Chapter 10: Spatial association between seabirds and prey on the mid-Atlantic Outer Continental Shelf

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Richard R. Veit

CSI/CUNY, 2800 Victory Boulevard, Staten Island, New York, Department of Biology, and CUNY Graduate School, 365 Fifth Avenue, New York, NY 10016

Project webpage: *www.briloon.org/mabs*

CSI CUNY

Chapter 10 Highlights

Examines the spatial relationship between acoustically detected prey and foraging seabirds

Context[1]

In this chapter, we determine whether abundance of birds at sea can be predicted on the basis of abundance of their prey. In other chapters in Parts III and IV of this report, models incorporate a variety of physical (sea surface temperature) and biological (presence of other species of seabirds or marine mammals) variables as predictors of seabird abundance. Prey abundance is not generally included as a direct covariate in those models, which employ remotely sensed environmental covariates to predict seabird abundance across a larger spatial area. Rather, covariate data accessible via remote sensing, such as measures of primary productivity (chlorophyll *a*), are used as proxies for prey availability in these models.

The exception to this is Chapter 11, which examines the utility of hydroacoustic data on aquatic biomass (collected via a scientific echo sounder during boat surveys) to predict seabird distributions. It is possible that the low association between seabirds and biomass identified in Chapter 11's model is not because birds do not follow their prey, but rather because temporal and spatial lags between seabirds and prey obscure patterns of association that are in fact present. In this chapter, we use auto- and cross correlation analysis to identify patterns of seabird-prey association that may not have been evident in our other models.

Study goal/objectives

Identify seabirds that show statistically significant association with acoustically detected prey.

Highlights

- Four species of seabirds (Northern Gannets, Laughing Gulls, Common and Royal Terns) were statistically associated with patches of prey, as identified by the echo sounder.
- The strength of the statistical association depended on the spatial scale at which it was measured.
- The species of birds for which we detected significant association with their prey feed largely or entirely near the water's surface. Seabird-prey association was not detected for deep diving species such as loons and sea ducks.

Implications

There are significant associations between seabirds and their prey, although these associations are taxonomically, temporally and spatially variable; spatial and temporal lags appear to be important in identification of seabird-seabird prey associations. Data on prey distributions may be important for delineating seabird hotspots and patterns of habitat use, particularly for foraging.

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[1] For more detailed context for this chapter, please see the introduction to Part III of this report.

Abstract

We surveyed seabirds from a 55-foot charter vessel off the coasts of Delaware, Maryland, and Virginia over two years (April 2012 to April 2014), and quantified abundance of their prey using a hull-mounted echo sounder. Our objective was to identify areas of importance to foraging birds. As part of this objective, we sought to identify areas where seabirds concentrated due to the abundance or availability of prey. Most of the area we surveyed was within 75 km of the coast, and within the 30 m isobath, allowing us to collect hydroacoustic data in all but roughly the top 5 m of the water column. We found strong association between Northern Gannets (*Morus bassanus*) and Laughing Gulls (*Leucophaeus atricilla*) and acoustically detected prey; and significant but less consistent association for Common and Royal Terns (*Sterna hirundo* and *Thalasseus maximus*). Based on visual observations and existing knowledge of the pelagic fishes of the area, we suspect that much of the prey that we detected and gannets followed was menhaden and Atlantic Herring.

This analysis supplements other modeling efforts in Parts III-IV of this report by explicitly considering the role of seabird prey in determining the spatial distribution of birds. The time series methods presented here yield patterns not evident in other models, because we allow for spatial lags between seabirds and prey. Further, this analysis utilizes *in situ* data, collected in real time from the boat, allowing for the identification of fine-scale patterns that may not be discernible using remotely sensed covariate data. Distribution and relative abundance of prey fishes are clear drivers affecting seabird distributions. These populations should be more carefully considered when attempting to identify biologically important areas for seabirds, both generally during marine spatial planning efforts and specifically for siting offshore development on the Atlantic Outer Continental Shelf.

Introduction

The mid-Atlantic region is used by a broad range of marine wildlife species across the entire annual cycle (Rowlett 1980). This is largely due to a relatively high level of productivity, as compared to the rest of the western North Atlantic (Yoder et al. 2001), as well as the region's central geographic location on the eastern edge of the continent. Areas near the mouths of the Delaware Bay and Chesapeake Bay typically have the highest offshore levels of primary productivity in the region, due to year-round mixing of saline and fresh waters through estuarine circulation, in combination with strong tidal currents. As water flows from the bays into the study area, nutrient and phytoplankton rich waters are swept southwards by the Labrador Current. In these shallow coastal waters, sunlight is able to penetrate a relatively high proportion of the water column (Xu et al. 2011; Schofield et al. 2008), fueling photosynthetic activity and growth of phytoplankton where nutrients are available.

The Mid-Atlantic Bight exhibits a large pulse in productivity each year due to a winter-spring bloom of phytoplankton, and occasionally an additional phytoplankton bloom in summer months (Yoder et al. 2001). This is followed by a pulse in secondary productivity – zooplankton species foraging on the phytoplankton – which in turn become food for larger predators, such as small fishes. The area is generally rich with these small, schooling epipelagic fishes (Pikitch et al. 2014). In the mid-Atlantic region, key fish species include the Atlantic menhaden (*Brevoortia tyrranus*), Atlantic mackerel (*Scomber scombrus*), Bay Anchovy (*Anchoa mitchilli*) and 'river herring', including the alewife (*Alosa*

pseudoharengus) and blueback herring (*Alosa aestivalis*). Two large invertebrate species – the longfin inshore squid (*Loligo paeleii*) and the northern shortfin squid (*Illex illecebrosus*) – are also important prey items for a broad range of predators in the Mid-Atlantic Bight (Dawe et al. 2007; Hendrickson 2004). The presence of these pelagic fish populations indicate the elevated productivity of the area, and are likely responsible, in part, for the relatively high density of predators that use the area. Rowlett (1980) conducted shipboard surveys of the area during the 1970s and showed that this elevated productivity translates into high abundance of marine mammals and birds.

Non-invasive, quantitative estimates of fish abundance and aquatic biomass have been made possible in recent years with the development and subsequent improvement of acoustic echo sounding hardware, including split- and multi-beam transducers employing echo-counting and interpretation software. During the past decade, the development of stable scientific echo sounders, multi-frequency applications, new transducer deployment techniques, standardized calibration procedures, and more realistic models of the sound-scattering properties of biological targets have improved accuracy of biomass estimations (Rudstam et al. 2013; Simrad 2012). The echo sounder sends acoustic signals into the water column and detects resulting backscattered energy reflected from fish and other objects. These data can be integrated and summed by distance and depth intervals in order to estimate the contribution of backscattered energy from all targets within each sampling volume and to estimate prey abundance by area and by volume along survey transects.

Pelagic seabirds are often categorized into feeding guilds, based on their method of food capture and the depths to which they are able to dive (Ashmole 1971). While different seabirds very broadly differ in their physical ability to reach particular depths, the shallow (<= 40 m) waters of the US East coast largely obliterate these differences between species, as the fishes and plankton upon which the birds feed routinely travel from surface to bottom. There are probably some exceptions: the shellfish upon which scoters feed (Bordage and Savard 2011) certainly stay on the bottom and storm-petrels are rather strictly restricted to the immediate surface layers (Warham 1996). Loons may dive to depths of 70m to feed at or near the bottom of the water column (Evers et al. 2010). Gannets, shearwaters, and gulls are pelagic feeders and can likely access any fish or plankton within the 40 m water column.

Seabird prey have been successfully detected by echo sounders in the Antarctic (Veit et al. 1993; Veit 1999; Veit et al. 2008), in coastal waters of California (Santora et al. 2011), and in Newfoundland (Davoren et al. 2003a, b). While there are certainly correlations between seabirds and prey, these relationships can be complicated and difficult to discern because of the dynamic nature of predators searching for mobile prey. Relationships are strongly scale-dependent, with associations at differing scales showing different aspects of predator-prey interactions. (Veit et al. 1993; Rose and Leggett 1990).

Acoustic detection of prey is based upon the difference in density between that of seawater and that of prey, and detection of prey depends on their linear dimensions, as well as their density (Simmonds and MacLennan 2006). Thus, because we used a 120 kHz transducer, we have an approximate idea of the size of organisms detected (small fishes and large zooplankton). Nevertheless, we do not know for sure what the backscattering detected by our instrumentation consisted of. Due to substantial general knowledge of the marine biota of the area (e.g., Rowlett 1980; Overton et al. 2008; Scofield et al. 2008)

we can be reasonably certain that a substantial fraction of the biomass we detected was from schooling pelagic fishes, especially menhaden. Indeed, many of the menhaden schools that we detected visually from the ship and identified through photography were accompanied by large acoustically-detected patches, similar to those found throughout the surveys. Thus, for purposes of this study, we refer to acoustically detected biomass as acoustically detected prey, assuming that the majority of detected biomass was comprised of prey species (while acknowledging that there were likely additional species detected that may not have been prey for the seabirds we examined).

In this study, we conducted two years of boat-based surveys for wildlife within a study area on the mid-Atlantic Outer Continental Shelf. Standardized boat-based surveys are a well-established and widely used method of obtaining abundance estimates for pelagic seabird species. While conducting these boat-based surveys, we also collected hydroacoustic data in order to index the relative abundance of aquatic prey species (fish and zooplankton) present beneath the survey vessel. We examine the relationship between acoustically detected prey and seabird predators on the mid-Atlantic Outer Continental Shelf at varying spatial and temporal scales, ranging from aggregated surveys (across the entire study area and two year study period) to individual transects within single surveys. We included eight seabird species in the analysis, including one surface feeder (Wilson's Storm-Petrel), two benthic feeders (Common Loon, *Gavia immer;* and Red-throated Loon, *Gavia stellata*), and five pelagic feeders (Northern Gannet, *Morus bassanus*; Laughing Gull, *Leucophaeus atricilla*; Common Tern, *Sterna hirundo*; Royal Tern, *Thalasseus maximus*; and Dovekie, *Alle alle*).

Methods

Sixteen boat-based surveys were conducted between April 2012 and April 2014, each covering 12 transects running perpendicular to shore and spaced roughly 10 km apart, offshore of Delaware, Maryland, and Virginia in the vicinity of three federally designated areas for potential offshore wind energy development (Wind Energy Areas, or WEAs; Figure 10-1). During each boat survey, observers recorded data on wildlife encountered, including species identification, number of individuals observed, locations of observations, and behavior. Detailed methods regarding boat-based survey protocols are found in Chapter 7 of this report.

