirds).

In order to investigate potential differences in fishing practices across risk areas, we calculated seabird-bycatch rates for each targeted fish species (i.e., spiny dogfish, groundfish, and skate). Uncertainty around estimated seabird-bycatch rates were then obtained through standard nonparametric bootstrapping techniques (Canty & Ripley 2012), and statistically significant differences were assessed through overlapping 95% confidence intervals. For this study, bycatch rates were defined as the total number of seabirds bycaught per metric ton of landed kept catch, as other measures of effort were sparsely recorded or contained inaccuracies (Murray 2009).

Results

Seabird tracking

A total of 4,259 3-hour positions were estimated for the 10 satellite-tagged seabirds. Using the posterior average of estimated locations, the tagged shearwaters traveled a mean distance of 4,866 km over an average duration of 53 days, transiting roughly 92 km/day. Several areas of use were identified in the Gulf of Maine, and represented high- (50% contours), medium- (75% contours), and low-density (95% contours) regions (Figure 1b). Negligible differences were detected between the weighted and nonweighted estimation schemes (Figure 1b). As such, we used nonweighted bivariate kernel densities to ascertain overlap between seabirds and commercial fishing vessels.

Commercial fishing records

Self-reported fishing locations were shown to be an adequate proxy for the average fishing location over an entire fishing trip (linear regression; longitude $R^2 = 0.99$, latitude $R^2 = 0.98$). As such, commercial fishing grounds in the Gulf of Maine were identified, and represented high- (50% contours), medium- (75% contours), and low-density (95% contours) regions (Figure 1c). A total of 5,598 VTRs were used to demarcate commercial fishing grounds for the NESG fishery (Table 1), of which 737 were observed with an estimated observer coverage >12% (Table 1).

Spatial intersection

Overlap between seabirds and commercial fishing vessels was determined by spatially intersecting high-, medium-, and low-use areas for each (Figure 1d), and reflected varying levels of bycatch risk. High-risk areas were represented by intersections of 50% contours, and included an area that constituted 1% (2,186 km^2/179,008 km^2) of the Gulf of Maine (Figure 1d). Medium-risk areas were represented by intersections of 75% contours, and included areas that constituted 3% (6,169 km^2/179,008 km^2) of the Gulf of Maine (Figure 1d). Finally, low-risk areas were represented by intersections of 95% contours, and included areas that constituted 20% (35,008 km^2/179,008 km^2) of the Gulf of Maine (Figure 1d).

Vessels fishing within the high-, medium-, and low-risk areas emanated from 4, 11, and 24 ports, respectively (Table 1). The 4 home ports of vessels fishing in the high-risk area were located within southeastern Massachusetts, while the 11 and 24 ports of vessels fishing in the medium- and low-risk areas were housed within the states of Massachusetts, New Hampshire, and Maine (Table 1). For comparison, vessels within the entire NESG fishery have home ports located within the states of North Carolina, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

Fisheries observer data

Bycatch

A total of 88 shearwaters were observed taken in the NESG fishery on 46 commercial fishing trips that set 51 gillnet strings. A majority of takes on gillnets were of one or two individuals (42/51 or 82%), with a maximum of 6 individuals being taken on a single gillnet string in July. Most successive takes occurred within an average of 4 days and within an average of 70 km, suggesting that rafting or large feeding aggregations were not solely responsible for observed bycatch patterns. The majority of takes occurred in summer months from June to August (72/88 or 82%), although takes were also observed from September to December.

Validation of spatial intersections

Exactly 50% (44/88) of observed shearwater takes occurred within the predicted high-risk area (intersections of 50% contours), 52% (46/88) of observed shearwater takes occurred within the predicted medium-risk areas (intersections of 75% contours), and 93% (82/88) of observed shearwater takes occurred within the predicted low-risk areas (intersections of 95% contours). Only 7% (6/88) of observed shearwater takes occurred outside of the high-, medium-, and low-risk areas. Sampling of vessels participating in the NESG fishery was also shown to be representative, with the proportion of kept landings

Table 1 Cumulative numbers of observed sets, observed trips, commercial fishing trips, home ports, home states, bycaught Great Shearwaters, and observed sets targeting spiny dogfish for the New England sink gillnet fishery from June to December of 2013 by risk area.

