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Acoustic survey of northern shrimp (*Pandalus borealis*) distribution/abundance in relation to trap catches in midcoast Maine

Report to the Maine Department of Marine Resources

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Summary

- GMRI was sub-contracted to conduct an acoustic survey for northern shrimp in midcoast Maine during the winter of 2020 in conjunction with a DMR-commissioned trap survey.
- Acoustics and trapping revealed different trends in distribution/abundance (temporal) but also revealed similarities (slight movement of resource offshore during survey period, and similar depth patterns)
- Acoustics and trapping may not always agree since they sample shrimp in different states; acoustics relies on shrimp activity off the bottom and trapping relies on shrimp activity near the bottom.
- Shrimp activity appears to be strongly influenced by the lunar cycle; shrimp appear to be much more active during full moons and this may inflate acoustic estimates of biomass.
- A next phase of this study should make greater efforts to coordinate trapping locations and acoustic transects in time and space (i.e., trap along the acoustic transects).

Background

The Gulf of Maine Research Institute was contracted by the Maine Department of Marine Resources (DMR) to conduct an acoustic survey of northern shrimp (*Pandalus borealis*) distribution in connection with a shrimp trap survey commissioned by DMR in the coastal area off of Boothbay Harbor between Sheepscot Bay and Pemaquid Point in the winter of 2020. GMRI previously completed a larger, coastwide acoustic survey of northern shrimp (Sherwood et al. 2019) and found that shrimp distribution at this scale was mostly confined to the southwestern portion of the state and at depths greater than 100 m. Fishermen from the area reported trappable quantities of shrimp in the Boothbay area, at shallower depths, and thus the finer scale survey was launched in support of a possible small-scale fishery.

In addition to contracting with fishermen to trap shrimp in the study area (see full report by DMR), DMR also contracted with a participating fisherman, Alex Hutchins, who has taken part in GMRI's previous acoustic surveys for herring and shrimp (Sherwood et al. 2017, Sherwood et al. 2019), to collect acoustic data. This effort made use of previously installed, and calibrated (Wurtzell et al. 2016), acoustic equipment on Mr. Hutchin's vessel that is capable of collecting and recording acoustic data for the purposes of biomass estimates. The purpose of the acoustic survey portion of this work was to explore if any correlations exist between shrimp trapping results and acoustic characterizations of shrimp biomass and distribution patterns and to elucidate any pattern in shrimp distribution/abundance around the trapping sites.

Methods

Acoustic data for this survey was collected using a Simrad ES70 echosounder with 38 and 200 kHz transducers (12 and 7 degree beam angles, respectively) hull mounted to the vessel. Power outputs for both frequencies was 1000W and ping rate was 1000ms. Surveys were conducted over 4 dates during the night to capture shrimp off the bottom (see Figure 1 for survey tracks). Survey tracks varied between 43 – 50 nautical miles in length and took about 7 hours to complete resulting in a speed of about 6 knots which was designed to minimize noise (see Table 1 for details including dates and start and end times).

We analyzed all acoustic data in Echoview software version 8.0 (Myriax ®) utilizing dB differencing methods, Echoview is the standard software for analyzing fisheries acoustics data. Acoustic data was processed using a volume backscattering (Sv) threshold of -70 dB. The data from both transducers were smoothed so that one target was the mean of the three by three matrix using the surrounding targets. This makes it easier to tell if there is a valid signal regardless of noise. Shrimp signal was mixed with the fish signal of each survey, this meant that using a visual scrutiny method would not yield the correct information since it was not separated from other targets. We needed to separate the shrimp out from the fish by subtracting the signal on the 38 kHz from the 200 kHz signal. By completing this dB differencing, we were able to determine the signal that was only on the 200 kHz indicating it as shrimp signal. We created a mask that used the minus data and divided into 1/16th nautical mile bins. The exported variables for each bin included nautical area scattering coefficient (NASC), mean backscattering volume (Sv), latitude, longitude, and depth. We used NASC as a proxy for shrimp biomass.

NASC was plotted by 1/16th nautical mile bins over the survey area. Trap catches (pounds per trap) was also plotted in this way for comparison of spatial trends. To assess temporal patterns in the data set we also plotted NASC and catch by trip. In this case, only catch data around the time of the acoustic survey was used. This included catch data on the date of the acoustic surveys ± 2 days. In addition to plotting NASC and associated catch spatially, we examined means by trip and further broke down the data into sub-regions within the full survey area. These three sub-regions were 'west' (west of -69.675° longitude), 'east' (east of -69.600° longitude), and 'mid' which was the sub-region in between (see Figure 3). Mean NASC and catch was calculated by trip and sub-region (Table 2) and these values were compared directly via linear regression. We also considered variations in NASC and catch as they related to depth and latitude (latitude was used as a proxy for inshore vs. offshore).

Results

Nautical area scattering coefficient (NASC) results, a proxy for biomass, are shown for each trip by 1/16th nautical mile bin in Figure 2. Also shown in figure 2 is trap catch data for the period around the acoustic survey dates (i.e., acoustic survey date ± 2 days). Mean NASC and mean catch (pounds per trap) by trip and by trip/sub-region are included in Table 2. Catch increased from 2.6 lbs per trap to 6.38 lbs over the 4 trips from the beginning to end of February. On the other hand, NASC was greatest during the first two dates, highest on the second date (trip B), and lowest towards the end of the survey period. By splitting the survey area into 3 sub-regions (west, mid and east), it was possible to generate 12 different NASC means to compare to trap data (Table 2). Figure 3 shows the NASC and catch values plotted spatially for each date. It was apparent from this that NASC values were highest for trip B. Figure 4 shows mean NASC and catch values by trip and by sub-region. NASC varied significantly among trips and sub-regions (ANOVA: $p < 0.01$); the interaction was also significant ($p < 0.0001$). NASC was highest during trip B and also uniformly highest in the east sub-region. Interestingly, NASC appeared to be related to the lunar cycle. The highest values, which were apparent in all the sub-regions, occurred on February 8-9th which incidentally was a full moon. Trap catches around the time of acoustic surveys also varied significantly among trips and sub-regions (ANOVA: $p < 0.0001$); as well, the interaction was significant ($p < 0.0001$). Trap catches were generally highest for the later two trips. There were no consistent differences among sub-regions, although, following the first trip, catches were generally lowest in the mid sub-region.

