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Purple sandpipers (*Calidris maritima*) feeding in an Arctic estuary: tidal cycle and seasonal dynamics in abundance

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ABSTRACT

The purple sandpipers (*Calidris maritima*) are the most common waders in the high arctic archipelago of Svalbard, Norway. There they have to cope with a very short summer season and high metabolic costs of migrating far north and breeding in an arctic environment. The food on land is usually scarce, whereas there are rich feeding grounds in the littoral zone, such as in the intertidal zone of river flats. These feeding grounds are though only available to the purple sandpipers during low tide and as long as the estuary is not covered by sea ice. One of these intertidal flats was used as the fieldwork area in this study.

To study when the birds are coming to this intertidal flat for feeding, a count study was performed during the entire stay of the purple sandpipers in Svalbard in summer 2010. Point counts were performed at low tide during 118 different days. Additionally, point counts were performed at twenty days during the six hours of the entire low tide period, to study when during the tidal cycle most sandpipers were feeding at the estuary.

Most sandpipers were counted at the intertidal flat at the beginning of June with the highest number, 921 individuals, on 8th June. When the tundra was free of snow and the birds could start breeding, numbers where rapidly declining with very few sandpipers left in the estuary in July and the first part of August. From the end of August numbers were increasing again with a second but lower peak in the end of September and beginning of October. By the end of October all sandpipers had left the estuary.

The study on the appearance of purple sandpipers at the estuary at the different periods of low tide showed that there were significantly more sandpipers between low tide and half an hour later than at the rest of the low tide period. This might be due to better access to their prey at that time. This knowledge could be used in future studies aiming at recording the maximum numbers.

The result of the phenologic study could be included in a long term monitoring to see if the numbers and the timing of purple sandpipers are stable in this area or not: Are the peak numbers differing significantly? Is the timing of the arrival, the stay on the tundra and the timing of leaving the archipelago in the fall changing? Long-term monitoring would be especially interesting in the view of possible influences of the climate change on the purple sandpipers. Rising sea level as a result of the climate change would change the morphology of the estuaries and thereby influence the food resources available for sandpipers.

CONTENTS

INTRODUCTION

The time period available to purple sandpipers (*Calidris maritima*) for breeding depends on which latitude and altitude they are feeding at. The further North or more exact in as colder habitats they breed, the shorter the laying season and the later the breeding can start (Summers & Nicoll 2004). In Svalbard, the tundra is covered with snow until sometime in June, so the purple sandpipers cannot start breeding there before that. In 2010, most snow had disappeared from the Advent valley on 8^{th} June (Philipp Semenchuk**,** personal communication) and even later on the higher plateaus, which are also breeding grounds for sandpipers (own observation). Another difficulty with breeding in Svalbard is the scarcity of food and nutrients on land.

Purple sandpipers breeding in Svalbard migrate to the archipelago and feed at the intertidal flat of the Advent estuary already several weeks before breeding on the tundra starts (Bengtson & Fjellberg 1975). At the estuary they feed mainly on intertidal invertebrates (Rosa *et al*. 2007) such as amphipods, gastropods and polychaetes (Bengtson & Fjellberg 1975, Leinaas & Ambrose 1992). Additionally, the purple sandpipers, both the grown-ups and the young, come to the intertidal flat for feeding before leaving the archipelago. Yearlings that are not breeding yet, and the birds that fail with their brood, are at the estuary for feeding even during the summer (Cramp & Simmons 1983).

While being on the tundra the sandpipers find mainly solitary insects and spiders to feed on (Bengtson & Fjellberg 1975). Compared to the low amount of nutrients on land, the ocean around Svalbard includes a lot more nutrients, especially since Svalbard's coast is influenced by the North Atlantic Drift (Loeng & Drinkwater 2007). Besides the ocean as a nutrient source, there are also other advantages with migrating so far North for breeding. Some advantages are the permanent daylight, limited competition and lower pathogen as well as predation pressure than in more Southern areas (Gilg & Yoccoz 2010). These are probably important reasons for the migrating birds to cope with the high costs of migrating and with the higher metabolic costs of breeding in an arctic environment (McKinnon *et al*. 2010, Alerstam *et al*. 2003).

It is not known yet how many purple sandpipers are breeding in Svalbard each summer. Estimates vary between 2000-10 000 breeding pairs (Strøm 2006). Therefore it is also difficult to evaluate how climate change influences the sandpipers. But in general the predicted climate change probably contributes to rising sea level. This would change the morphology of the estuaries that are important as feeding grounds for waders (Austin & Rehfisch 2003) and change the availability of invertebrate prey there. Additionally, coastal tundra habitats would disappear (Rehfisch & Crick 2003). There could even be possible advantages for the purple sandpipers resulting from a climate change: prolonged and/or warmer breeding season in the high arctic could lead to more time for moulting and gaining fat reserves (Rehfisch & Crick 2003).

Several studies have been performed around Longyearbyen about the breeding habits of the purple sandpipers (Bengtson 1970, Bengtson 1975, Pierce 1993, Pierce 1997, Pierce & Lifjeld 1998). But these studies do not analyze the relative importance of feeding at the intertidal flat during the different phases of their stay within the area. Luukkonen (2009) started to investigate when the sandpipers are coming to the flat for feeding, and my investigations are based on her study.

