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NOTE

The Changjiang River discharge affects the distribution of foraging seabirds

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ABSTRACT: Little is known about the effects of river discharge on the distribution of foraging seabirds at sea. Here, we tracked a pelagic seabird, the streaked shearwater *Calonectris leucomelas*, breeding on an island in the East China Sea, by using a GPS-PTT to examine how its foraging area was related to the river plume area. In the East China Sea, the Changjiang River (i.e. Yangtze River), the largest river in Asia, discharges a large amount of fresh water and nutrients into the sea, with the river plume extending northeastward offshore. Streaked shearwaters concentrated foraging efforts in areas with relatively high chl *a* concentration (1.70 mg m^{-3}) and sea surface temperatures of around 25°C, conditions which were probably associated with the outflow from the Changjiang River. Primary production and thereby fish stock are known to be enhanced in the Changjiang plume, where a strong vertical thermohaline front exists and schools of forage fish are distributed in the upper layers above the thermocline, which may ensure predictable resource availability for the shearwaters. Our results suggest that large rivers can serve as a large spatial-scale determinant of oceanic physical features and shape oceanic foraging hotspots for marine predators.

KEY WORDS: Changjiang River · East China Sea · Seabird · Foraging · Oceanic physical feature · Productivity

INTRODUCTION

Freshwater discharge from large rivers (e.g. the Amazon and the Mississippi) is known to enhance oceanic primary production by supplying nutrients into the sea, inducing upwelling by convergent fronts, and/or generating vertical stability of the water column, thus influencing the marine ecosystem on the shelf (Lohrenz et al. 1990, Drinkwater & Frank 1994, Smith & Demaster 1996). Herbivorous zooplankton are often aggregated in enhanced primary production areas, which in turn generally attracts assemblages of forage fish and any predators that feed on them, such as seabirds (Hunt et al. 1999). Therefore, we expect that areas under the influence of river discharge should attract foraging seabirds, though only a few studies have considered the ecological role of such areas (Dias et al. 2012, Zamon et al. 2014).

The East China Sea (ECS) is one of the largest marginal seas in the world, and 70% (0.9×10^6 km^2) of its area is occupied by the continental shelf. The Changjiang River (i.e. Yangtze River) is the largest river in Asia and discharges large amounts of fresh water (an annual mean discharge of 30×10^3 m^3 s^{-1}; Beardsley et al. 1985) with abundant nutrients into the upper layer of oceanic water in the ECS (Gong et al. 2003, Chen 2009), supporting high biological production (Gong et al. 2011). Here, we tracked a pelagic seabird, the streaked shearwater *Calonectris leucomelas*, breeding on an island in the ECS (ca. 600 km

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from the estuary of the Changjiang River) to examine how the river discharge plume affects their foraging distributions.

MATERIALS AND METHODS

Fieldwork was conducted at Meshima Island in the Danjo-gunto archipelago (31.6° N, 128.2° E; Fig. 1a) on 8 September 2010. We attached a solar-powered GPS-PTT (PTT = platform transmitter terminal) (28 g, 62 × 22 × 14.5 mm with 178 mm antenna, Microwave Telemetry) to the back feathers of 6 randomly chosen streaked shearwaters using Tesa® tape. During the breeding season, streaked shearwaters forage over large areas at sea and surface-feed on pelagic fish, mainly Japanese anchovy *Engraulis japonicus* (Matsumoto et al. 2012). Although data are limited, anchovy were identified in the stomach contents from several individuals of the study colony that regurgitated at the time of their capture (S. Matsumoto unpubl. data). The GPS-PTT was programmed to record fixes every 2 h during the daytime (06:00, 08:00, 10:00, 12:00, and 14:00 h). Two birds were tracked until 22 September and 1 October 2010, respectively. For the rest of the birds, positions were recorded until 1, 9, 23, and 27 November 2010, respectively. Streaked shearwaters migrate southward to tropical oceans during their non-breeding period, and the start of migration was determined through analyzing the rapid southward movement by the tracked birds. We analyzed their positions during the chick-rearing period (9 September–20 October), including 33 ± 12 d of tracking data (see the Supplement at www.int-res.com/articles/suppl/m555p273_supp.pdf). All data were pooled for further analysis (Fig. 1b). We estimated the 95% (foraging area) and 50% (core area) utilization distributions of tracked streaked shearwaters using the kernel estimation method in the ESRI ArcGIS 10.2.2 Spatial Analyst tool. The smoothing parameter (h) was determined by least squares cross-validation using the Home Range extension for ArcView 3.3. Bird density close to a breeding colony is stochastically high due to geometric spreading as birds commute to and from the island; therefore, we subtracted concentrically predicted density values from the kernel density estimate to extract the shearwater–marine environment relationship, following the formula in Yamamoto et al. (2015).