Figure 5 shows the relationship between NASC and catch for the 12 generated trip/sub-region combinations. While not significant, there appeared to be a tendency for NASC to decrease with increasing catch rates. This was particularly apparent in the east sub-region of the study area. Overall, there did not appear to be a strong correlation between shrimp abundance estimated from acoustics and shrimp catches from traps.

We also examined variations in NASC and catch as a function of depth. Figure 6 shows NASC and catch versus depth for the four trips. Aside from trip B (which may be influenced by a full moon; Figure 5), NASC appeared to be highest at around 50-70 m deep. This was most evidence for trips C and D. Catch rates followed a similar trend with catch increasing at around 60 m, and peaking around 70 m (Figure 6, bottom). We also examined trends in NASC and catch as a function of latitude (which was a proxy for inshore versus offshore). Maximum NASC values for each trip trended further south (offshore) over the course of the survey (Figure 7); the maximum was most inshore for trip A and furthest offshore for trip D. A similar pattern was seen for catch although it was less pronounced and didn't continue through to trip D. Finally, we examined NASC values as a function of time of day. Figure 8 shows NASC reaching minimum values during the middle of the night (around 02:00 – 04:00). Highest values were seen before midnight and before dawn. The notable exception to this pattern was with trip B. This is the trip that coincided with the full moon (Figure 4). In this case, the highest NASC values were recorded in the middle of the night (around 02:00).

Discussion

While relatively limited in scope, this pilot study has revealed important patterns in shrimp distribution, abundance and activity that may have implications for further surveys and possibly an inshore fishery. First, results from this acoustics survey and a trap survey in the same general area may reveal some similarities in distribution/abundance, but also notable differences. Indeed, patterns of abundance were different depending on which data source was used. If we relied only on trap data, we may have concluded that shrimp abundance is increasing throughout the dead of winter (February) in the area off of Boothbay. On the other hand, our acoustic survey showed that abundance may be highest in the early part of February in this area. If we remove the second trip, which appeared to be highly influenced by a full moon (more on this next), there still appears to be a declining trend throughout the month for each of the sub-regions; however, this did not appear to be significant.

There may be multiple explanations for the apparent difference in abundance trends between acoustic and trap data in this area. For instance, trapping did not focus on all the same areas covered by the acoustic survey. One area, in particular, in the mid sub-region and south of Damariscove Island, held high shrimp NASC for trip B but was not sampled by traps. Again, trip B appeared to be influenced by the moon and it is interesting to speculate the origin of these shrimp. Were they already there, and more active, and therefore more visible to the acoustics during a full moon, or did the full moon have the effect of driving more shrimp onshore from deeper areas? Sherwood et al. (2019) found that most shrimp surveyed acoustically in the winter are found at depths greater than 100m, significantly deeper than this area. Interestingly, Koeller et al. (2007) found that shrimp trap catches in Nova Scotia increase during periods of higher tidal range such as during full moons. This is believed to be related to higher horizontal movements resulting in increased interaction with traps. Unlike Koeller et al. (2007), we did not see higher catches during the full moon in February. Notwithstanding possible movements from deeper areas of the Gulf of Maine during certain periods like full moons, one area of agreement between the two data sets was that there appeared to be a general shift from the inshore to the offshore over the course of February for the shrimp in the area. This was most apparent in the acoustic data but also evident in trapping data up until trip C. There also appeared to be a general agreement in depth distributions between the acoustics and trapping data sets with shrimp abundance peaking around 50 – 70 m (Figure 6).

It must be stated that acoustics is not an infallible method for surveying organisms like northern shrimp. There are a number of acoustic principles that allow us to separate invertebrates from fish and therefore our acoustic signal is not likely to be contaminated in this way. Particularly, fish have uniform target strengths over multiple frequencies (within the range we employed), whereas invertebrates like shrimp have variable target strengths (Berger et al. 2018). As such, we can apply dB differencing to remove fish signal from our acoustic data leaving behind invertebrates. We can also attempt to remove smaller invertebrates from the data by applying target strength (TS) thresholds. For instance, shrimp resonate at TS values above -70 dB, whereas mysids and euphasiids resonate below -70 dB (Conti et al. 2005). This is mostly based on size and therefore smaller shrimp may be confounded with mysids and euphasiids. But, if we set our TS threshold at -70 and above, we are likely to only observe larger shrimp (i.e, trappable sizes). Thus, our acoustic filtering processes are likely to result in mostly shrimp. However, there is always a possibility that some of what we are interpreting as shrimp may be something else. In this sense, validation studies are always valuable. While some of the patterns that we saw matched between the data sets (e.g., similar depth dependencies and similar movement offshore over course of survey), and may therefore be useful for cross-validation, a more closely aligned survey design may be preferable moving forward. Particularly, given that trapping and acoustic transects were not perfectly aligned, a better design may place more emphasis on surveying as close as possible to where trapping is occurring. It is recommended that traps be set in a line along predetermined transects for this purpose.