Hydroacoustic data were simultaneously collected using a Simrad EK60 scientific echo sounder unit (Kongsberg Maritime AS, Horten, Norway) with a hull mounted 120 kHz split-beam transducer, documenting the relative abundance of acoustically detected prey along the survey transects throughout the water column. Hydroacoustic data were collected during all 16 boat-based surveys (a total of 66 survey days), and were calibrated for the speed of sound and absorption coefficients using mean water temperature and salinity values collected every 30 minutes during boat-based surveys. Data were filtered to exclude very small targets (< 2 cm), as well as surface and bottom noise potentially caused by non-biotic objects. A surface line was drawn at a depth of 2 m below the water's surface (roughly 0.8 m below the surface of the transducer), and a bottom line was manually edited to exclude the bottom substrate and targets indistinguishable from the bottom (roughly 20 cm above the ocean floor). All backscattering signals occurring above the surface line or below the bottom line were excluded from analysis. Remaining data were integrated by 1 m depth intervals (or "layers") and 500 m

distance intervals (or "intervals") to calculate the nautical area-scattering coefficient (NASC) value for each 1 x 500 m cell within the survey (Chapter 9). The total NASC represented an index of total available biomass within the water column; additional details regarding hydroacoustic data collection and post-processing are found in Chapter 9 of this report.

Boat-based survey and hydroacoustic data were combined in ArcGIS version 10.2.2 (ESRI, Redlands, California) and binned into 2 km transect segments, summing the total number of individuals observed per species per segment, as well as total NASC per segment. Areas surveyed between transects, or "doglegs," were included in analyses if both survey and hydroacoustic data were consistently collected, and were assigned transect numbers for data management and analysis purposes (Transects 13-31; Figure 10-1).

We initially chose to examine associations between birds and acoustically detected prey for eight bird species, including Wilson's Storm-Petrel, Northern Gannet, Laughing Gull, Common Tern, Royal Tern, Dovekie, Common Loon, and Red-throated Loon. We chose these species as they were relatively abundant in our surveys. The five pelagic foragers (Northern Gannet, Laughing Gull, Common Tern, Royal Tern, and Dovekie) were also judged to be likely to feed upon pelagic prey. We partitioned the bird data into two groups for each species. The first group included all observed individuals. The second group consisted only of birds whose behavior suggested feeding activity, including diving, plunge diving, feeding, and milling (thus capturing observations where birds dove into the water, dove under the water, were seen with prey in the beaks, or were flying in tight circles as if in the process of searching for food; Veit 1999; Camphuysen and Garthe 2004). For each group of each species, we calculated Spearman rank correlation coefficients to assess spatial association (at a spatial lag of 0 km) between observed birds and acoustically detected prey across all surveys and locations. Species that showed no statistically significant association at this scale, such as Dovekie, were excluded from further analysis.

For species that showed significant association with prey across all surveys, we used cross-correlation analysis in Statistica (StatSoft© 2005) to assess spatial association between birds and their prey at spatial lags ranging from 0 to 15 lags (30 km) in either direction, and at geographic and temporal scales ranging from the entire study (16 surveys over two years, for a total of 10,698 linear transect km) to individual surveys or transects. We tested statistical significance of detected patterns using randomization of the bird relative to the hydroacoustic data (Rose and Leggett 1990; Veit et al. 1993; Veit et al. 2008).

Generalized Linear Models (GLMs; Zuur et al. 2009) were constructed for Northern Gannets and Laughing Gulls, the two species most highly associated with acoustically detected prey. Data were summarized by transect for the 12 long transects (Transects 13-31 were excluded, because they were shorter than what cross-correlation analyses suggested was required to detect many associated bird and prey aggregations). Data were included for survey months during which each species was most abundant (Northern Gannet: October through early May; Laughing Gull: mid-April through November). Resulting datasets contained 107 transects for Northern Gannets and 129 for Laughing Gulls. Three variables were calculated for each transect: mean bird abundance across 2 km bins, mean echo sounding backscatter (NASC), and maximum cross-correlation (ccf) for any scale (lag) between birds and

prey. For maximum cross-correlation, values were restricted to those within spatial lags of < 10 km, or 20 km. We first calculated Spearman rank correlation coefficients among these quantities, and then built regression models for each species.

We then constructed Generalized Linear Models with negative binomial distribution of errors (Zuur et al. 2009, pp. 233-236) of the form:

$$\text{Bird abundance} = \text{prey abundance} + ccf(\text{birds,prey}) + \text{error}$$

using the logic that both prey abundance and the spatial correlation among birds and prey ought to combine to give useful information about where birds are abundant. We modeled data from the longer transects (20 + km) from the season during which modeled species was present. We counted the number of transects on which we found significant cross-correlation between gannets and prey, in an attempt to characterize persistence of such feeding aggregations.

Results

At the largest spatial scale, that of the entire two-year study (16 surveys), Northern Gannets, Laughing Gulls, Common Terns and Royal Terns were statistically associated with acoustically detected prey; no statistically significant association was observed between acoustically detected prey and Common Loons, Red-throated Loons, Wilson's Storm-Petrels, or Dovekies (Table 10-1). This coarse scale analysis does not take into account spatial lags between birds and prey, as are bound to occur (Veit et al. 1993), due to feeding taking place sometime before the ship encounters the aggregation. To detect these relationships, we analyzed the entire dataset using cross-correlation analysis for species found to be statistically associated with prey. Of these, Northern Gannets and Laughing Gulls were most strongly associated in space with prey detected by the echo sounder; weaker associations were observed between acoustically detected prey and Common Terns and Royal Terns.

Northern Gannets

Across all surveys, Northern Gannets were significantly correlated with acoustic prey at spatial lags of zero, 2, and 4 km, and also at lags of -14 to -18 km and positive 18 km to 22 km. The maximum correlation was at a lag of zero (Figure 10-2, Figure 10-3, and Figure 10-4).

Finally, much of the "noise" in the single-survey-scale pictured in Figure 10-4 is due to the spatial lags between birds and prey (Veit et al. 1993, Veit et al. 2008); if birds are encountered before prey patches on a transect at one place and after prey patches at another, these lags will obfuscate one another and lower the overall correlation. To circumvent this issue, we plotted cross-correlation function (CCF) and time series plot from single transects. Figure 10-5 and Figure 10-6 show examples of these analyses using data from two transects surveyed in March 2013.

Laughing Gulls

Laughing Gulls were the next species most associated with prey as detected by acoustics. Laughing Gulls were most abundant May to October. As with Northern Gannets, we began by examining bird-prey association across all surveys (Figure 10-7, Figure 10-8). There was significant cross-correlation across a broad range of spatial scales, suggesting that this species feeding at a broader range of prey patches

than Northern Gannets. As was true for Northern Gannets, Laughing Gulls track their prey even more closely when examined at the scales of single surveys (Figure 10-9) and individual transects (Figure 10-10). Also as for Northern Gannets, there were spatial lags between Laughing Gulls and the prey they were likely feeding upon. At the largest spatial scale, the most significant associations occurred at a lag of 10 km (Figure 10-8).

Common and Royal Terns
The data on Common Terns show very little consistent association between birds and prey at large scales, due mainly to large numbers of patches of prey unattended by birds (Figure 10-11). There was no correlation between terns and prey at the scale of all surveys, or even within a single survey (Figure 10-12). However, at the scale of an individual transect, terns tracked fish schools well. Figure 10-13 shows associations along Transect 11, an enlargement of the far right end of the transects represented in Figure 10-12.

As with Common Terns, Royal Terns showed no statistical association with fish at the scale of all surveys or within a single survey. However, there was evidence of this association for the whole of the June 2012 survey (Figure 10-14), and a tight association along Transect 3 (Figure 10-15).

Models of Gannet and Laughing Gull Distributions
We first calculated Spearman rank correlation coefficients among these quantities, and then built regression models for each species (Table 10-2 and Table 10-3).

The GLM modeling showed that inclusion of both prey abundance and the spatial correlation among birds and prey combine to give more useful information about where birds are abundant than prey abundance alone. Thus, by including spatial association between birds and prey one includes both prey abundance and prey availability to birds (Table 10-4).

Finally, we counted the number of transects on which we found significant cross-correlation between gannets and prey, in an attempt to characterize persistence of such feeding aggregations. There was not much variation among transects; all of them tended to have feeding gannets, so this approach was not useful in distinguishing among transects (Table 10-5).

Discussion
The seabirds we surveyed on the mid-Atlantic Outer Continental Shelf fell into two groups: those which were clustered in association with acoustically detected prey, and those which were not. Northern Gannets were substantially more associated with acoustically detected prey than any other species. This is likely because Northern Gannets feed on relatively large (> 4") fish located close to the surface. We suspect, but cannot prove directly, that the majority of these prey items were either Atlantic menhaden or possibly other similar schooling species such as Atlantic Herring (*Clupea harengus*; Reid et al. 1999). Laughing Gulls were also significantly associated with acoustically detected patches, but were less tightly clustered around big patches than were Northern Gannets. We do not know if Laughing Gulls eat the same fish as Northern Gannets, but in general they capture smaller individuals (Burger 1996). Common Terns and Royal Terns were associated with acoustically detected patches during some transects and surveys, but these correlations were less consistent than for Northern Gannets or Laughing Gulls.

Common Loons and Red-throated Loons, Dovekies, and Wilson's Storm-Petrels showed no statistically significant association with acoustic patches. Loons generally feed on fishes located at or close to the bottom (Evers et al. 2010), which are less likely to be detected by acoustics, as backscattering signals indistinguishable from the ocean floor were excluded from analysis during post-processing of hydroacoustic data (Chapter 9). Wilson's Storm-Petrels and Dovekies both feed on zooplankton (including small fishes) but of a size range that may fail to appear prominently in our acoustic data. Wilson's Storm-Petrels, moreover, feed at the immediate surface (top 6"), an area not detectable by our hull mounted echo sounder (Veit et al. 2008; Chapter 9).

Since a major objective of these surveys was to identify areas of the mid-Atlantic Outer Continental Shelf that are particularly important (or unimportant) to foraging birds, it is pertinent to determine how these acoustic data can be used to identify important foraging areas. It is clear that our acoustic data yields insight into important foraging areas for Northern Gannets and Laughing Gulls, and perhaps terns as well. From repeated sampling of our transects, we can estimate what proportion of those transects had 1) aggregations of feeding birds associated with prey and 2) patches of prey with similar characteristics to those that at other times were attractive to birds. The acoustic data on seabird prey is the only real time information we have that is immediately relevant to the foraging needs of the birds (although real time data on sea temperature and salinity, also collected from the survey boat, provide an indirect tool). Therefore more extended analysis of the bird-prey association is warranted as part of a habitat assessment for seabirds.

Using echo sounders to assess abundance of prey has been a controversial practice, although most controversy surrounds the conversion of backscattering strength to an absolute estimate of biomass, which we are not attempting (Simmonds and Maclennan 2006). We are concerned with the location of patches of prey, and their relative size, rather than the actual biomass of the organisms in the patches. Thus, we are using acoustic detection of prey as an index of abundance. This goal substantially minimizes the types of criticisms to which the use of acoustics has been exposed.