Risk Area	Observed Sets	Observed Trips	VTR Trips	Home Ports	Home States	Observed Bycatch	Observed Dogfish sets
High	646	196	956	4	1	44	89
Medium	930	281	1,539	11	3	46	145
Low	2,790	671	3,685	24	3	82	260
Total	3,216	737	5,598	45	8	88	271

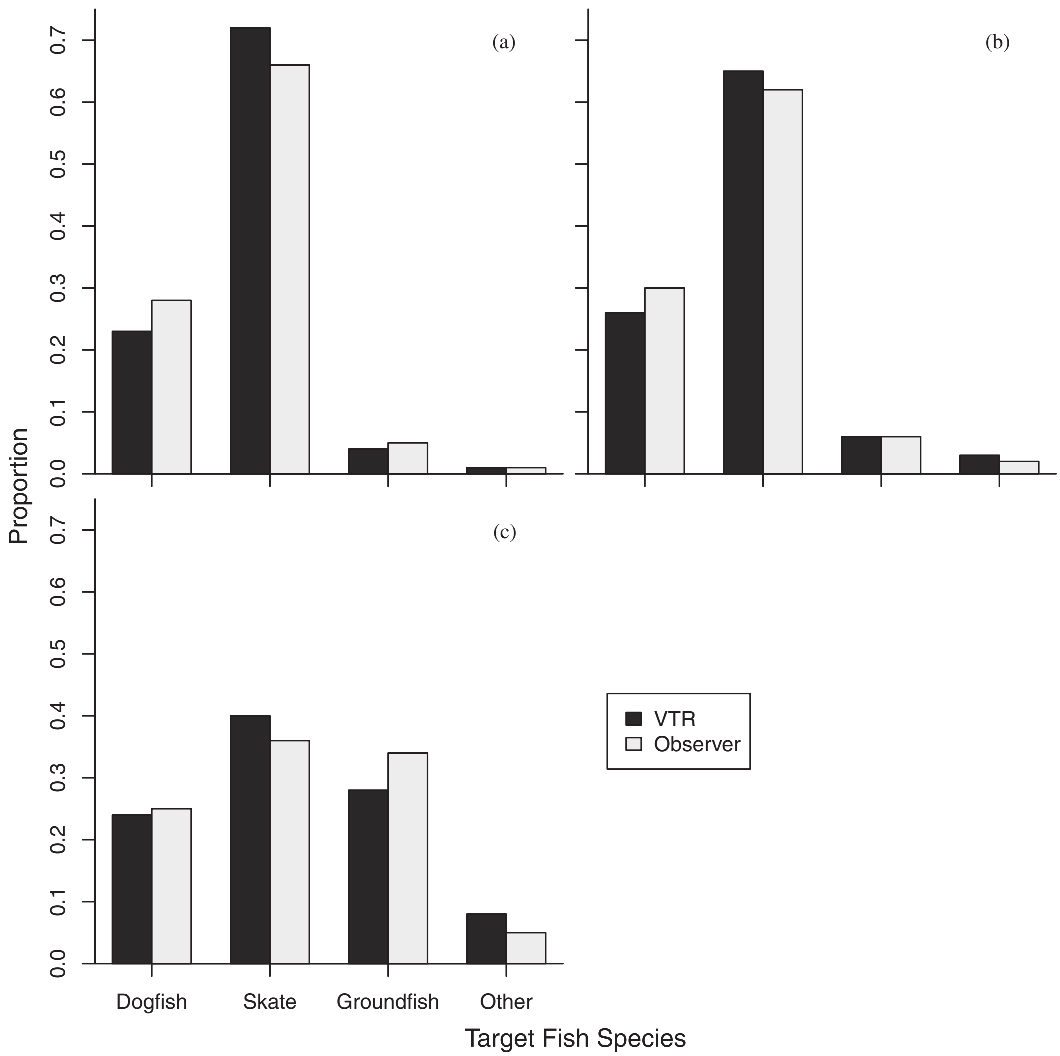

Figure 2 Proportion of kept landings for spiny dogfish, skate, groundfish, and other targeted fish species observed and self-reported on VTRs for the (a) high-, (b) medium-, and (c) low-risk areas.

observed in each risk area closely matching that reported on VTRs across targeted fish species (Figure 2).