This acoustic survey took place at night primarily because northern shrimp are believed to be nocturnal (Nakanishi and Nishiyama 1984) where they move off the bottom and are more active at night (Barr 1970). We did not collect data over a 24 hour period because it is believed that shrimp would be too close to the bottom (or in the bottom) and therefore invisible to acoustics during the day. That said, not including trip B which we think was influenced by a full moon, we did observe what appeared to be an activity maximum around 22:00 hours (possibly earlier) and activity peaked again prior to dawn (we assume the NASC is a proxy for activity since shrimp would have to be swimming off the bottom to be observed with acoustics). Both times would be dark in the winter. However, there was an activity minimum around 02:00 hours. This resembles crepuscular behavior. Surveys over more hours of the day and night may be useful for determining when shrimp are most active and therefore most observable by acoustics.

Overall, we were able to collect important data on shrimp distribution, relative abundance and activity/behavior that may be useful for future survey designs and a possible inshore fishery. Future surveys should take into account nocturnal/crepuscular activity of shrimp and the possible influence of lunar cycles. Given that patterns of abundance did not perfectly align between acoustics and trapping, future work should focus on coordinating these two methods more closely so that more direct spatial/temporal comparisons can be made. It is not surprising that acoustics would give different depictions of shrimp in this area than trapping. Acoustics works when shrimp are active and off the bottom, including possibly just moving through like is possible during trip B (full moon), whereas traps work when shrimp are close to the bottom. Greater understanding of how these two data sources complement each other will lead to a greater understanding of the resource.

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Table 1. Dates, and start and end times for each acoustic survey trip (date applies to start time; trips ran into the next morning).

Trip	Start date	Start time	End time*	Distance (NM)	Average speed (knots)
A	1/31/2020	22:30	5:12	44.2	6.6
B	2/8/2020	22:22	6:18	50.7	6.4
C	2/16/2020	22:09	5:30	43.1	5.9
D	2/22/2020	22:00	4:49	44.3	6.5

*next day

Table 2. Mean catch (lbs per trap) and mean NASC by trip and by trip/sub-region. Sample size for catch is number of trap hauls. Sample size for NASC is number of 1/16th NM bins. Std is standard deviation and SE is standard error.

		Pounds per trap				NASC			
Trip	Region	Mean	Std	N	SE	Mean	Std	N	SE
A	all	2.6	2.26	92	0.24	50.3	165.1	707	6.2
B	all	4.18	3.4	58	0.45	169.5	260.0	811	9.1
C	all	5.83	5.15	56	0.69	40.3	83.6	690	3.2
D	all	6.38	5.75	101	0.57	27.1	60.8	709	2.3
A	W	1.45	0.81	42	0.12	57.8	240.2	214	16.4
A	M	3.11	2.87	32	0.51	38.1	105.1	284	6.2
A	E	4.41	1.92	18	0.45	86.6	369.2	213	25.3
B	W	5.22	4.1	28	0.77	109	151	203	10.6
B	M	2.13	1.62	15	0.42	172.6	294.8	439	14.1
B	E	4.27	2.32	15	0.60	263.3	443	174	33.6
C	W	11.03	4.71	18	1.11	45.6	101.8	214	7.0
C	M	2.52	2.65	25	0.53	42.4	72.5	324	4.0
C	E	5	3.49	13	0.97	64	412.2	156	33.0
D	W	9.17	5.85	39	0.94	26.2	34.1	195	2.4
D	M	1.39	0.9	37	0.15	26.4	55.5	340	3.0
D	E	9.43	4.66	25	0.93	63.4	390.2	177	29.3