Monthly mean sea surface temperatures (SSTs) and chl *a* concentrations in September and October 2010 (0.025° resolution, measured by Aqua-MODIS) were

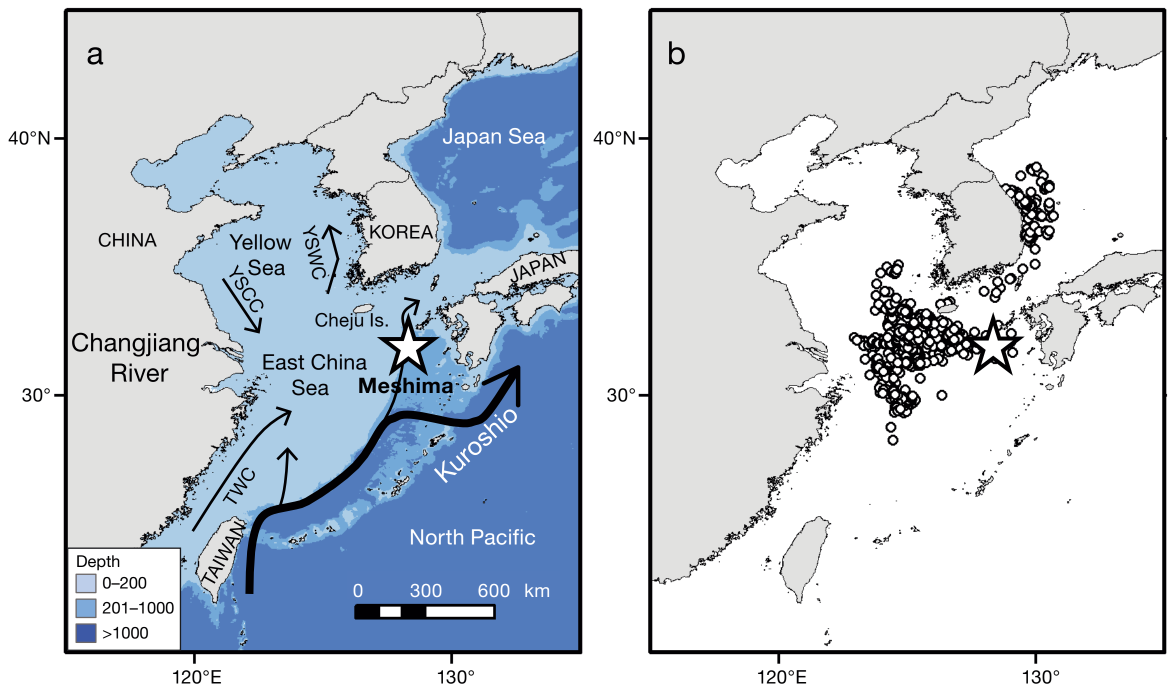

Fig. 1. (a) Oceanographic features in the East China Sea overlaid on its bathymetry (modified from Beardsley et al. 1985). Arrows indicate currents: Kuroshio, Taiwan Warm Current (TWC), Yellow Sea Coastal Current (YSCC), and Yellow Sea Warm Current (YSWC). (b) *Calonectris leucomelas*. GPS positions of streaked shearwaters during the chick-rearing period (9 September–20 October 2010). Star indicates the study colony

downloaded from NOAA BloomWatch 180 (http://coastwatch.pfel.noaa.gov/coastwatch/CWBrowserWW180.jsp), and the values in each cell were averaged. We applied a generalized additive model (GAM) to identify the characteristics of shearwater oceanographic habitat (Yamamoto et al. 2015). Values for the kernel density (ranging from 0 to 1) and oceanographic variables at each cell within the area 25–40° N and 120–135° E were determined, and a smoothed spline fit with predictors was applied in the GAMs, assuming a binomial distribution with the logit link function.

Statistical analyses were performed in R software, version 3.2.2 (R Development Core Team 2014), using the package mgcv.

RESULTS

The foraging area (95% utilized area) of streaked shearwaters was distributed over large areas in the ECS and the Yellow Sea as well as a small area along the east coast of the Korean Peninsula, while the core foraging area (50% utilized area) was concentrated in the north of the ECS (Fig. 2).