Nevertheless, we do have issues of species identification and bias in the portions of the water column sampled. To a certain extent, the size of organisms (Madureira et al. 1993; Logerwell and Wilson 2004; Lawson et al. 2008) can be determined from backscattering strength, and species of fishes and zooplankton can be identified especially if the acoustic data can be compared to net samples or local knowledge of the dominant species. Acoustic data were filtered to exclude objects less than about 2 cm in diameter (Chapter 9), and it is highly likely that that the overwhelming majority of aggregations we detected acoustically were fish rather than zooplankton, potentially menhaden and herring (Overholtz et al. 2000; Overton et al. 2008). However, we had no supplementary data on prey species or biomass composition for this region. Additionally, since our transducer was mounted on the keel (approximately 2 m below the waterline) and surface noise commonly reached depths of approximately 5 m, objects in the upper 0-5 m of the water column were invisible to the acoustics. This means that prey for the real surface feeders (certainly storm-petrels, perhaps terns as well) were not quantified (cf. Veit et al. 2008). For this reason, it is not surprising that Wilson's Storm-Petrel abundance was not correlated with acoustic data on our surveys.

By analyzing and modeling relative seabird and prey abundance at the transect level, we have provided statistical evidence that co-occurrence of feeding birds and prey swarms are an important indicator of quality habitat for Northern Gannets and Laughing Gulls. What remains to be done is to use the acoustic data on prey abundance to make predictions about what portions of the area we surveyed are most important to seabirds. One way to do this would be to incorporate either acoustic prey relative abundance or bird-prey co-occurrence (since some prey patches are inaccessible) as independent variables in a habitat model. The problem with that approach is that prey patches are highly mobile so there is a strong stochastic component to the exact location of the patches. An alternative might be to construct a probability-of-occurrence map for prey swarms, and include those values within a habitat model. In any event it seems critical to do this, at least for the species that this analysis shows to be statistically associated with prey. Thus, further analysis should focus on identification of hotspots incorporating real-time data on prey (as we have done here), and ascertain whether such prey-based hotspots are spatially coincident with hotspots identified on the basis of other environmental data, or from data on bird abundance by itself.

It is important to collect data on prey abundance during seabird surveys for two reasons, as supported by our results. First, predator-prey interactions are an essential component of ecological systems (Barbosa and Castellanos 2005), and the high levels of variability in marine systems may make prey distribution patterns particularly important for predicting the distributions of higher trophic level predators such as seabirds in the marine environment (Fauchald et al. 2000). Second, our acoustic data on seabird prey was collected simultaneously with the data on seabirds, and the two datasets are thus spatially and temporally linked to a closer degree than for most dynamic environmental variables we examined in this report (which were often at a ≥1 km spatial scale, and represented daily, weekly, or even monthly averages; Chapters 11-12, 15-16, 18-19). The high mobility of both birds and their prey make spatial associations complex and difficult to measure, as predator-prey interactions, ocean currents, and other dynamic factors ensure that there are often temporal and spatial lags between aggregations of seabirds and their prey. Nevertheless, such associations potentially provide the strongest indication of what parts of the ocean the birds find most important for foraging. It is critical to consider prey populations, including their distributions and the variability in those distributions, when attempting to identify important habitat use areas for upper trophic level predators.

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Figures and tables
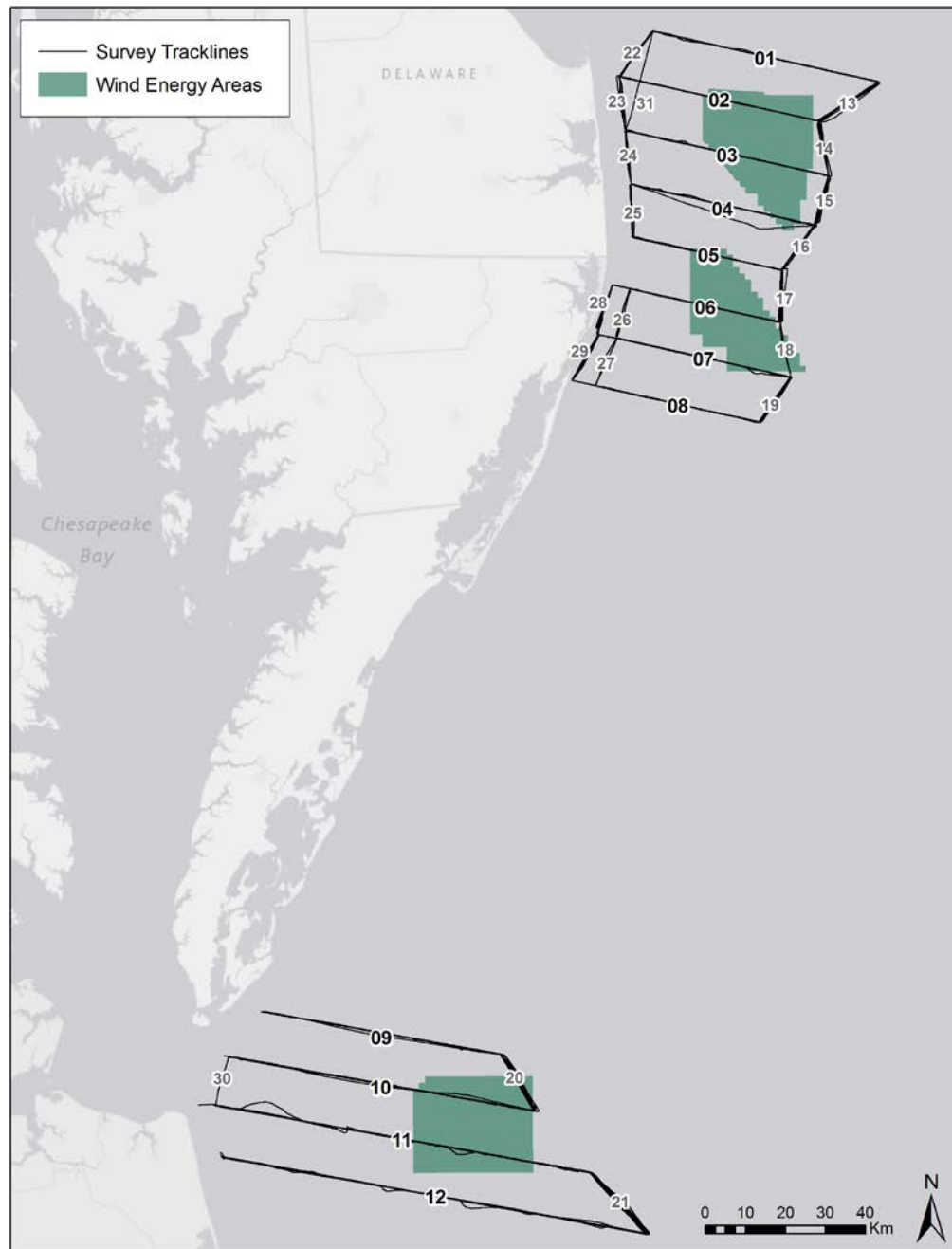
Figure 10-1. Boat-based survey tracklines. Survey transects are labeled by transect number. Transects 1-12 were repeated in each of the 16 surveys conducted between April 2012 and April 2014. Transects 13-31 are 'doglegs' connecting official transects, and were numbered for data management and analysis purposes where both survey data and hydroacoustic data were consistently collected. Exact transect locations varied slightly between surveys due to avoidance of military activities and other vessels, among other factors. Green areas are federally designated locations for potential offshore wind energy development.
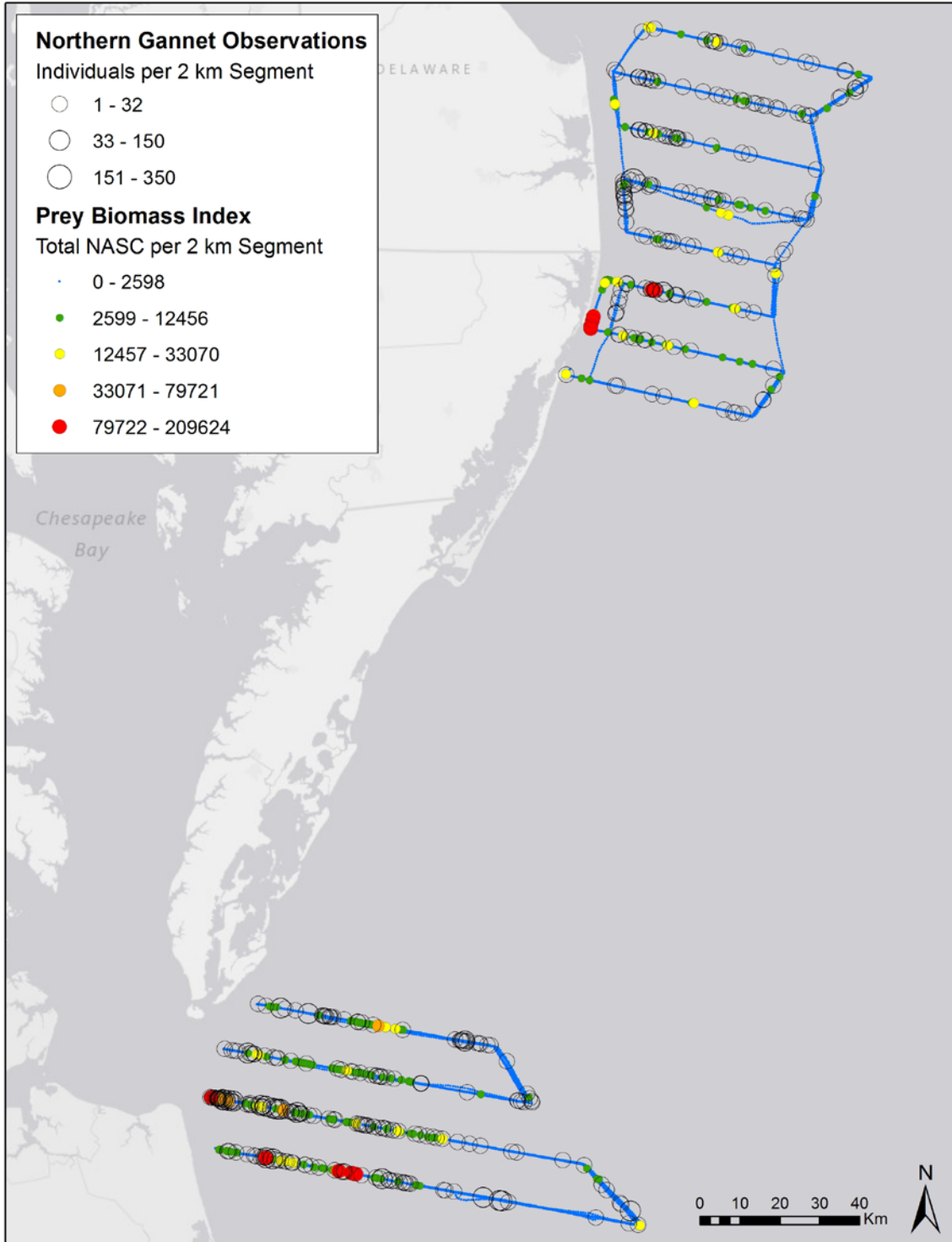
Figure 10-2. Feeding Northern Gannet observations and prey biomass index per 2 km transect segment for data collected October-April, 2012-2014. Observation counts and biomass index values are classified by natural breaks.
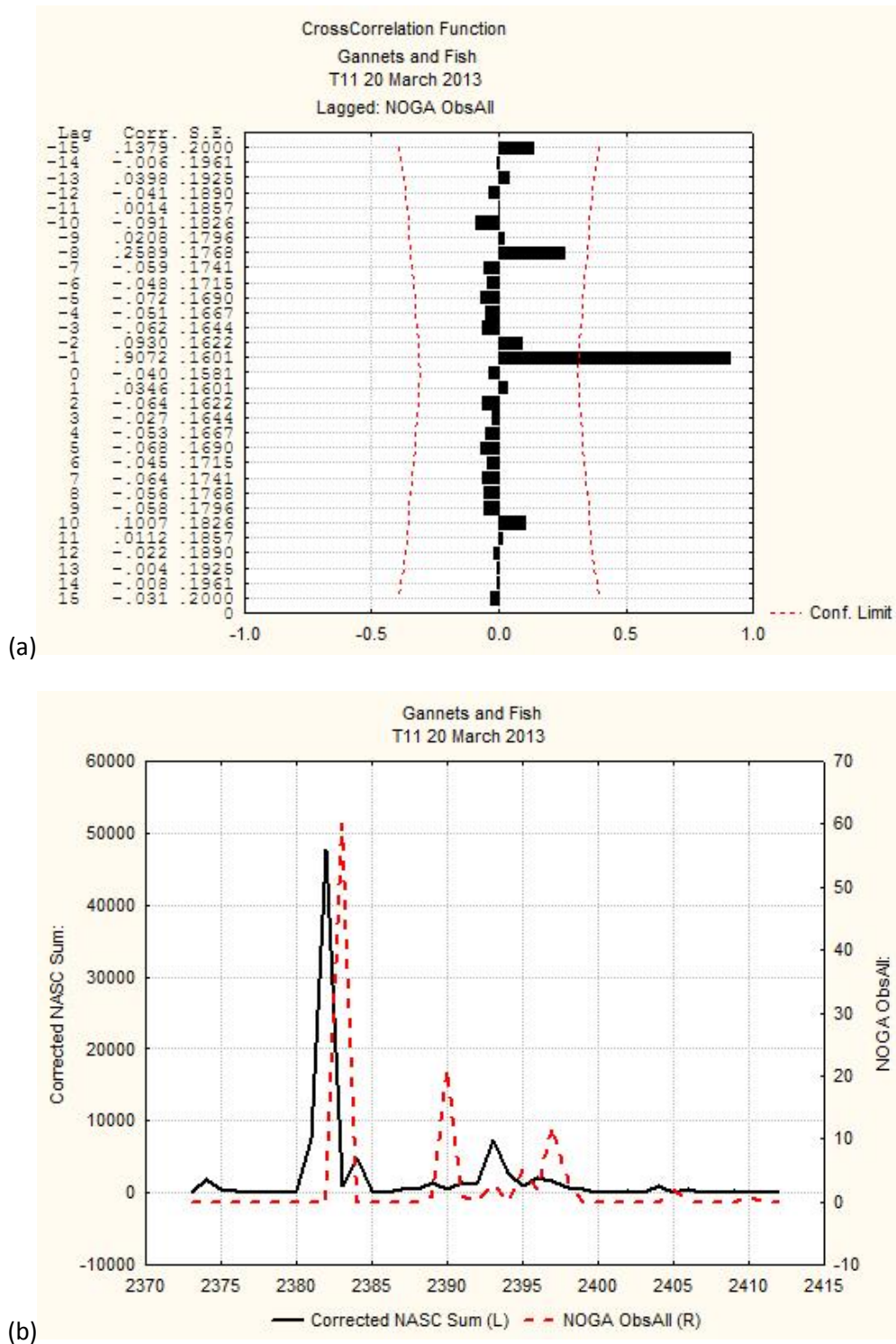
(a)