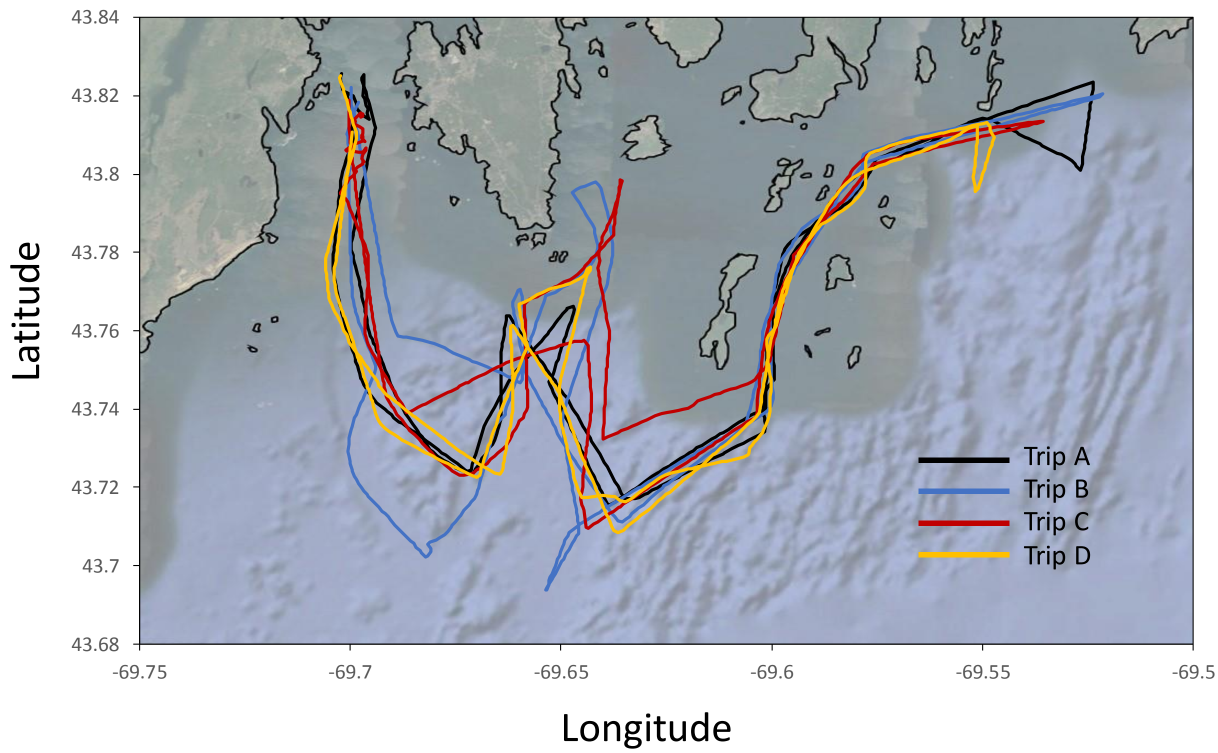

Figure 1. Map showing acoustic survey tracks over 4 trips. Trips started off Southport Island and wound their way up to Pemaquid Point and back. See Table 1 for trip details.

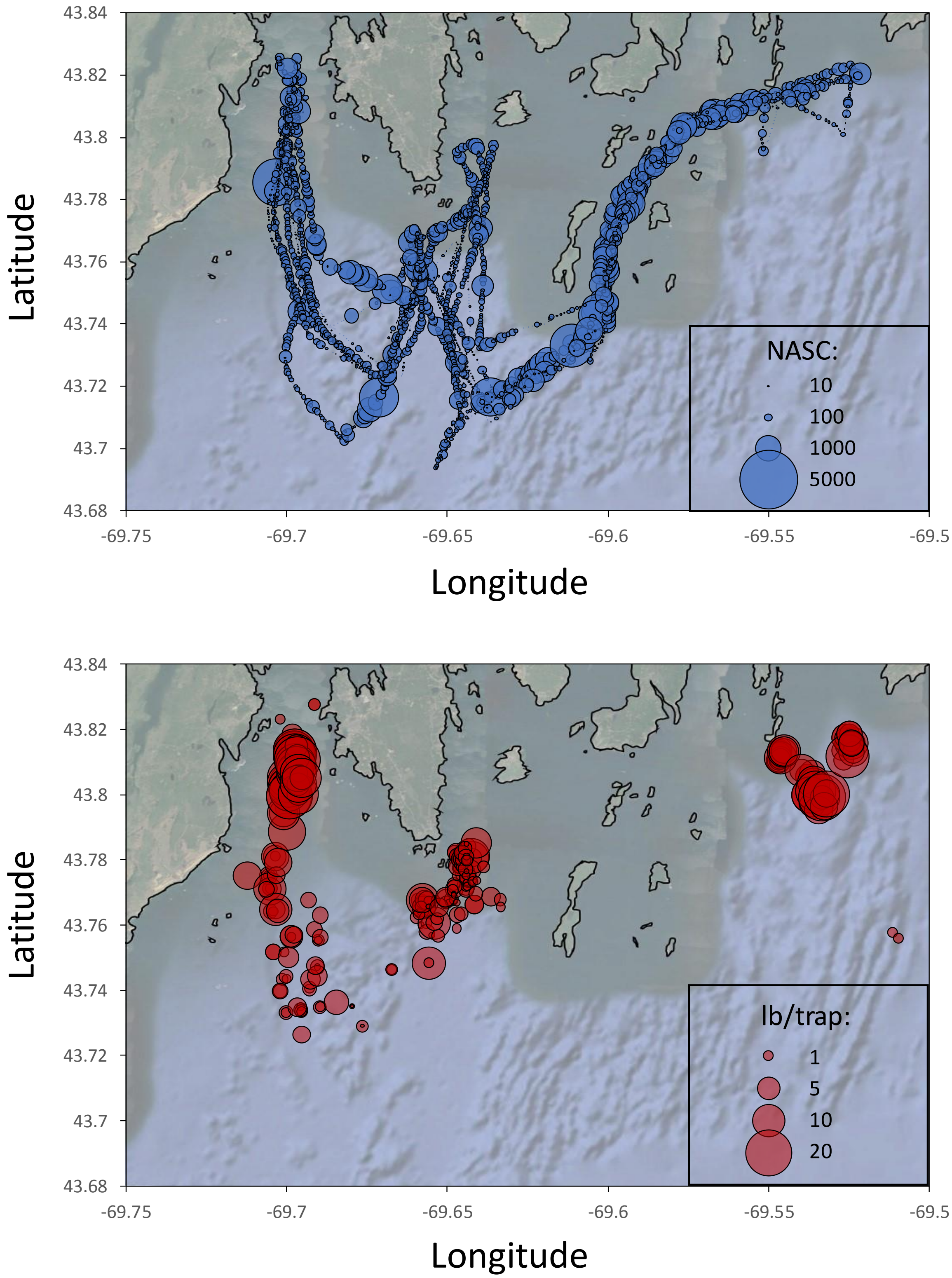

Figure 2. Map of shrimp distribution from acoustics (as NASC; upper panel) and from trapping (lower panel) over entire study period.