Study species

The purple sandpiper has a semi-circumpolar breeding range in the Canadian Arctic islands, Greenland, Svalbard, Taymyr and Arctic Russia. They winter at rocky shores as far North as the coast remains free of ice, e.g. the Northern coast of Norway or the West coast of Sweden (Dierschke 1994, Cramp & Simmons 1983). The purple sandpiper thus has the Northernmost range of all waders in both winter- and summertime (Bengtson 1975, Cramp & Simmons 1983).

The purple sandpipers are relatively small brownish waders with quite short legs and a comparatively long, downcurved bill (Strøm 2006) (figure 1). They are rather long-lived shorebirds often reaching an age of at least seven years (Pierce & Lifted 1998). Male and female purple sandpipers do not differ in plumage or size. But there is a bill-size dimorphism with males having a shorter bill (Hallgrimsson *et al*. 2008). However, the difference is only about half a centimetre, with males having in average a 29.8 mm long bill and females in average a 34.5 mm long bill (Hallgrimsson *et al*. 2008). Therefore it is not possible to define sex from distance. At distance, it is neither possible to differentiate the grown-ups from the month old chicks visiting the estuary later in the season. The purple sandpipers have monogamous pair bounds (Pierce & Lifjeld 1998). But, different to most other monogamous sandpiper species where both sexes take care of the brood, in this species the female is leaving the young after having helped with incubating the eggs (Strøm 2006) and the male alone takes care of the brood from hatching to fledging (Pierce & Lifjeld 1998). The females should therefore be expected to return to the shore about a month earlier than the males and maybe even migrate Southwards earlier.

Figure 1. Purple sandpiper at the shore of the Advent Fjord in Svalbard. Photo: Maximilian Janson

The density of breeding pairs is often quite low and observed to be about 1-5 pairs/km^2 or 1.1 pairs/km^2 respectively (Summers & Nicoll 2004, Pierce & Lifjeld 1998). They normally have clutches with four young (Summers & Nicoll 2004). According to Leinaas & Ambrose (1999) there are no efficient predators on adult and fledged juvenile purple sandpipers in Svalbard, but the polar fox (*Alopex lagopus*) and also the arctic skua (*Stercorarius parasiticus*) are important predators at least on eggs and chicks (Strøm 2006, Pierce 1997).

Main aims

There are two main aims with my studies of the purple sandpipers at an intertidal flat on Svalbard. The first one is to better understand the phenology of the species.

The second is to find out when during the low tide period the peak number of sandpipers occurs at the intertidal flat.

Phenology

There are a lot of questions regarding the phenology of the purple sandpipers in Svalbard: when are they arriving, when do they leave the estuary to start breeding on the tundra, when do they come back to feed at the estuary and when are they leaving Svalbard in the fall to fly to their wintering grounds? Is it possible to find variables, like the varying temperature, which can explain the timing of these events? The lower the tide is the more feeding area is exposed. Does this result in more sandpipers coming to the estuary for feeding? Phenology studies on purple sandpipers in this area were also part of a previous study with field data from 2008 (Luukkonen 2009). However, the main focus of the work by Luukkonen (2009) was on testing to what degree purple sandpipers are tide followers when they feed in the estuary. Therefore, a study focusing on the phenology instead is needed and can benefit from the opportunity to compare phenology observations from two different years.

The result could additionally be used in the future: If more total counts are performed during several years, the combined results would give a long time dataset to indicate if the phenology of the sandpipers is changing and also if the number of purple sandpipers in that area is stable or not. It would be especially interesting to study possible changes of phenology and numbers of purple sandpipers in relation to the ongoing climate change. The climate change has big influences on the Barents Sea and therefore also on animals depending on food resources from it (Ellingsen *et al*. 2008).

Varying number of sandpipers throughout the low tide period

Another purpose of this study was to show if there is a relationship between the different phases of the low tide period and the number of birds feeding at the Advent estuary. At what time of the low tide period are most sandpipers feeding at the intertidal zone? Is it before, after or during the low tide? An earlier study by Luukkonen (2009) within the same area proposes that the peak of the number of sandpipers is about two hours after low tide, during rising tide. However, this result is based on counts of sandpipers inside a transect, not on total counts of the whole area. Therefore, this hypothesis needs to be tested. To know at which time most purple sandpipers are visiting the intertidal flat would be helpful for choosing the best time for future studies that rely on detecting the maximum number of birds feeding.

METHODS

Study area

The study area was the high Arctic mud flat of the delta of the Advent River running into the Advent Fjord located on Western Svalbard. Svalbard is an archipelago belonging to the Norwegian administrative area. It lies between latitude 74° and 81° N and longitude 10° and 35° E. The study took place on the west side of the main island of the archipelago, Spitsbergen, at 78° 13′ N, 15° 38′ E at the settlement called Longyearbyen (figure 2).

Figure 2. The location of the study area. The study area is indicated with red lines on the map to the right.

The temperature in Longyearbyen in the warmest month July is on average +6˚C (Gjærevoll & Rønning 1999). Between April 20th and August 23rd the sun is not setting at any time (Harland 1997). It was therefore possible to carry out the fieldwork either in day- or nighttimes during almost the whole study period.