(b)
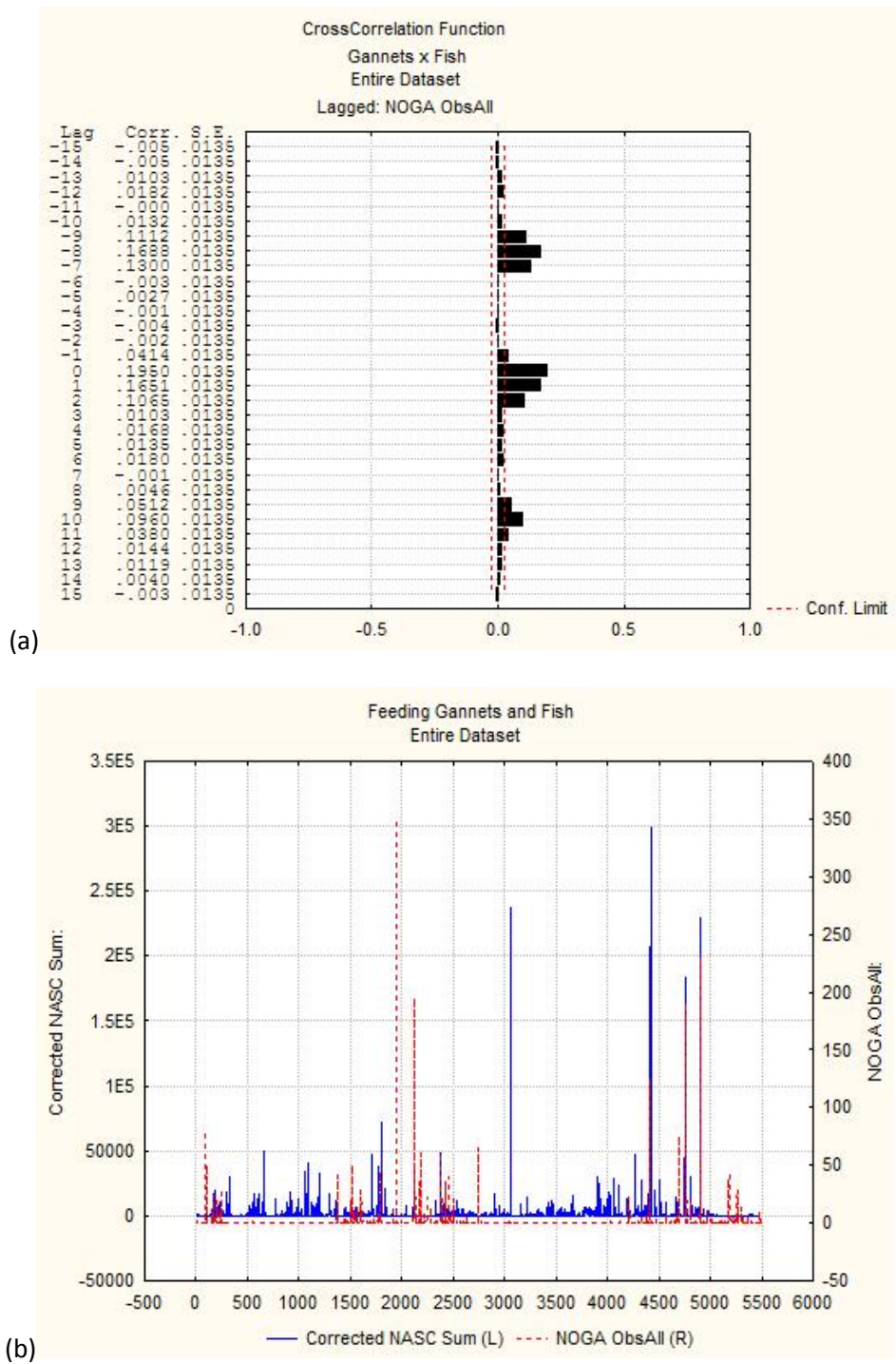
Figure 10-3. (a) Cross-correlation and (b) time series plot between feeding Northern Gannets and acoustically detected prey across all surveys. In (a), the "lag" value represents 2 km segments between gannet counts and NASC measurements of prey biomass; x-axis is correlation between these two values at different lag values. Red dotted lines are confidence limits. In (b), the x-axis is distance, and numbers represent consecutive 2 km bins along the transect lines. The two right hand bars reaching above 200 Northern Gannets represent feeding flocks closely associated with schools of fish detected by echo sounder.

(a)

(b)
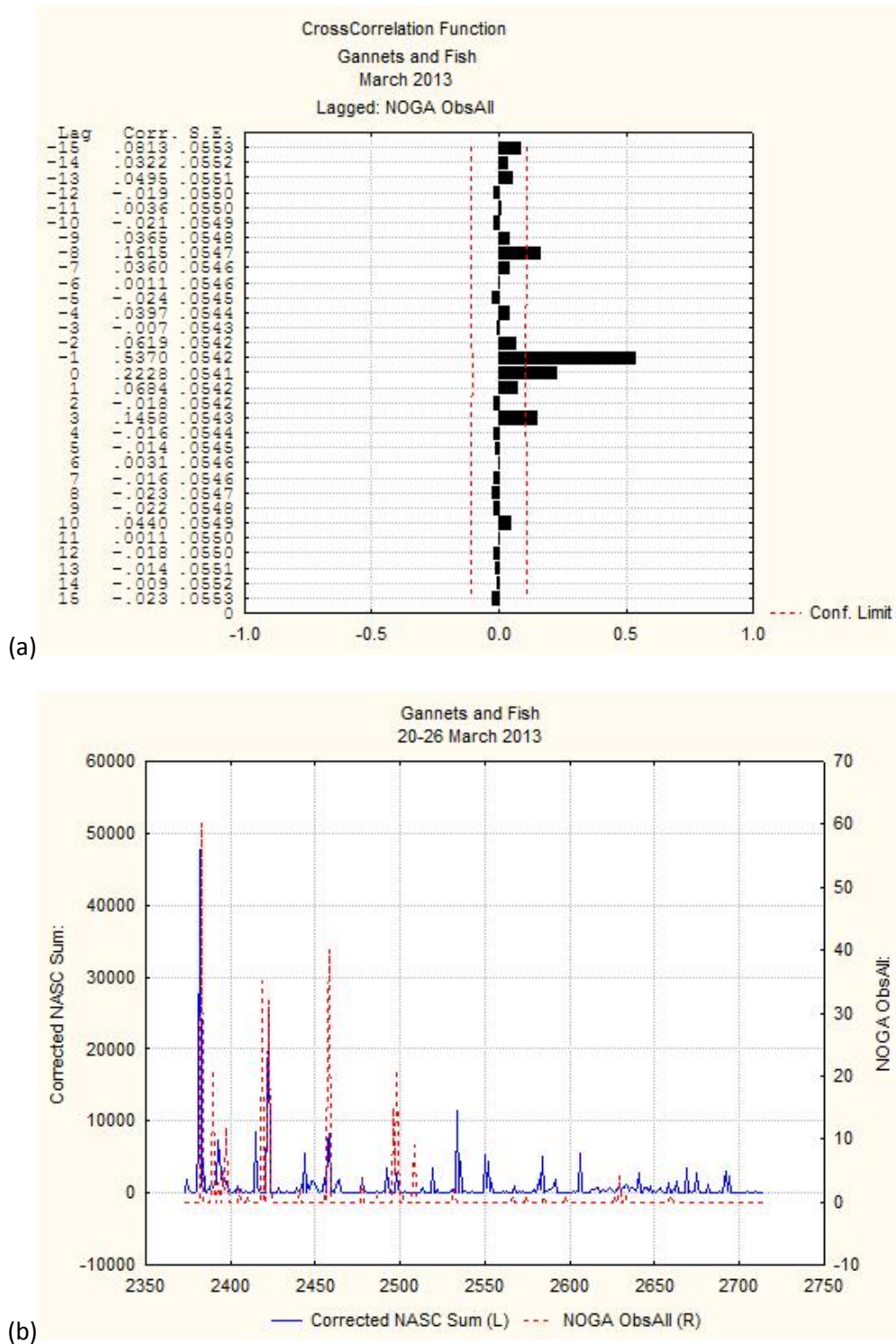
Figure 10-4. (a) Cross-correlation and (b) time series plot between feeding Northern Gannets and acoustically detected prey within a single survey, 20-26 March 2013. Note that the strongest correlation is at 1 spatial lag (2 km). Also note the tighter association between predators and prey than is shown in Figure 10-3(b).