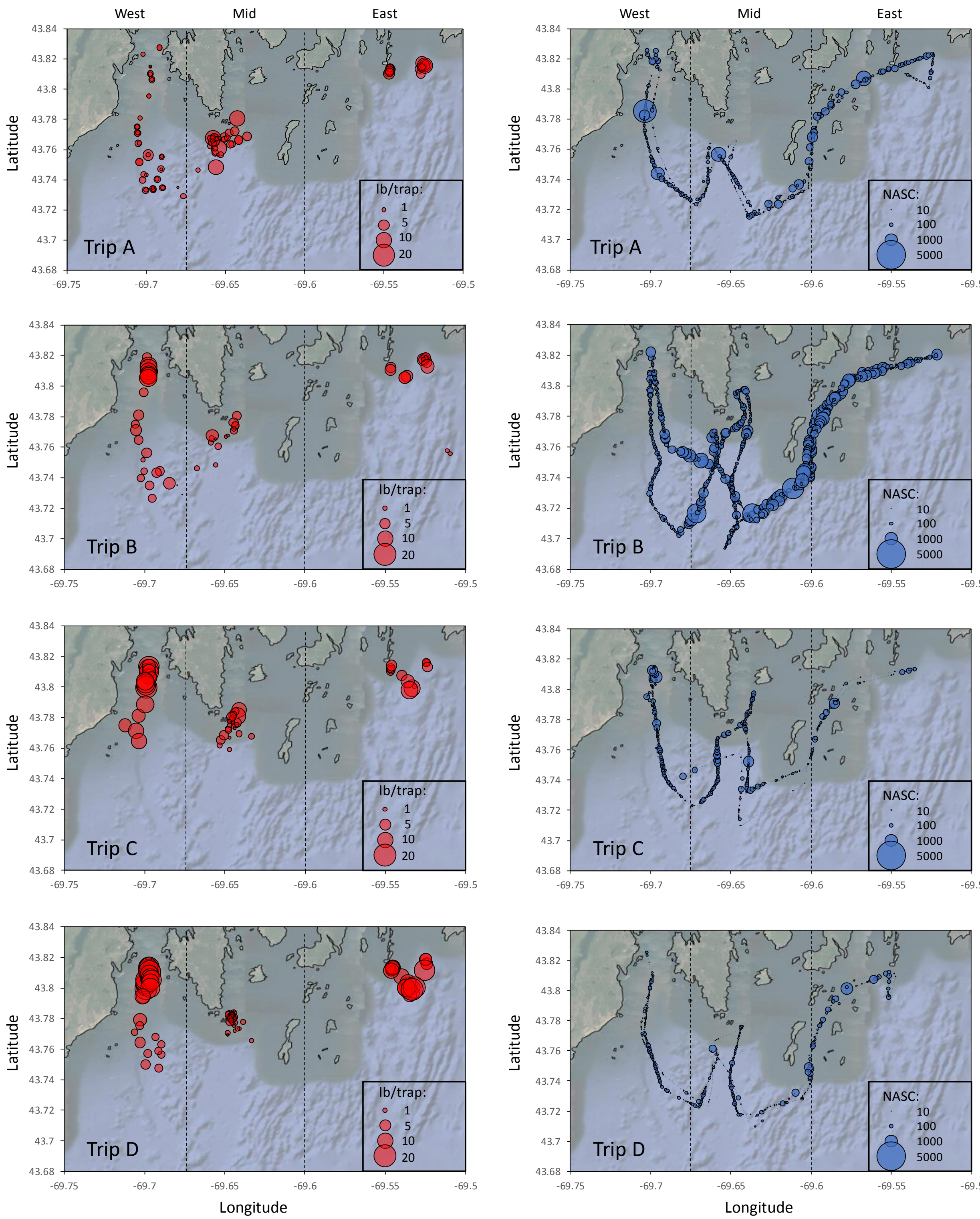

Figure 3. Map of shrimp distribution from acoustics (as NASC; right panels) and from trapping (left panels) by trip. Dashed vertical lines represent divisions between survey sub-regions.