The study area is about 2.5 km wide and 1 km long with rocky shores at the upper meters and mud at the rest of the intertidal flat. There are some rocky peninsulas reaching into the water which are also feeding areas for the purple sandpipers. The choice of this specific study area had different reasons. One is the high numbers of sandpipers feeding in this large estuary. Additionally it is one of just few estuaries that normally are free of ice in the spring which made a study of the whole Svalbard visit of the purple sandpipers possible. At the same area counts and other studies on purple sandpipers had been performed earlier, so count data was available from a previous year. Expanding this dataset could help for later studies in the area, e.g. long-term studies on possible changes in the presence of purple sandpipers. Another important reason was its accessibility, since the area was situated close to Longyearbyen. Other practical reasons include the possibility to survey such a big area from a single observation point.

Sandpipers were counted at the study area from a site at the shore of the Advent Fjord, from where it was possible to see all the birds occurring in the estuary by using binoculars and a scope. The same spot was used for point counts in a former study of purple sandpipers (Luukkonen 2009). This observation point is right outside the bird observation house belonging to the local field biologist group LoFF (LoFF = Longyearbyen Feltbiologiske Forening) a few hundred meters Northeast of the Svalbard Science Centre where the University Centre in Svalbard (UNIS) is located. The study area was divided in two parts: 1) the Southwestern side, from which the counting was performed, and 2) the Northeastern side of the estuary, which is about 2.5 km away from the observation point (figure 3). The Southwestern and Northeastern sides of the study area are separated by the main inflow of the Advent River into the fjord from Southeast (yellow line in figure 3). The same division of the study area into two parts was used by Luukkonen (2009), which makes the results of the two studies comparable.

On the Southwestern side almost every single purple sandpiper was counted. On the Northeastern side the results did probably just give an estimate of the number of sandpipers, since it was not possible to differentiate the much more common purple sandpipers from the also occurring dunlins and sanderlings (wader species of about the same shape and size). Moreover, sandpipers on the Northeastern side were sometimes standing too close to each other to allow identification of each individual. Some were also behind stones or ice blocks, or feeding on the rocky shore where it was much more difficult to count them.

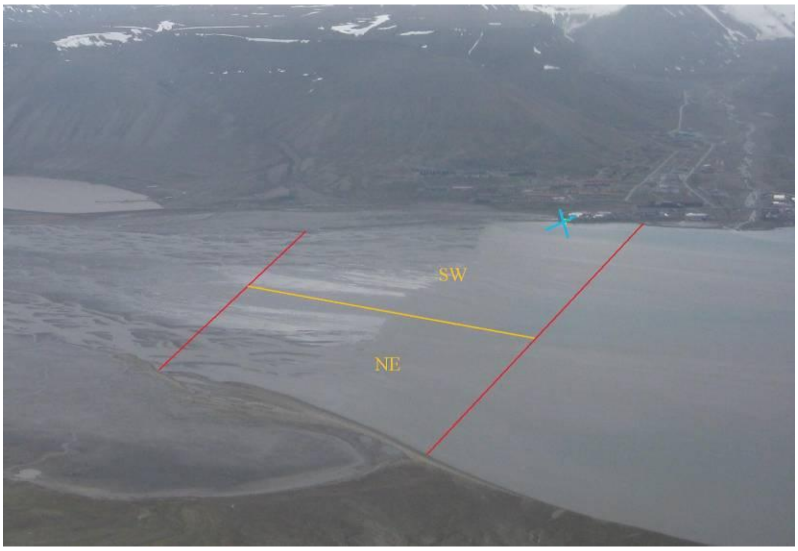

Figure 3. Study area. The picture is taken from the mountain Hiorthfjellet North of the study area during low tide period. The red lines indicate the borders of the study area. The yellow line divides the Southwestern from the Northeastern part of the study area. The blue cross represents the site from which the counts were performed. Photo: Beke Regelin

The fieldwork was performed between the end of May, when the first sandpipers arrived to Svalbard, and mid October, when the last sandpipers left the Advent River estuary.

Counting method

The time chosen for counting was dependent on the tidal cycle. The predicted tidal amplitude for the different times was taken from a tide table from the Norwegian map office (Statens kartverk Sjø 2009). The counts were performed at most of the days the sandpipers stayed on Svalbard, but usually not at two consecutive low tides to avoid autocorrelation.

For counting, both binoculars and a scope were used. The binoculars that were used for counting the sandpipers at the main part of the Southwestern side of the study area had a magnification of eight times. For the most distant part on this side and close to the edges of the rocky peninsula in the South, the scope with a magnification of about twenty times was used. The purple sandpipers on the Northeastern side were counted by using the scope with a magnification between twenty and forty times. Up to sixty times magnification was used when the visibility was low or the birds were standing close to the coast where they were more difficult to differentiate from the stones. Before a counting started, the binoculars were used to see if there were several other waders like sanderlings or dunlins around, to not include a wrong species into the count. To eliminate the risk of forgetting the number of individuals during a count, a hand tally counter was used.

Every counting event started by counting the Southwestern side of the fjord. The count started from a fixed point, the tip of a peninsula Northwest of the counting point, and continued along the water edge and the shore towards the middle of the fjord. The counting on the Northeastern side started on the most Southeastwards part of it, which was defined to be the point on the opposite side of the rocky peninsula, which is the end of the fjord on the Southwestern side. This was not an exact point, but since no birds were observed in this area, this vagueness did not have any influence on the results. The counting continued towards Northwest until reaching the end of the study area defined by a red cabin on that side of the fjord. Each counting event lasted for about five to ten minutes depending on conditions like wind, sun reflection and especially on the number of purple sandpipers at the intertidal flat. If purple sandpipers were observed flying, they were counted in case they came from the direction of a not yet observed area but not if they flew into an area that was going to be counted later on. If big flocks of sandpipers were flying away before counts were completed, their number was estimated. To be sure that the counting results did not differ too much depending on the person carrying out the fieldwork, the four field workers who participated in the counting did repeated counts to assure that the results were comparable.