(a)

(b)

Figure 10-5. (a) Cross-correlation and (b) time series plot between Northern Gannets and acoustically detected prey along Transect 11, 20 March 2013. Note that the largest prey patch is accompanied by the largest aggregation of Northern Gannets along the 76 km transect. The other two aggregations of Northern Gannets seem to flank the second largest prey patch. The tightness of the association is reflected in the correlation coefficient (0.9) in (a) above.
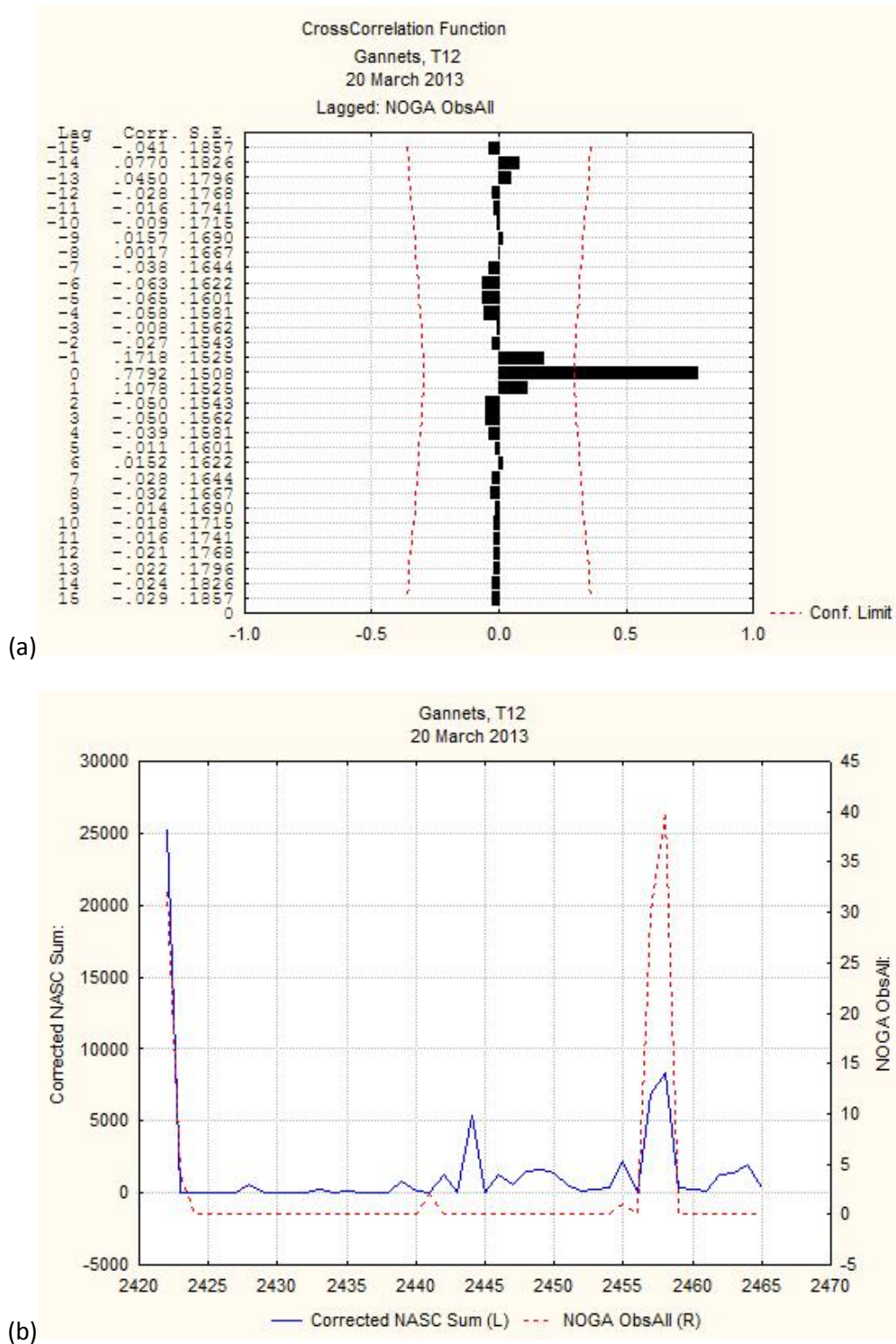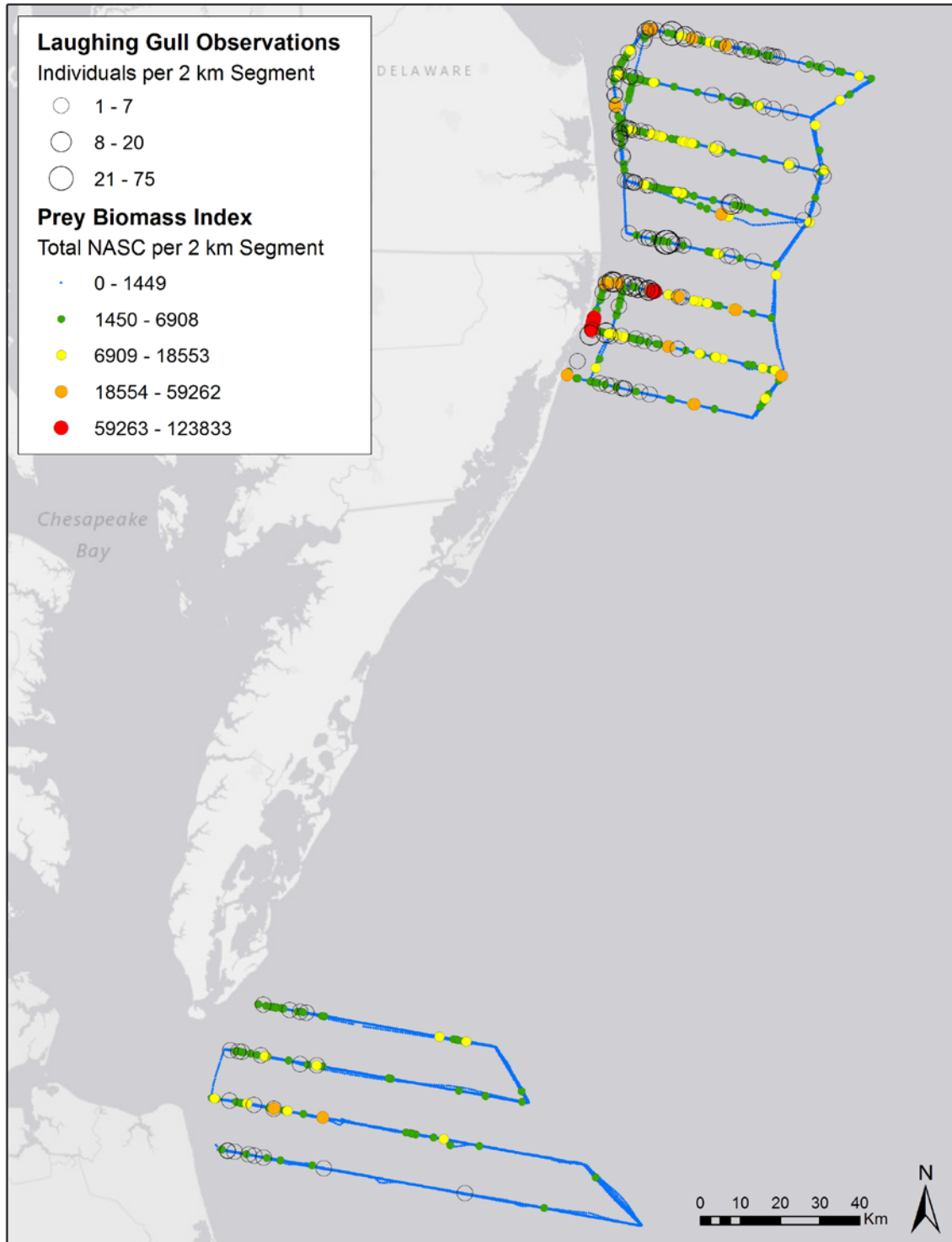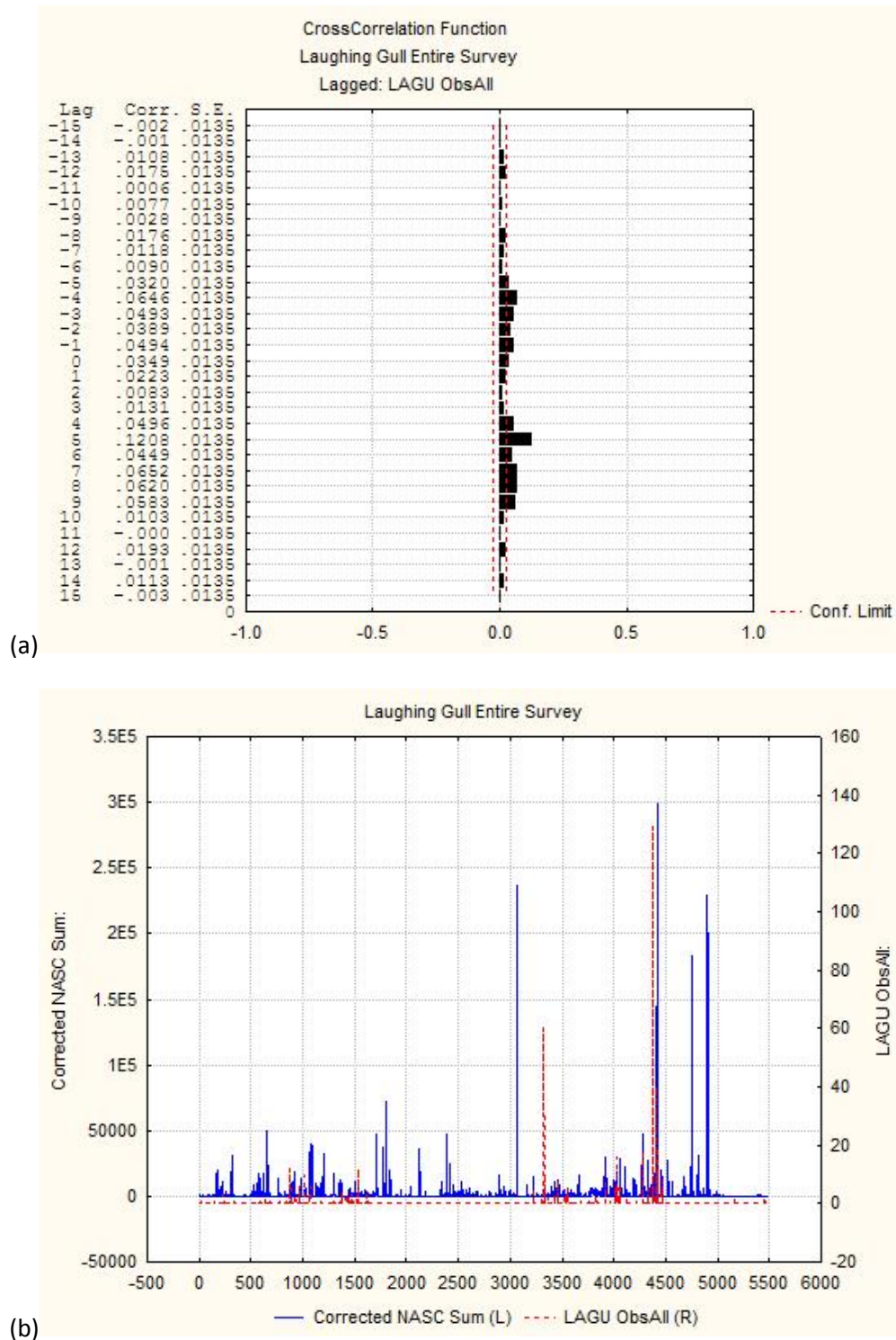
(a)