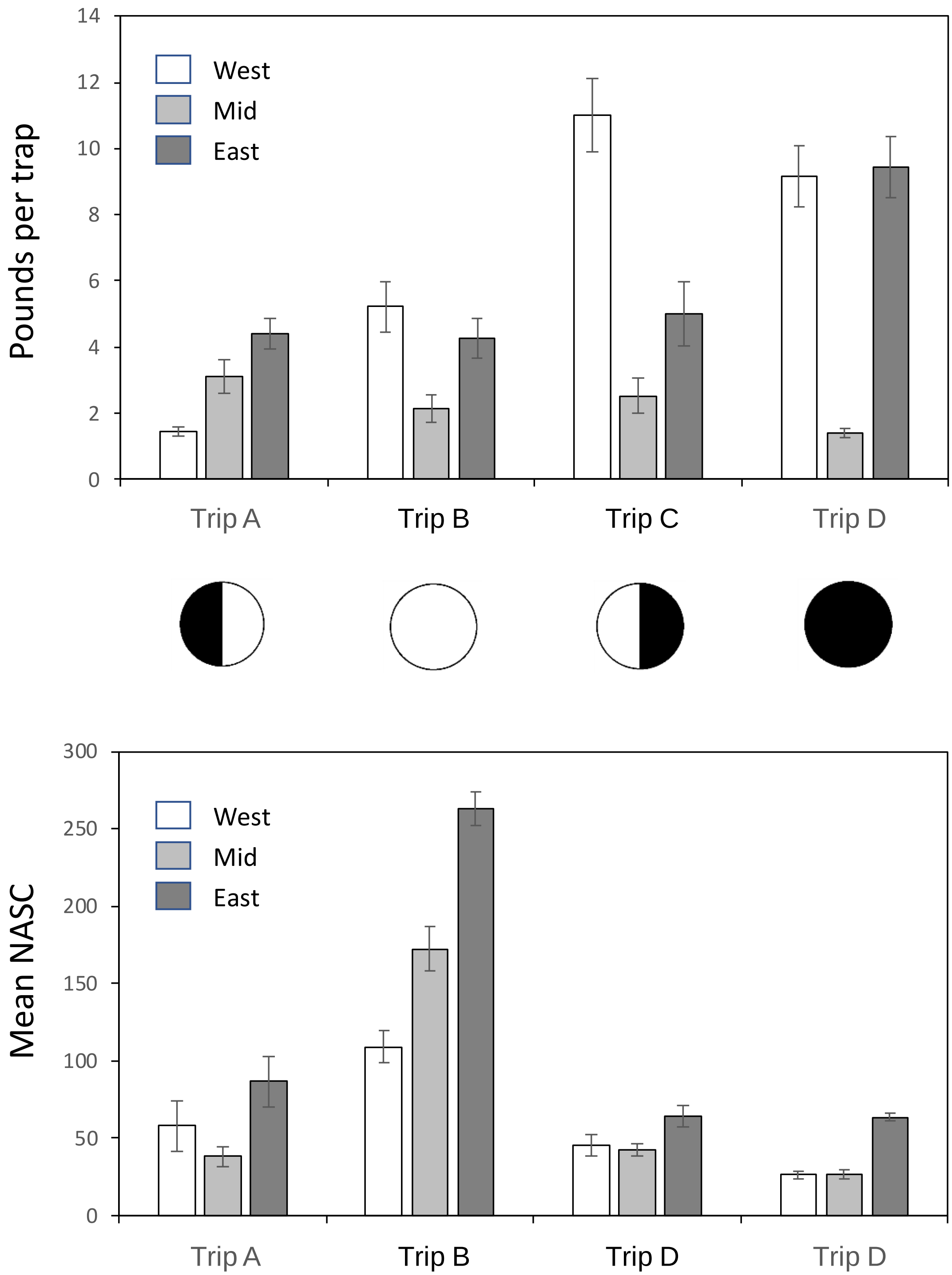

Figure 4. Mean trap catch by trip and sub-region (top panel) and mean NASC by trip and sub-region (bottom panel). Error bars are standard error. The lunar cycle is shown; a full moon occurred during trip B and new moon during trip D.

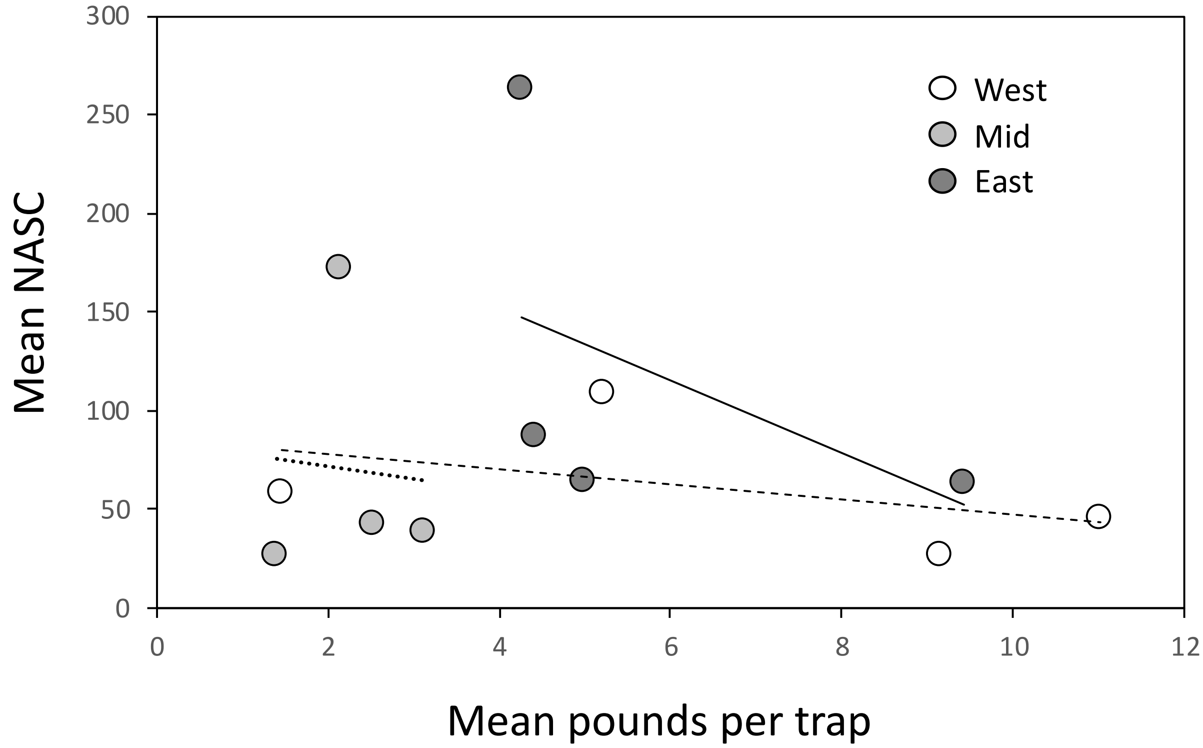

Figure 5. Relationship between mean NASC and mean catch for the 12 combinations of trip and sub-region. Trendlines are not significant.