All the statistical analyses were done by using the program R, version 2.11.1 (R Development Core Team 2008).

Phenology

The total number of sandpipers in the estuary was counted during 118 days from the end of May until the middle of October. The birds were counted on the exact time when the low tide was predicted to occur. They were always counted from the same spot.

I was on Svalbard from the 7th June to the end of August in 2010. The remaining fieldwork was carried out by Aino Luukkonen, Øystein Varpe and Christiaane Hübner.

Varying number of sandpipers throughout the low tide period

The purple sandpipers at the intertidal flat of the Advent Fjord were counted at twenty days during the entire low tide period to achieve a dataset of the different numbers of sandpipers throughout the whole period. The sandpipers were first counted exactly three hours before the predicted low tide and then every thirty minutes until exactly three hours after the predicted low tide. That made together thirteen counts per low tide period.
To make the twenty different counting events comparable with each other and equally influential, the total counts were transformed into relative numbers. To do this, each count for a given day was divided with the count at time 0, which is the time of the lowest tide, of the same day (figure 5). Both a linear and a quadratic function were then fitted to the count data. The Akaike Information Criterion (AIC) was used to see which model fits better. A lower AIC-value indicates a better model.

The general formula for describing a quadratic function is $y=ax^2+bx+c$, where y and x are variables giving the y- and x coordinates. Parameter a decides in which direction the graph is open and how wide it is, b has to do with the point of the changing point of the graph and is also called vertex, c is the variable giving the y-intercept. The derivative $y'= 2ax+b$ is used to find the vertex of the curve, the x-value when $y'=0$. The vertex gives the point of the time of the low tide period with the highest number of birds at the estuary. By pasting this x-value into the function $y=ax^2+bx+c$ the y-value giving the height of the turning point is received. Since all numbers were transferred into relative numbers, this value also gives a relative number of the average peak number of purple sandpipers.

Additionally, at all 118 days of counting at low tide, a second count half an hour later was also performed. An additional analysis, a paired t-test, was run on this data. The aim here was also to test if the number of sandpipers differed significantly between these two counting times.

To see how reliable the time of the predicted low tide was, I compared it to the observed low tide.

Comparing the number of purple sandpipers to other variables

I also included other variables like temperature, wind, and observed height of the tide at the study area. A multiple regression was run on all the variables including n-1, day, tide height, temperature and wind speed, to see how much the number of purple sandpipers at the different days throughout the whole summer season could be explained by these variables. The number n-1 was included to account for temporal autocorrelation in the data. “n-1” represents the number of purple sandpipers counted the previous time, which does not necessarily need to be the previous day. The regression was run on the variables compared to the total numbers of sandpipers at the given times, without differentiating between the different parts of the area.

Repeated counts

To see how good the counting method is, I recounted the amount of purple sandpipers directly after the first count at twenty counting events in the beginning of the field season. There was a time lag of five to ten minutes between the repeated counts.

The dataset for the repeated counts performed by different people was too small to run a statistical analysis. But since there was enough data available on my own repeated counts, this was addressed using correlation analysis.

RESULTS

Phenology

The first purple sandpipers were counted in the study area on May 20th 2010. The number of sandpipers peaked at the beginning of June with a counted record number of 921 individuals on June 8th. Numbers were then steadily declining; between the middle of July and the middle of August often only around 20 individuals or sometimes even less were at the estuary (figure 4). In the second half of August there were between 100 and 200 purple sandpipers at the study area and numbers were further increasing in September and October with a second, lower peak (figure 4). By the end of October all purple sandpipers had left the study area. I differentiated between the total number of sandpipers at the entire estuary and the number of sandpipers in the Southwestern area of the estuary only. In the first part of the fieldwork a lot of sandpipers were feeding also at the Northeastern side of the study area. But from the 12th July on most sandpipers were seen only in the Southwestern area.