Fishery characteristics

Great Shearwater bycatch disproportionately occurred on vessels targeting spiny dogfish (*Squalus acanthias*), relative to other targeted fish species. Percentages of observed shearwater takes that occurred on gillnets targeting spiny dogfish within the high-, medium-, and low-risk areas were 86% (38/44), 83% (38/46), and 48% (39/82), respectively. However, only 14% of observed nets within the high-risk area, 16% of observed nets

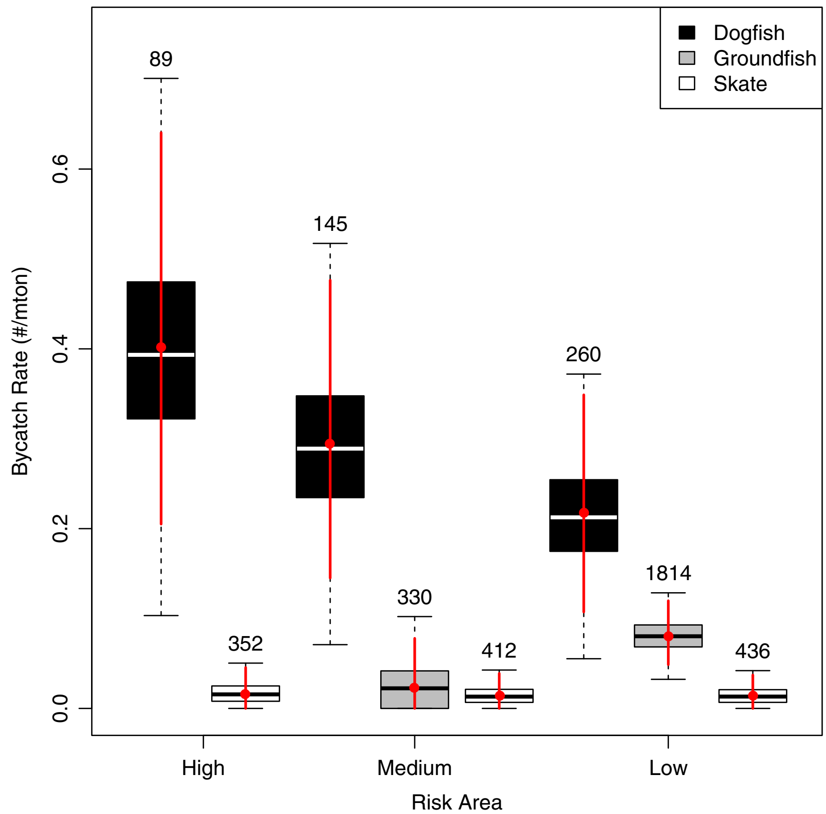

Figure 3 Bootstrapped distributions of bycatch rates defined as the number of seabirds bycaught per metric ton of landed kept catch for the high-, medium-, and low-risk areas across targeted fish species. Numbers above boxplots denote the total number of observed sets targeting a particular fish species within a specific risk area (i.e., sample size). Red lines denote 95% confidence intervals, and red dots denote the mean.

within the medium-risk area, and 9% of observed nets within the low-risk area actually targeted spiny dogfish (Table 1). This incommensurate effect is also reflected in the bootstrapped distributions of seabird-bycatch rates, with rates for sets targeting spiny dogfish being significantly higher than those targeting groundfish or skate ($\alpha = 0.05$; Figure 3). For the low-risk area, 95% confidence intervals around seabird-bycatch rates for sets targeting spiny dogfish versus groundfish overlapped slightly (Figure 3).

One reason that could help explain the disproportionate contribution of fishers targeting spiny dogfish to shearwater bycatch may be in the baiting of gillnets during gear deployments. Beginning in 2012, observers started to comment on the practice of baiting nets with fish carcasses during sets, most of which were targeting spiny dogfish. Among the variety of information observers were required to collect, the baiting of nets was recorded opportunistically and does not have a dedicated field on observer logs. The opportunistic nature of data collection around the use of baiting prohibits the rigorous testing of differences between baited and nonbaited nets for seabird bycatch. Still, there does appear to be a striking difference in seabird-bycatch rates between sets targeting spiny dogfish versus other fishes (Figure 3), with 79% (19/24) of observed gillnets targeting spiny dogfish having baited their nets, relative to the subset of observed sets where observers noted baiting practices.

Discussion

While previous studies have investigated the fine-scale (tens of kilometers over several days) spatiotemporal overlap between commercial fishing vessels and seabird habitat (Torres *et al.* 2013a; Bodey *et al.* 2014), our analysis represents one of the first to show that broad-scale (thousands of kilometers over several months) patterns in co-occurrence can be used to inform bycatch management. We identified a strong association between overlap and subsequent observed seabird-fishery interactions, suggesting that broad-scale knowledge can be informative to bycatch mitigation when fine-scale information is lacking. For U.S. Northwest Atlantic waters, fishery observer data showed that a small area (1%) of the Gulf of Maine accounted for the majority of shearwater bycatch and that a subset of the gillnet fleet (sink gillnets targeting spiny dogfish originating from four ports) constituted the primary interaction. Such highly resolved identification of problematic areas and fishing practices allows for tailored education and mitigation measures that can be effective at reducing seabird bycatch while minimizing cost across the fishing industry.