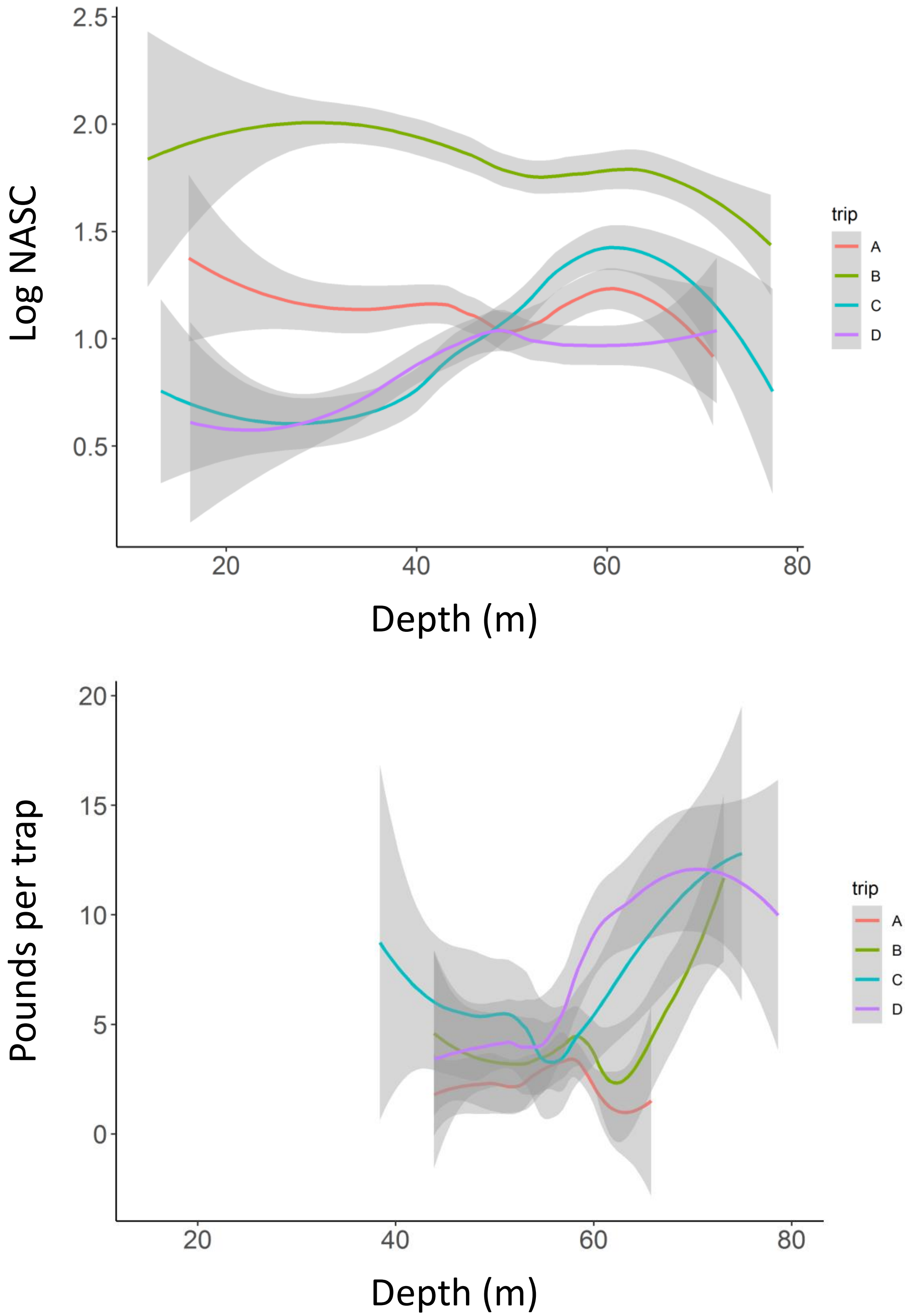

Figure 6. Smoothed lines showing trends in log NASC (upper panel) and catch (lower panel) in relation to depth. Grey areas are 95% confidence intervals.