(b)

Figure 10-6. (a) Cross-correlation and (b) time series plot between Northern Gannets and acoustically detected prey along Transect 12, 20 March 2013.

Figure 10-7. Feeding Laughing Gull observations and prey biomass index per 2 km transect segment for data collected during 10 surveys between April and October (2012-2014). Observation counts and biomass index values are classified by natural breaks.

(a)

(b)

Figure 10-8. (a) Cross-correlation and (b) time series plot between Laughing Gulls and acoustically detected prey across all surveys. Note that Laughing Gulls have found 3 out of four of the major prey aggregations detected.
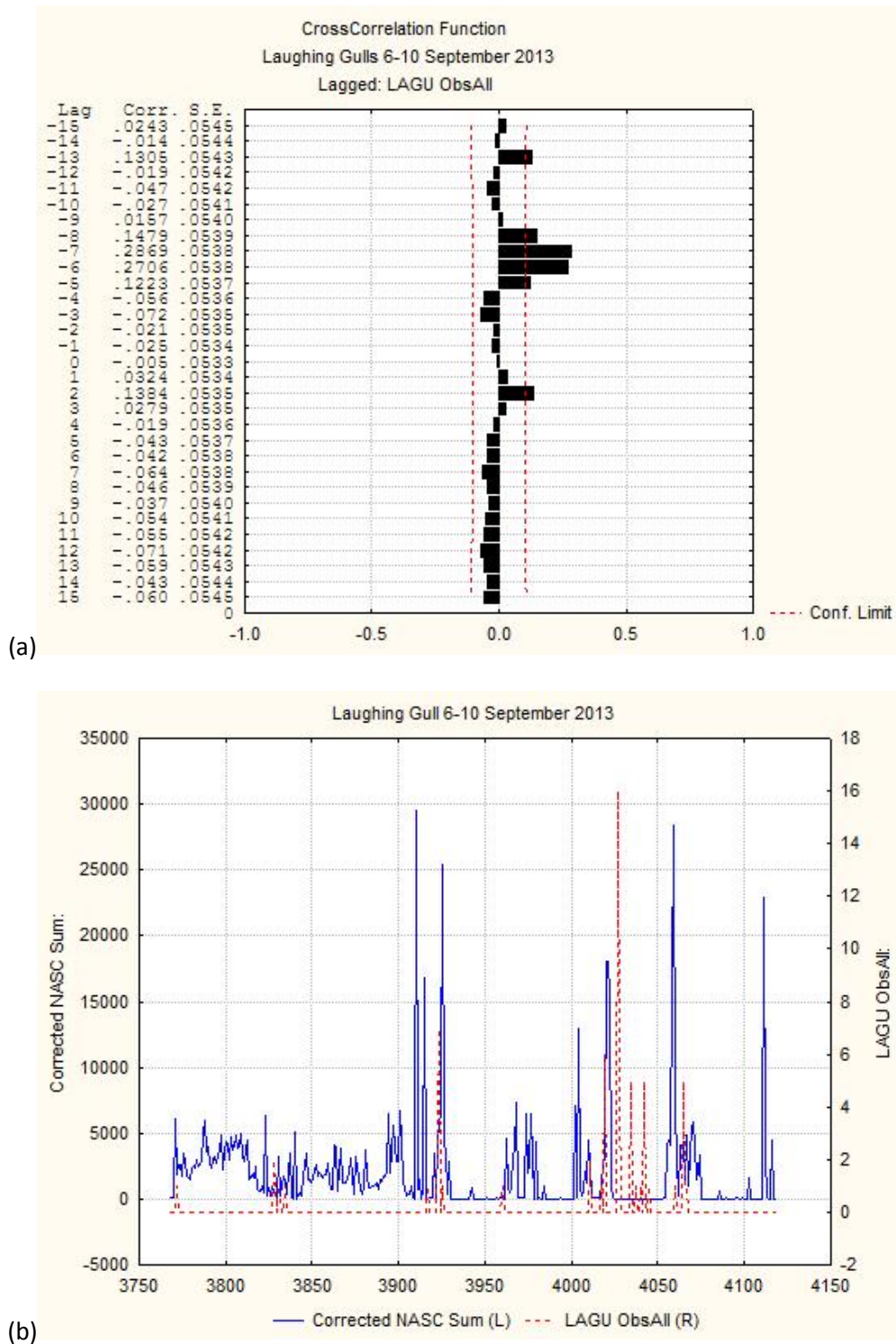
(a)

(b)

Figure 10-9. (a) Cross-correlation and (b) time series plot between feeding Laughing Gulls and acoustically detected prey within a single survey, 6-10 September 2013.
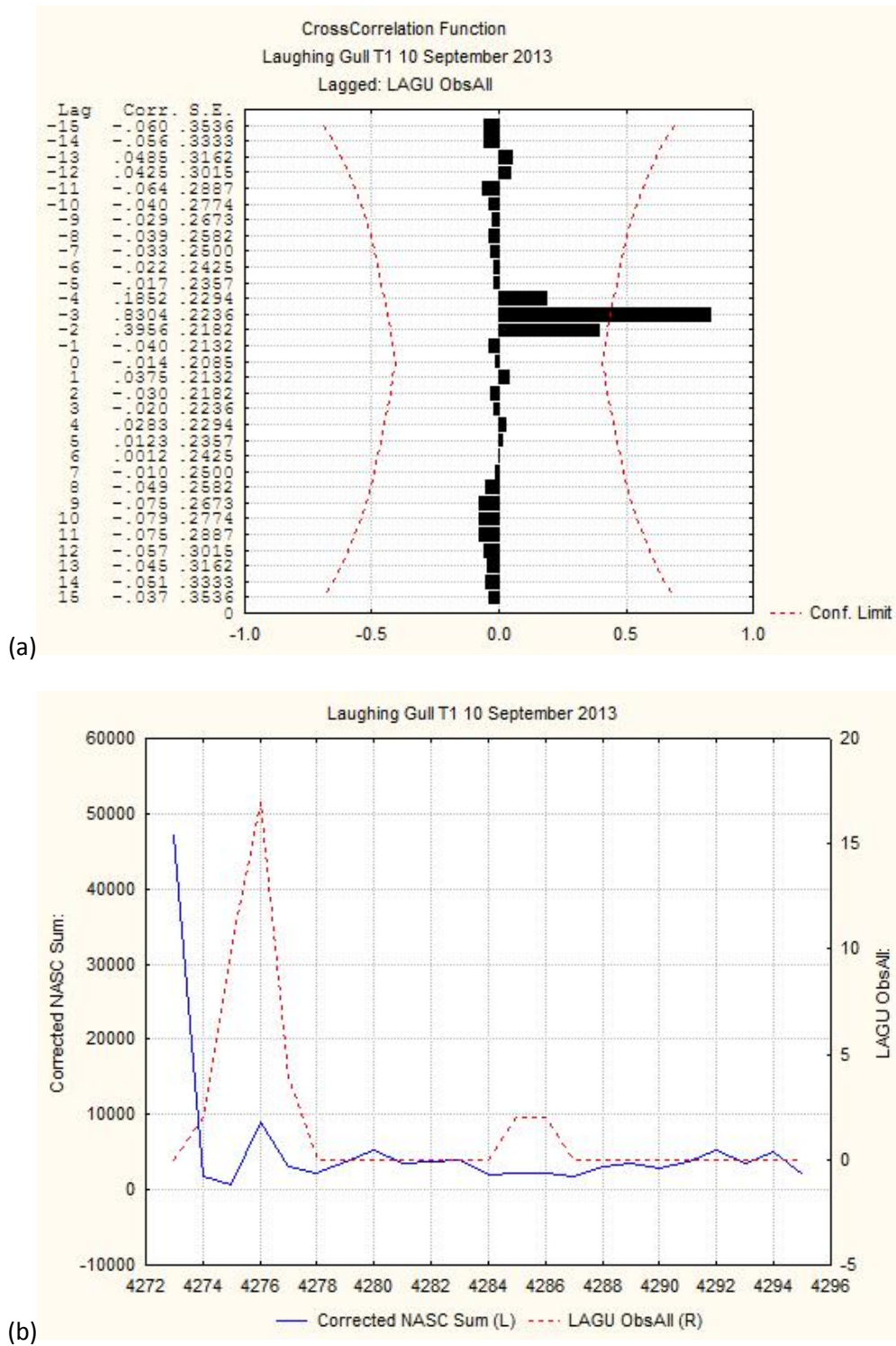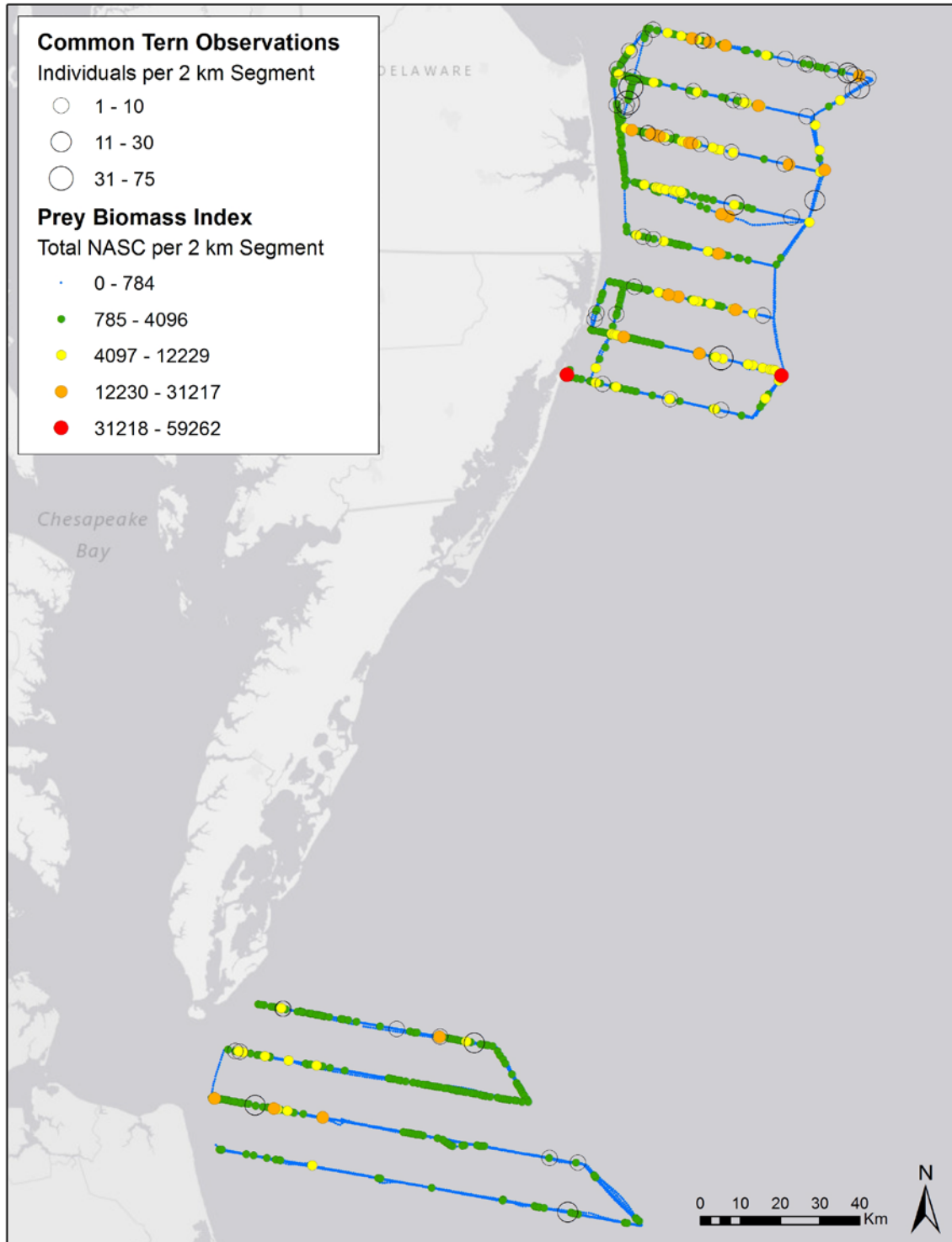
(a)