The tracked birds used areas with SSTs of 19.6 to 28.4°C and chl *a* values of 0.14 to 15.06 mg m^{-3} (Figs. 2 & 3). According to the model response curves, the probability of occurrence was high in relatively productive water (peaked at 1.70 mg m^{-3}) and SSTs of around 25°C (Fig. 3).

DISCUSSION

In this study, streaked shearwaters foraged mostly in the northern part of the ECS rather than searching in all directions or foraging in the warm waters influenced by the Kuroshio. A small portion of the foraging area was also found along the east coast of the Korean Peninsula, as 1 individual concentrated foraging in this region (see the Supplement). As we attached the GPSs to randomly selected individuals of unknown breeding status, this individual probably did not breed and occupied different areas from the breeders (Yamamoto et al. 2015).

Within the possible foraging range, the tracked birds foraged intensively in the offshore waters of the ECS. Previously, Kim et al. (2009) examined water mass characteristics in the ECS using salinity data measured by an oceanographic survey and chl *a* data measured by satellite and suggested that areas with relatively high chl *a* (0.49–1.82 mg m^{-3}) can be interpreted as the Changjiang plume. The model results showed that streaked shearwaters concentrated their foraging in areas with high chl *a* (1.70 mg m^{-3}) and SSTs of around 25°C (Figs. 2 & 3), which corresponded to conditions most likely associated with the outflow from the Changjiang River. In the continental shelf region of the western ECS, the hydrography is mainly characterized by the northeastward-flowing Taiwan Warm Current, which is a branch of the Kuroshio, and the southward-flowing Yellow Sea Coastal Current (Ichikawa

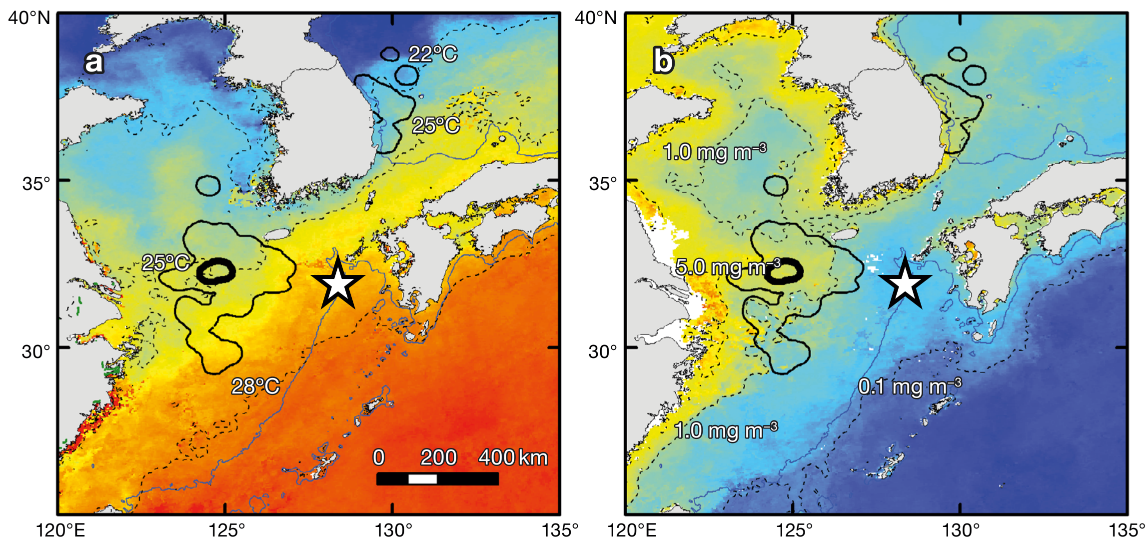

Fig. 2. *Calonectris leucomelas*. Utilization distributions (95% foraging area [thin line] and 50% core area [thick line]) of streaked shearwaters overlaid on (a) mean sea surface temperature (SST) in September and October 2010 and (b) mean chl *a* concentration in September and October 2010 in the area within 25–40° N, 120–135° E. Broken lines indicate 22, 25, and 28°C SST in (a) and 0.1, 1.0, and 5.0 mg m^{-3} chl *a* in (b); star indicates the study colony; blue line indicates 200 m depth