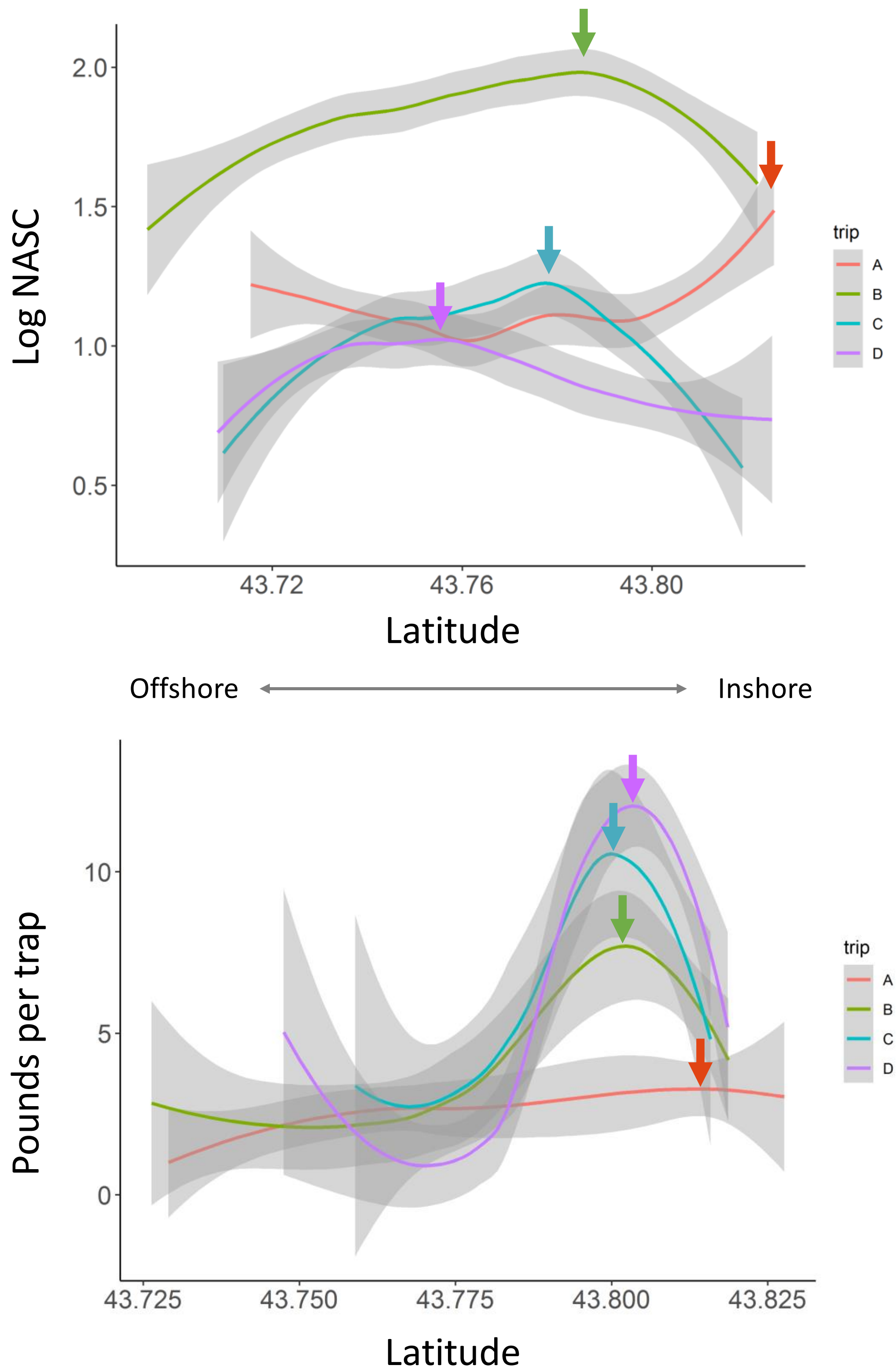

Figure 7. Smoothed lines showing trends in log NASC (upper panel) and catch (bottom panel) with latitude (taken as proxy for inshore vs. offshore) by trip. Grey areas are 95% confidence intervals. Notice tendency for maxima (arrows) to move sequentially offshore.

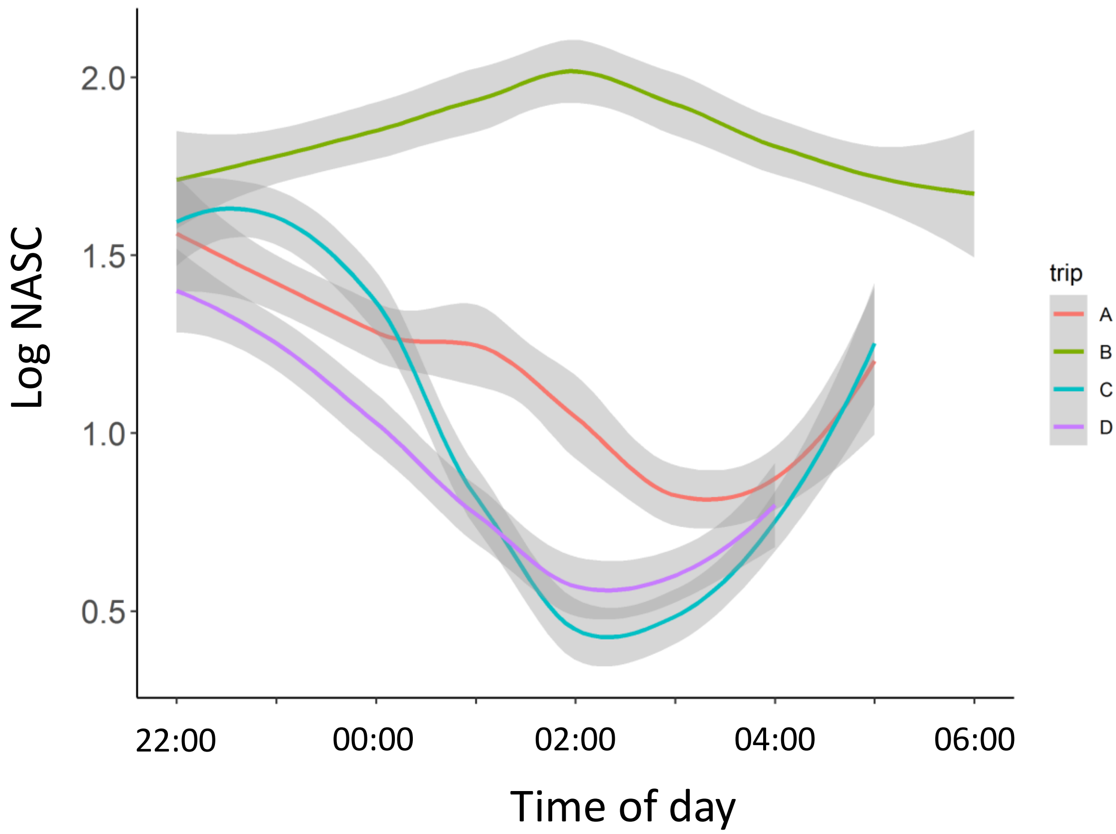

Figure 8. Smoothed lines showing trends in log NASC in relation to time of day by trip. Grey areas are 95% confidence interval.