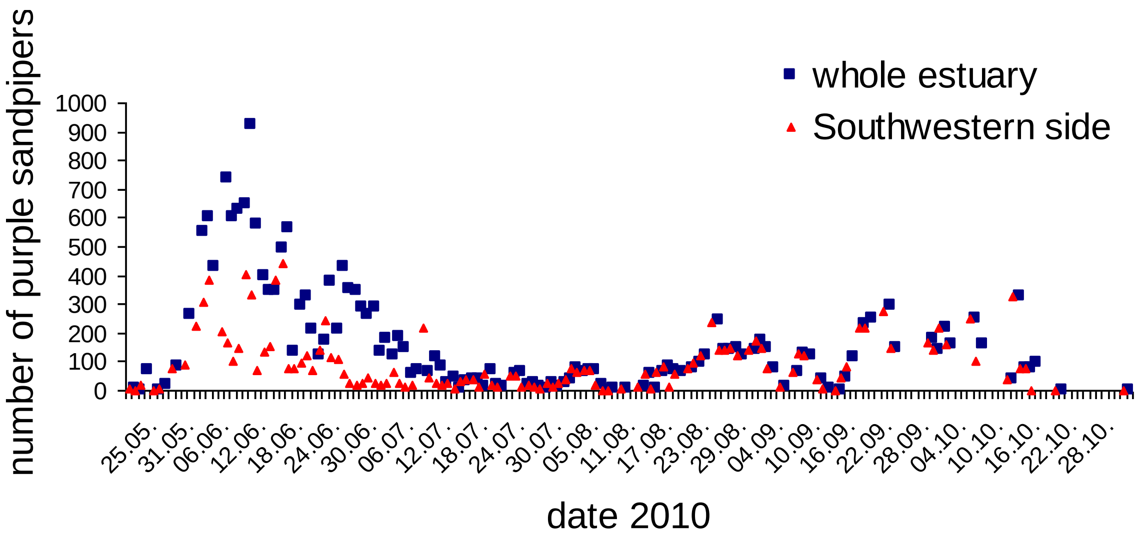

Figure 4. Number of purple sandpipers at the intertidal flat of the Advent Fjord at low tide in the year 2010 in total (estimate) and only at the Southwestern side (accurate number) of the study area.

Varying number of sandpipers throughout the low tide period

The quadratic regression model represented a better fit to the data than the linear model, based on AIC values and adjusted R^2 (table 1).

Table 1. AIC-values of using the linear or the quadratic regression for testing if there are differences in the number of purple sandpipers throughout low tide

model	df	AIC-value	p-values	Adjusted R^2
Linear model	3	618	5e-05	0.058
Quadratic model	4	578	2.7e-13	0.195

The quadratic function was highly significant (table 1). The result of the quadratic function was used to calculate the time of the highest number of birds, which appeared to be about 33 minutes after low tide (supplementary calculation 1). The highest point has the y-value 1.1 (supplementary calculation 2) which means that the number of sandpipers at 33 minutes after low tide was about 10% higher than at the time of the low tide at time 0. The relative amount of purple sandpipers was higher in the time after the low tide than during the time before (figure 5, supplementary figure 1).

Table 2. Coefficients of the quadratic regression on the number of purple sandpipers at the different phases of the low tide period

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1.07	6.81e-02	15.691	< 2e-16 ***
Minutes	1.8e-03	4.03e-04	4.460	1.23e-05 ***
I(minutes^2)	-2.71e-05	4.05e-06	-6.707	1.26e-10 ***

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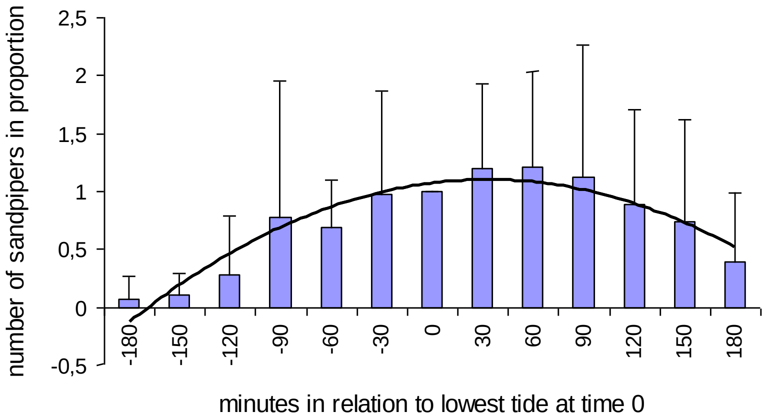

Figure 5. Average relative number of 20 times 13 counts throughout the whole low tide period. Standard deviations are given. Adjusted R^2=0.195. Trend line: $y=-2.71e{-}05x^2+1.8e{-}03x+1.07$

Also the second analysis, run on the data of 118 days of counting purple sandpipers at the time of low tide and also 30 minutes later, showed a similar result (figure 6). There were more sandpipers at the study site 30 minutes after low tide than right at the time of the low tide (paired t-test, t = - 2.234, df = 114, p-value = 0.027). On average there were 168 purple sandpipers at low tide and 181 half an hour later, a mean difference of 13 sandpipers.

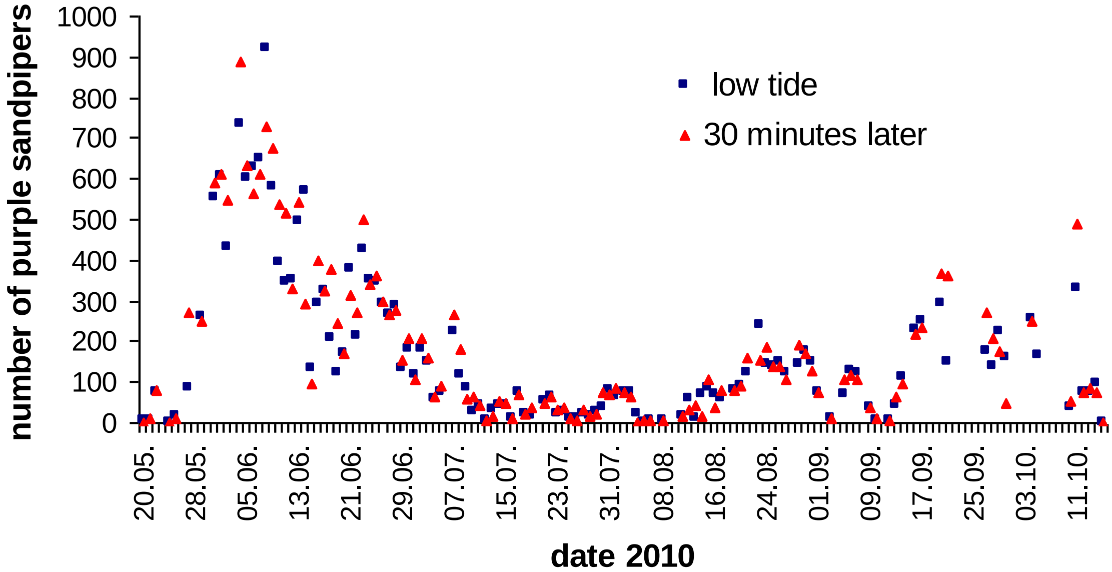

Figure 6. The number of purple sandpipers at low tide compared to the number of sandpipers 30 minutes later.