Care should be taken in generalizing our findings to other systems or seabirds, as the response of seabirds to fishing vessels has been shown to differ across fisheries and species (Torres *et al.* 2013a; Bodey *et al.* 2014). Recent research demonstrates the ability of seabirds to differentiate vessel type (e.g., trawlers vs. gillnets), as well as vessel activity (e.g., steaming vs. fishing) (Bodey *et al.* 2014). Bodey *et al.* (2014) found that seabirds adapted their behavior to match the discarding practices of nearby vessels, indicating broad-scale patterns in co-occurrence may be more than coincident. Still, attraction of seabirds to fishing vessels does not necessarily imply interaction, as many factors determine bycatch (Croxall *et al.* 2013). Not to mention, there may be uncertainty surrounding the response of individuals to fishing vessels in close proximity (e.g., age, sex; Torres *et al.* 2013a), information that is often lost when analyses are conducted over broad spatiotemporal extents (Torres *et al.* 2013a, b). Integrating data from tagging and fisheries observers can provide a means to focus broad-scale efforts on times and areas where the likelihood of interaction is high. Our results further corroborate the conclusion drawn by Torres *et al.* (2013b), in that tagging data and direct observations can be used in conjunction to better understand the nature of seabird-fishery interactions and better inform management at a finer scale.

Effective mitigation measures to reduce seabird bycatch rely heavily on buy-in from the commercial fishing industry, and require strategies that are achievable and easily implemented. Furthermore, alterations to fishing practices and/or use of deterrent devices should be based on sound scientific advice and not place an undue burden on commercial fishers (Torres *et al.* 2013b). Given the opportunistic nature of data collection for the baiting of nets, it is difficult to tease out a causal relationship with seabird bycach. Cooperative research efforts with the fishing industry could provide an opportunity to rigorously examine the impacts of baited nets on seabird bycatch through experimental trials. Such involvement with commercial fishers would improve credibility and understanding of bycatch reduction research, and provide greater appreciation and awareness for seabird bycatch issues.

An interesting aspect of our analysis lies in the fact that medium-risk contours only accounted for an additional 2% of observed takes in 2013 (52% total), and yet represent joint areas utilized by commercial gillnetters and tagged shearwaters 75% of the time. This incongruence may suggest tagged seabirds were unrepresentative of the overall foraging population, thereby underestimating bycatch risk areas. It may also suggest that overlap does not imply interaction for all risk areas, and merely represents an ecological association between fishers and seabirds. Interaction may further depend on fishing activities and/or practices during times and areas of co-occurrence and possibly other factors like the reduction in local forage fish populations making baited nets increasingly attractive to seabirds (Kai *et al.* 2013). While these hypotheses are purely speculative, it further demonstrates the need for more research into the spatial and temporal dynamics of seabird-fishery interactions, as well as the life history characteristics of the bycaught specimens.

While our work demonstrates where the majority of interactions currently take place, our ability to extrapolate these findings to the future is uncertain. More work will be needed to assess the spatiotemporal stability of high-risk areas, particularly as quota allocations for groundfish stocks in the study area are being reduced (Murphy *et al.* 2012), with a potential redistribution of fishing effort and subsequent areas of seabird-fishery interaction. In addition, environmental variability and/or climate-induced alternations to the ecosystem could modify current habitat use by fishers and Great Shearwaters (Genovart *et al.* 2013; ICES 2013). Our approach of combining multiple data sources, collected over broad spatial and temporal extents, represents a cost-effective method to identify priority areas and/or fishing practices for bycatch mitigation in this and probably other species of seabirds.

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References

Bivand, R. & Rundel, C. (2013) rgeos: interface to geometry engine - open source (GEOS). R package version 0.3-2.

Bivand, R., Keitt, T. & Rowlingson, B. (2014) rgdal: bindings for the geospatial data abstraction library. R package version 0.8-16.

Bodey, T.W., Jessopp, M.J., Votier, S.C., *et al.* (2014) Seabird movement reveals the ecological footprint of fishing vessels. *Curr. Biol.*, **24**(11), R514-R515.

Boyd, J.D. & Brightsmith, D.J. (2013) Error properties of Argos satellite telemetry locations using least squares and Kalman filtering. *PLoS ONE*, **8**(5), e63051.