(b)

Figure 10-10. (a) Cross-correlation and (b) time series plot between Laughing Gulls and acoustically detected prey along Transect 1, 10 September 2013.

Figure 10-11. Feeding Common Tern observations and prey biomass index per 2 km transect segment for data collected during 8 surveys between April 25 and September 30 (2012-2014). Observation counts and biomass index values are classified by natural breaks.
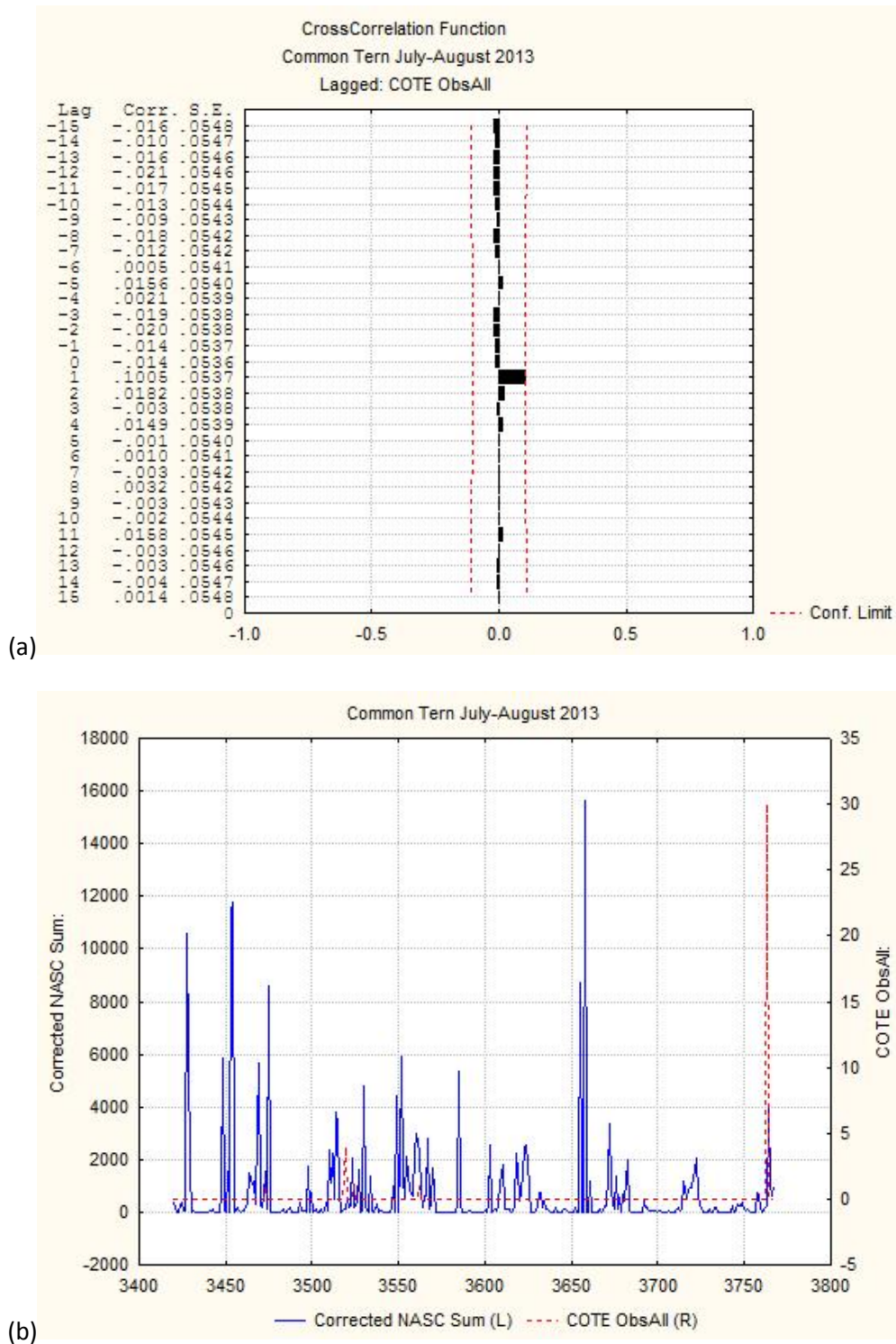
(a)

(b)

Figure 10-12. (a) Cross-correlation and (b) time series plot between feeding Common Terns and acoustically detected prey within a single survey, 30 July – 2 August 2013.
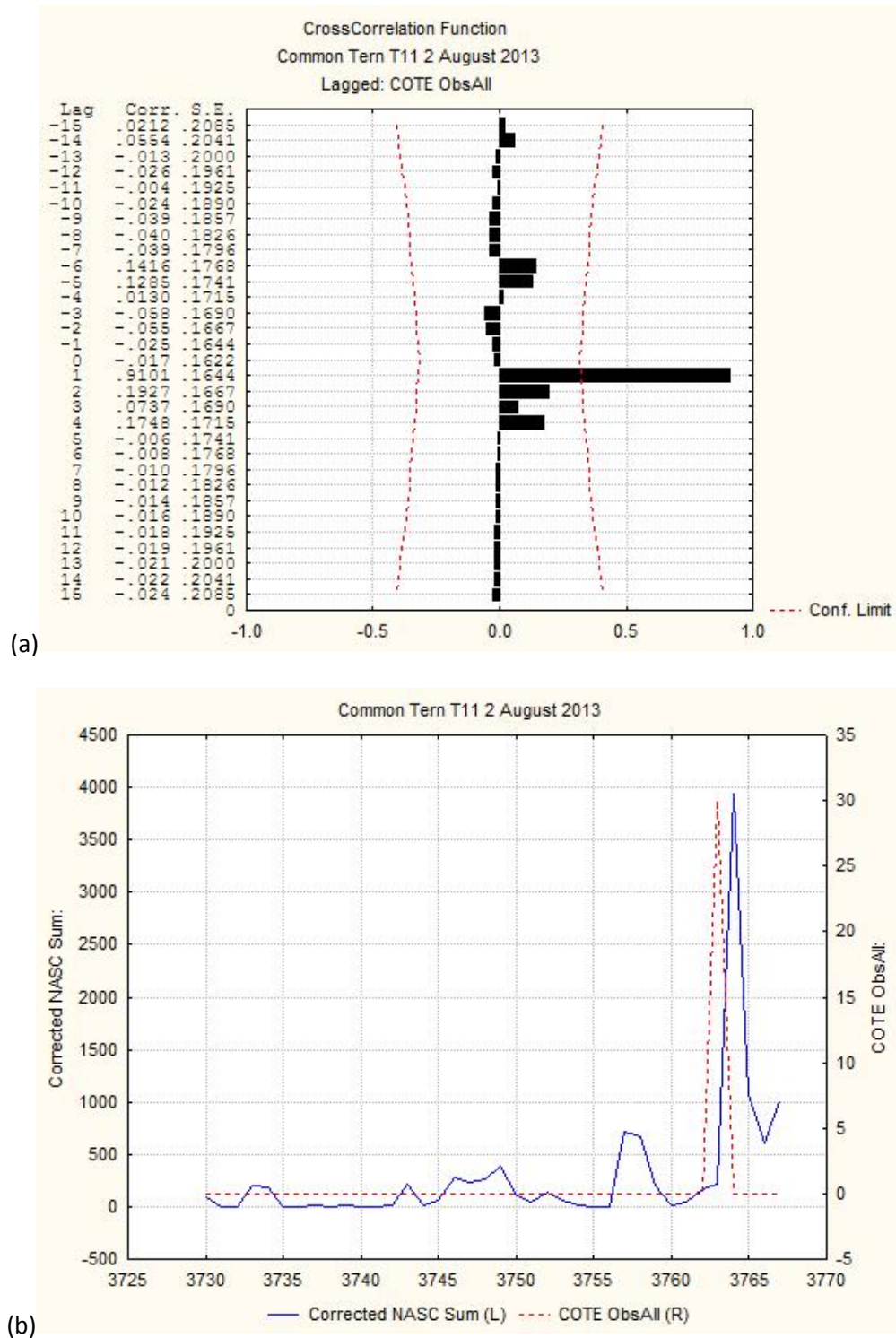
(a)