Since the predicted time of the low tide often did not correspond with the observed one, this result does not exactly represent the reality. The predicted times and heights of the tide table for Longyearbyen in 2010 that were used to estimate when to perform the counts, varied from the observed times and heights. The height of the tide was measured in Ny-Ålesund by the Norwegian map office and recalculated for the Longyearbyen-area by subtracting 16 minutes and changing the height by the factor 1.15 (Statens kartverk Sjø 2009). To see, how much the differences between the predicted and the observed data could influence the result, the observed data was compared to the predicted one. In average, the time of the observed low tide during the 118 days that the fieldwork was carried out, was 17 minutes later than the predicted time (figure 7). By only taking the data of the 20 days of counts at the entire low tide period into consideration, the time of observed low tide was in average 21 minutes later than the predicted one (figure 10).

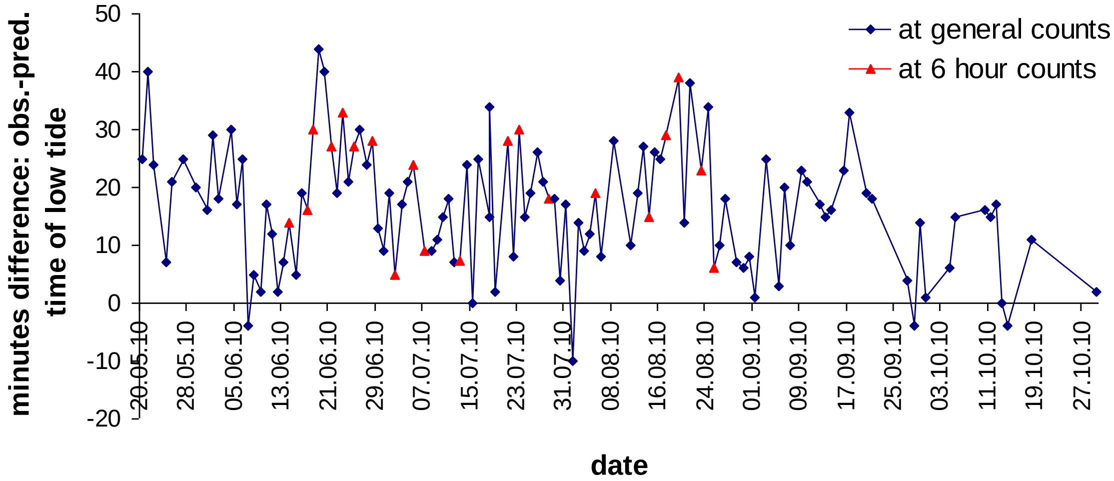

Figure 7. The time of the observed low tide differed from the time of the predicted low tide. Often the low tide was actually later than predicted. The red data-points indicate the difference of low tide time at the dates where 6 hour counts were performed.

Without being able to test this closer, due to the fact that I don't have the numbers of the purple sandpipers at the estuary at the time of the observed low-tide, I can say that the time of the most sandpipers is a bit earlier than this study showed, between low tide and half an hour later.

Comparing the number of purple sandpipers to other variables

The multiple regression on the different variables (figure 8) showed a significant influence on the number of purple sandpipers at the 116 counting events by the number of sandpipers at the previous counting event ($p<0.01$, positive relationship), date ($p=0.005$, negative relationship) and by the height of the tidal amplitude ($p=0.048$, positive relationship) (table 3).