Canty, A. & Ripley, B. (2012) Boot: bootstrap R (S-plus) functions. R package version 1.3-7.

Croxall, J.P., Butchart, S.H.M., Lascelles, B., *et al.* (2012) Seabird conservation status, threats and priority actions: a global assessment. *Bird Conserv. Int.*, **22**, 1-34.

Croxall, J., Small, C., Sullivan, B., *et al.* (2013) Appropriate scales and data to manage seabird-fishery interactions: comment on Torres et al. (2013). *Mar. Ecol. Prog. Ser.*, **493**, 297-300.

GEBCO One Minute Grid (n.d.) GEBCO one minute grid: 'the GEBCO one minute grid, version 2.0, http://www.gebco.net'. Accessed 15 May 2014.

Genovart, M., Sanz-Aguilar, A., Fernández-Chacón, A., *et al.* (2013) Contrasting effects of climatic variability on the demography of a trans-equatorial migratory seabird. *J. Anim. Ecol.*, **82**, 121-130.

ICES. (2013) Report of the Workshop to Review and Advise on Seabird Bycatch (WKBYCS), 14-18 October 2013, Copenhagen, Denmark. ICES CM 2013/ACOM: 77, p. 79.

Jonsen, I.D., Flemming, J.M. & Myers, R.A. (2005) Robust state-space modeling of animal movement data. *Ecology*, **86**(11), 2874-2880.

Kai, E.T., Benhamoul, S., Pichegru, L., *et al.* (2013) Are Cape gannets dependent upon fishery waste? A multi-scale analysis using seabird GPS-tracking, hydro-acoustic surveys of pelagic fish and vessel monitoring systems. *J. Appl. Ecol.*, **50**, 659-670.

Maxwell, S.M., Hazen, E.L., Bograd, S.J., *et al.* (2013) Cumulative human impacts on marine predators. *Nat. Commun.*, **4**, 2688-3688.

Moreno, R., Jover, L., Diez, C., Sardà-Palomera, F. & Sanpera, C. (2013) Ten years after the Prestige oil spill: seabird trophic ecology as indicator of long-term effects on the coastal marine ecosystem. *PLoS ONE* **8**(10), e77360.

Murphy, T., Kitts, A., Records, D., *et al.*, (2012) 2011 Final Report on the Performance of the Northeast Multispecies (Groundfish) Fishery (May 2011-April 2012). US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12–30; p. 111.

Murray, K.T. (2009) Characteristics and magnitude of sea turtle bycatch in US mid-Atlatnic gillnet gear. *Endanger Species Res.*, **8**, 211-224.

Plummer, M. (2003) JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. DSC 2003 proceedings.

Powers, K.D. (1983) Pelagic distribution of marine birds off the Northeastern United States. US Dept Commer, NOAA Tech Memo NMFS-F/NEC-27, p. 201.

R Development Core Team. (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Regular, P.R., Montevecchi, W., Hedd, A., Robertson, G. & Wilhelm, S. (2013) Canadian fishery closures provide a large-scale test of the impact of gillnet bycatch on seabird populations. *Biol. Lett.*, **9**(4), 20130088. http://rsbl.royalsocietypublishing.org/content/roybiolett/9/4/20130088.full.pdf.

Torres, L.G., Sager, P.M., Thompson, D.R. & Phillips, R.A. (2013a) Scaling down the analysis of seabird-fishery interactions. *Mar. Ecol. Prog. Ser.*, **473**, 275-289.

Torres, L.G., Sagar, P.M., Thompson, D.R. & Phillips, R.A. (2013b) Scale-dependence of seabird-fishery data analysis and management: Reply to Croxall et al. (2013). *Mar. Ecol. Prog. Ser.*, **493**, 297-300.

Tuck, G.N., Phillips, R.A., Thomson, R.B., *et al.* (2011) An assessment of seabird-fishery interactions in the Atlantic Ocean. *ICES J. Mar. Sci.*, **68**, 1628-1637.

Venables, W.N. & Ripley, B.D. (2002) *Modern Applied Statistics with S*, fourth edition. Springer, New York. ISBN 0-387-95457-0.

Votier, S.C., Bicknell, A., Cox, S.L., Scales, K.L. & Patrick, S.C. (2013) A bird's eye view of discard reforms: bird-borne cameras reveal seabird/fishery interactions. *PLoS ONE* **8**(3), e57376.

Wessel, P. & Smith, W.H.F. (1996) A global self-consistent, hierarchical, high-resolution shoreline database. *J. Geophys. Res.*, **101**, 8741-8743.