(b)

Figure 10-13. (a) Cross-correlation and (b) time series plot between Common Terns and acoustically detected prey along Transect 11, 2 August 2013.
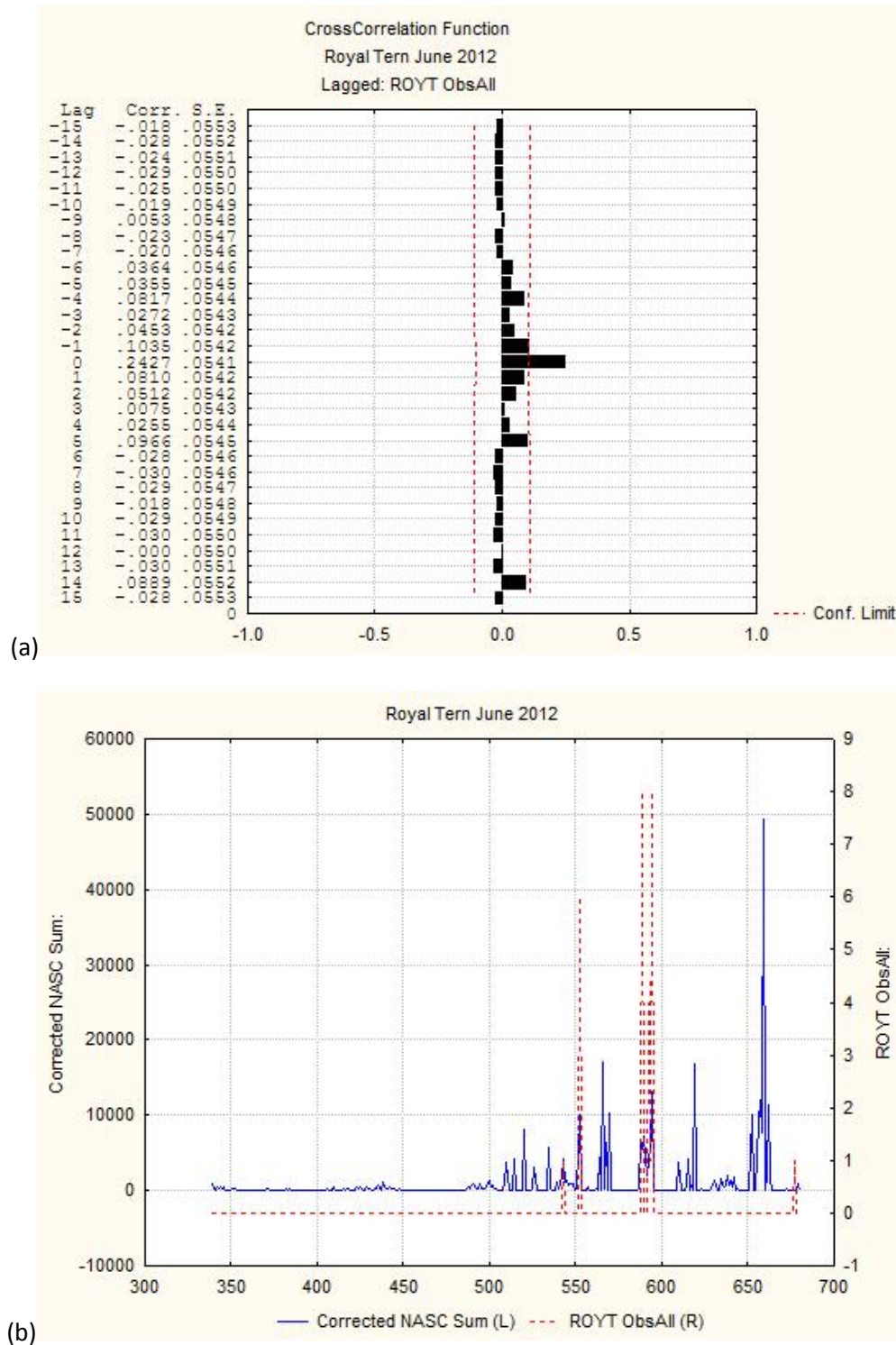
Figure 10-14. (a) Cross-correlation and (b) time series plot between feeding Royal Terns and acoustically detected prey within a single survey, 18-21 June 2012.
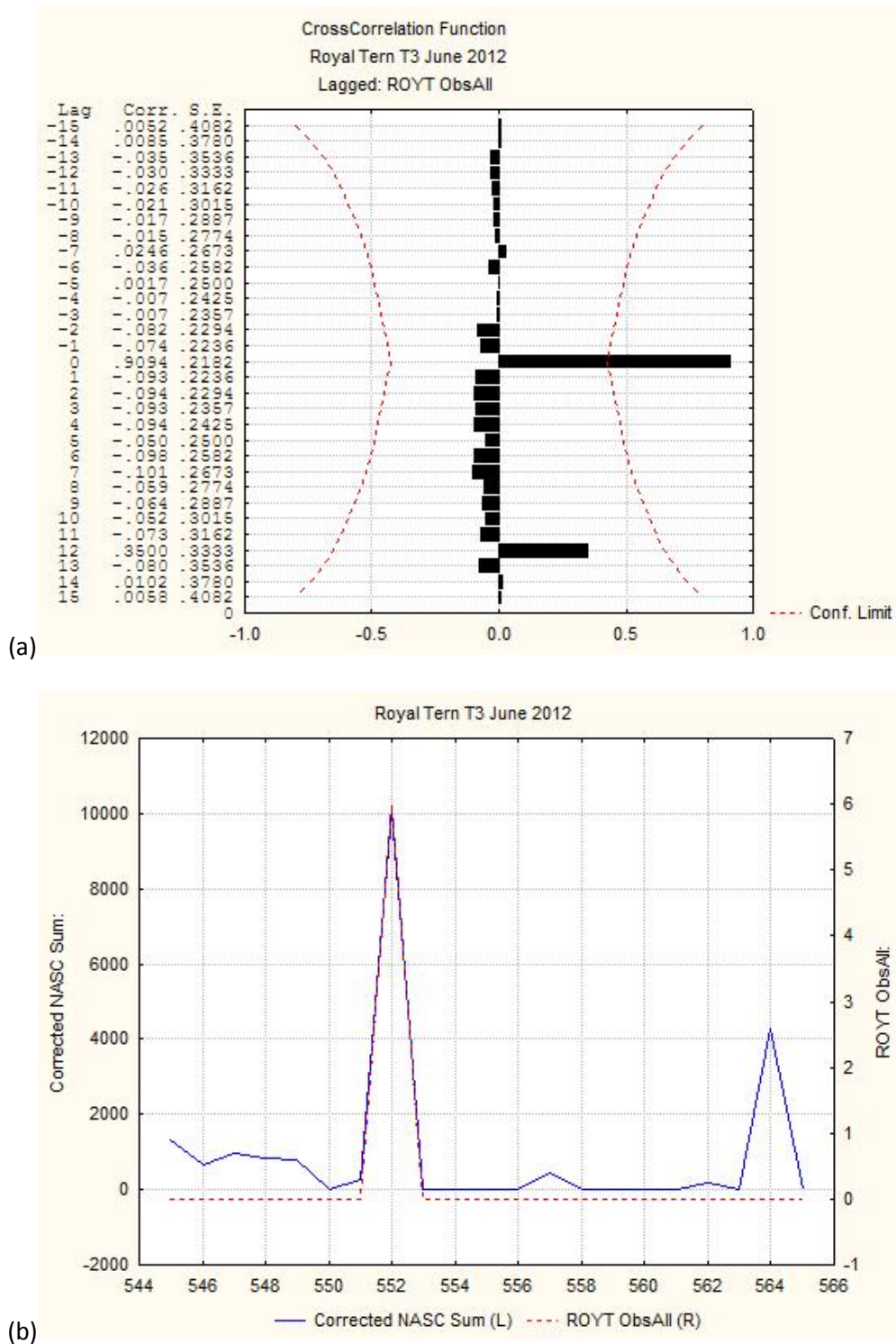
(a)

(b)

Figure 10-15. (a) Cross-correlation and (b) time series plot between Royal Terns and acoustically detected prey along Transect 3, 20 June 2012.

Table 10-1. Spearman rank correlation coefficients (r$_s$) of association between birds and acoustically detected prey in 5,499 two km transect segments, 2012-2014.

Species	All Birds		Feeding Birds	
Northern Gannet	r$_s$=0.05	p = 0.000021	r^s=0.09	P < 10^{-6}
Laughing Gull	r$_s$=0.19	p < 10^{-6}	r^s = 0.09	P < 10^{-6}
Common Loon	ns	ns	ns	
Red-Throated Loon	ns	ns	ns	
Dovekie	ns	ns	ns	
Wilson's Storm-Petrel	ns	ns	ns	
Common Tern	r$_s$ = 0.13	p < 10^{-6}	r^s = 0.04	P = 0.0008
Royal Tern	r$_s$= 0.15	p < 10^{-6}	r^s = 0.09	P < 10^{-6}

Table 10-2. Spearman rank correlation among mean Northern Gannet abundance, mean prey abundance (NASC) and cross-correlation among birds and prey at the scale of individual transects. Significant p values are highlighted in bold text.

	N	Spearman R	p
Mean Abundance x Maximum cross-correlation	107	0.47	**< 10^{-6}**
Mean abundance x NASC	107	0.24	**0.013**
Maximum correlation x NASC	107	0.168	0.083

Table 10-3. Spearman rank correlation among mean Laughing Gull abundance, mean prey abundance (NASC) and cross-correlation among birds and prey at the scale of individual transects. Significant p values are highlighted in bold text.

	N	Spearman R	p
Mean abundance x Maximum cross-correlation	129	0.79	**< 10^{-6}**
Mean abundance x NASC	129	0.33	**0.00015**
Maximum cross-correlation x NASC	129	0.24	**0.0063**

Table 10-4. Including cross-correlation between bird and fish abundance yields a better model than using fish abundance alone. GLMs calculated for data from individual transects. There were 107 2-km bins for Northern Gannets and 129 2-km bins for Laughing Gulls, as we restricted analysis to seasonally appropriate transects that were long enough to detect aggregations using time series methods. Probabilities are given under coefficients "NASC" and "Cross-correlation" and AIC values compare two models for each species.

	NASC	Cross-Correlation	AIC
Northern Gannet	0.0035	0.00017	276.3
	0.0027		287.8
Laughing Gull	0.0047	2.54 x 10-6	114.2
	0.0087		144.4

Table 10-5. Number of surveys on which significant cross-correlation was found between Northern Gannets and acoustically detected prey, by transect. This seems to not be a useful way to distinguish among transects, so was not attempted for other species.

Transect	Number of surveys with significant cross-correlation
1	3
2	3
3	5
4	6
5	6
6	5
7	5
8	5
9	7
10	5
11	5
12	4