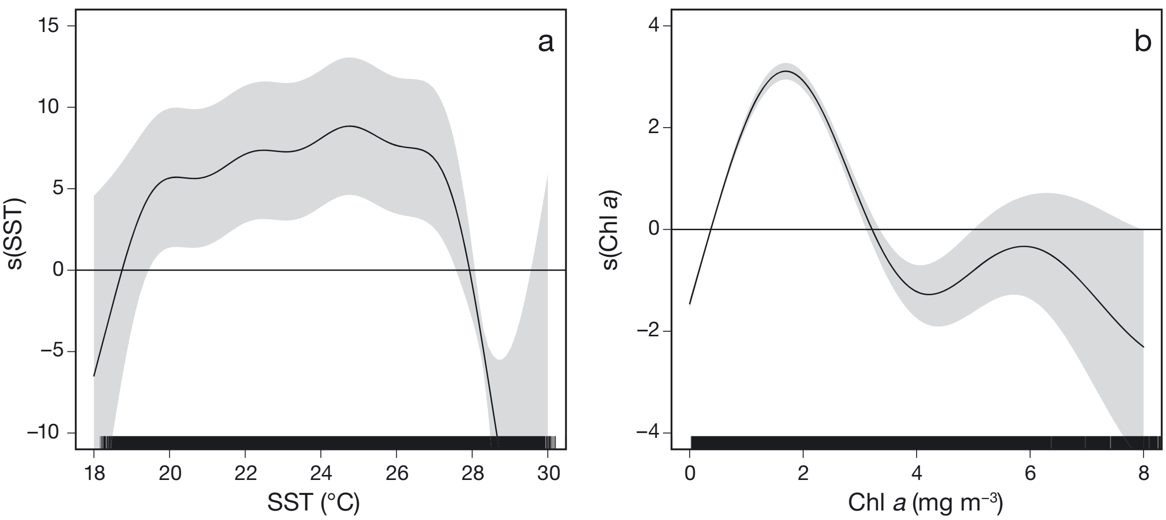

Fig. 3. *Calonectris leucomelas*. Response curves of environmental variables in the oceanographic habitat model (generalized additive model) of streaked shearwaters foraging in the East China Sea: (a) sea surface temperature (SST) and (b) chl *a* concentration. Solid line: regression estimated by the model; shading: 95% confidence intervals

& Beardsley 2002) (Fig. 1a). The intrusion of the Changjiang plume extends far offshore to the northeast in association with these currents in concert with summer monsoon winds (Beardsley et al. 1985, Lie et al. 2003). Freshwater discharge from a large river is known to enhance oceanic biological production by supplying nutrients into the sea (Lohrenz et al. 1990, Smith & Demaster 1996). Enriched nutrient conditions and thus intensive primary production have been especially observed around the Changjiang River estuary and also as a tonguelike distribution toward offshore from the mouth of the river (Chen 2009; Fig. 2), which represent major fish assemblage areas in the ECS (Gong et al. 2003, 2011, Chen et al. 2014). Japanese anchovy, the main prey for streaked shearwaters, is one of the most abundant forage fish species in the ECS and adjacent Yellow Sea (Iversen et al. 1993, Ohshimo 1996, Jin et al. 2003), estimated to make up ca. 3 million tons (Xianshi 2008). In the area off the Changjiang River, anchovy spawning takes place from April to October, with the peak season in May and June (Ohshimo 1996, Iseki & Kiyomoto 1997, Kim et al. 2005). Along with the northeastward extension of the Changjiang plume in the surface layer, a huge spawning ground develops offshore over hundreds of kilometers from the Changjiang River estuary, and early larval stages of anchovy are distributed along outflows of the Changjiang River (Iseki & Kiyomoto 1997, Jin et al. 2003, Kim et al. 2005, Chen et al. 2014). Hence, the abundance of prey should be high in the zones of the Changjiang plume. In addition to enhancing primary productivity, in the zones of the Changjiang plume, a strong vertical thermohaline front exists at the subsurface during the summer as a result of low-salinity fresh water (Kim et al. 2005, Park & Chu 2006). Schools of anchovy are often distributed in the upper layers above the thermocline (Ohshimo 2004), which should be beneficial to surface-feeding streaked shearwaters and provide a favorable foraging spot for them in the ECS. This is possibly part of the reason that shearwaters did not forage in all available productive waters, such as the coastal waters along the continent.

In this study, we demonstrated that pelagic seabirds foraged in areas associated with freshwater discharge from the large river. Our results suggest that river discharge, which enhances oceanic primary and secondary productions (Gong et al. 2003, 2011, Chen et al. 2014), acts as a large spatial-scale physical oceanographic feature of prey availability, not only in coastal waters (Dias et al. 2012, Zamon et al. 2014) but also in offshore waters.

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