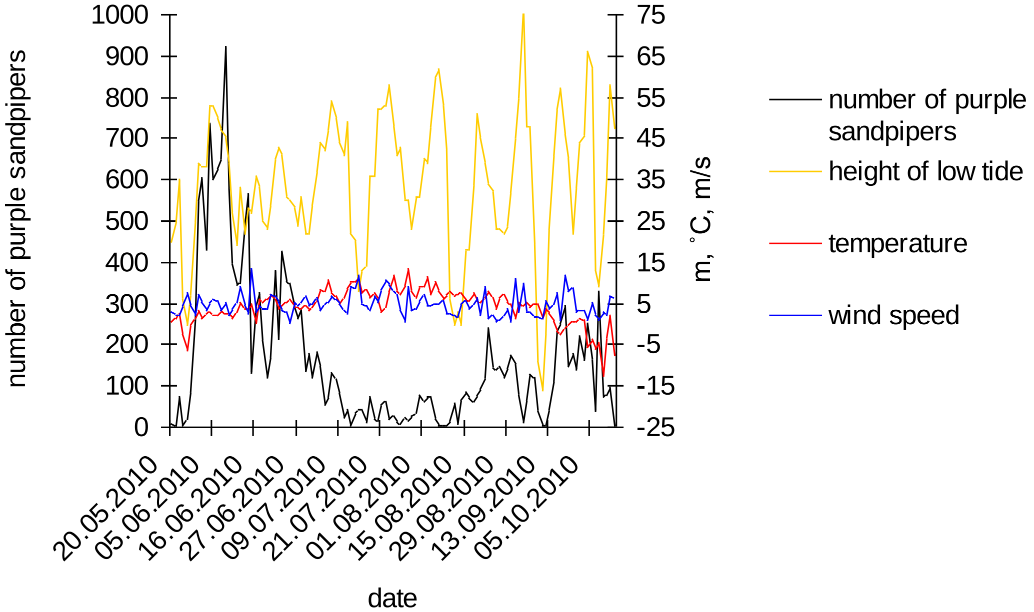

Figure 8. Different variables (shown on the right y-axis) and the number of purple sandpipers (shown on the left y-axis) at the different dates during the field season at the Advent estuary.

Table 3. Coefficients of the multiple regression on the different variables possibly influencing the number of purple sandpipers

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	214.8451	70.4925	3.048	0.00289 **
Day	-0.7792	0.2749	-2.835	0.00546 **
N - 1	0.7293	0.0612	11.918	< 2e-16 ***
Height	1.1465	0.5737	1.999	0.04813 *
Temperature	-3.5827	2.4921	-1.438	0.15338
Wind speed	-6.3582	3.5258	-1.803	0.07407

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Repeated counts

There was a strong correlation between the first and the second count I performed at twenty different days (Pearson's product-moment correlation, r=0.94, df=18, p<0.01). But since there is a time lag of five to ten minutes between the two counts (depending on how many birds were present) there was normally some bird movement between the counts. Therefore I rarely got exactly the same result on the repeated count. But also other reasons like birds being hidden behind each other or a stone, especially the birds feeding on the opposite side of the fjord, could be reasons for slight differences in the results. For example at one data point that is lying below the line (first count 357, second count 188; figure 9) there was a big flock of more than 100 purple sandpipers flying away right before the repeated count had started.

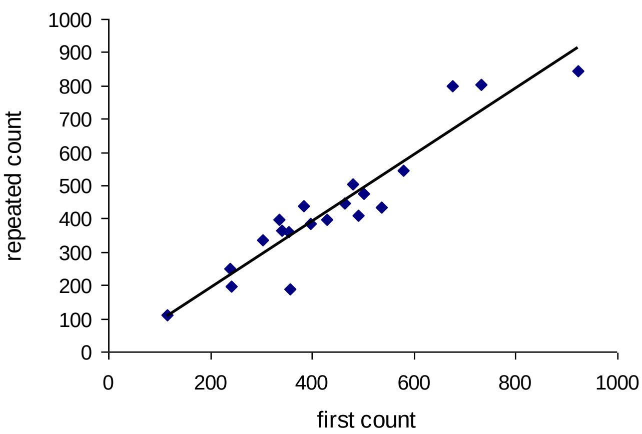

Figure 9.Comparison of results from repeated counts at twenty counting events. R^2=0.8854. Trend line y=1.0034x-10.51.

DISCUSSION

Phenology

Since male, female and month-old young sandpipers look very similar to each other, it was not possible to include this information in this study of total counts. That would have been very helpful though, since the different groups should be differently abundant at different times of the season at the intertidal flat.

In the middle of June most of the purple sandpipers had arrived in Svalbard and the first started to leave the Advent estuary to start breeding on the tundra when the breeding grounds were free of snow. In 2010 most of the snow had disappeared from the Advent valley on June 8^{th} (Philipp Semenchuk**,** personal communication). Compared to former studies in the Advent estuary the times for the peak number of purple sandpipers seems to be quite stable: Pierce (1997) writes that the peak number of purple sandpipers was on the 8^{th} and 9^{th} of June 1988 and 1993, respectively, which correlates very well with my study where the highest counted number was also on the 8^{th} of June. This does not correlate exactly with Luukkonen (2008) who counted the most sandpipers already on May 29^{th}.

Even between clutch completion and hatching relatively many sandpipers were counted in the estuary (figure 9). Both male and female parents help equally with the incubation. Each shift lasts for at about 15 hours (Pierce 1997) so that the other parent would have the possibility to fly to the estuary at low tide for feeding in the meantime. Additionally there are some yearlings that do not breed in their first season (Bengtson 1975) and others having failed to breed that year. Birds from both of these categories may use the estuary during this period.

After the young have hatched around July 11^{th} and the female left them soon afterwards, the numbers of sandpipers were not increasing at the estuary. This indicates that the females were not coming back to the estuary but instead either already migrated Southwards, as suggested by Pierce (1997) and Pierce & Lifjeld (1998), or stayed in the tundra for moulting.

At the beginning of August the young have fledged and are able to fly and feed independently, so that also the male can leave them. Right after this, the numbers of purple sandpipers at the Advent estuary were increasing again. But since the birds there were mainly observed to be young individuals (Ole Edvard Torland, personal communication) it is not clear what the males were doing in the meantime. Adult purple sandpipers have been observed to start the moult while being on Svalbard (Pierce 1993). Some males could already start moulting while breeding (Bengtson 1975) and probably finish their moult before the migration South in September, but since this builds on quite few observations, it needs to be further verified. Also, according to Cramp & Simmons (1983), all sandpipers do start moulting while still being on Svalbard (figure 10). Just by observing my own numbers and the fact that few adult sandpipers were seen at the estuary from August onwards, I could think of the possibility that sandpipers do not come to the estuary for feeding before migrating Southwards. Instead they may either moult in the tundra and then migrate, or migrate first and then moult at the wintering grounds. This is not in accordance with Metcalfe & Furness (1984), who state that birds normally feed more than otherwise before long migrations to gain some extra fat. The chicks that were observed by Pierce (1997) in August at the mudflat were 34 days old or older and totally independent. The bond between the male and the brood dissolves on the tundra when the young are fledged after about 24-34 days (Pierce 1997). Many male sandpipers were re-observed that year at the mudflat after the 11^{th} August (Pierce 1997). This does not correlate very well with the information that there were very few adult birds among the young ones at the estuary by that time in 2010 (Ole Edvard Torland, personal communication). But this could also be explained by adults not being trapped as easily as the young ones, so that the actual percentage of the adults was higher.

It was conspicuous that in the time after the middle of July very few sandpipers were observed at the Northeastern side of the study area, although there had been lots of birds earlier during the study period (figure 4). I assumed that the whole study area is more or less homogenous which it apparently is not. Maybe for some reason the young birds prefer the Southwestern side, which would explain why there were so few birds on the Northeastern side when there were mainly young sandpipers around.

On the 16th September the temperature dropped below 0˚C and the tundra started to freeze. This was immediately followed by an increase of sandpipers at the Advent estuary. They did probably not find any food on the tundra any more. The last sandpipers left the estuary before October 18th which was apparently correspondent with 1987 when the last sandpipers were observed on October 17th and in 1988 when the last sandpipers were observed on the 18th (Pierce 1993). This date might be related to the drastic decrease of daylight and the ice forming at the shores.

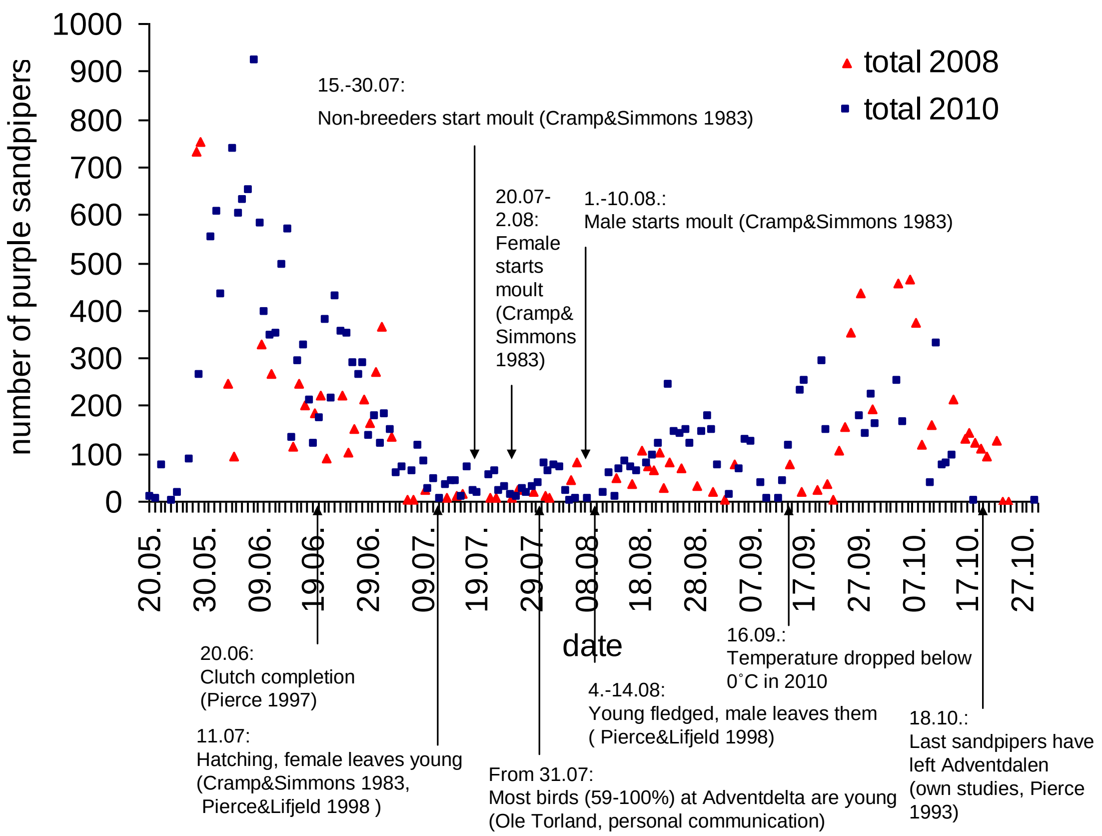

Figure 10. Different activities of the purple sandpipers, like breeding and moulting, fitted into the graph of the number of sandpipers counted at the Advent estuary in the years 2008 (Luukkonen 2009) and 2010.

Varying number of sandpipers throughout the low tide period

The purple sandpipers can only feed at the intertidal flat when part of the area is exposed, which only happens during the low tide period. At which phase during the low tide period the most sandpipers are found in the area could partly depend on their prey: while their prey is most active it is normally easier to recognize for the predators (Rosa *et al*. 2007). When the invertebrate prey is most active depends on the speed of the drainage of the area and also on the behaviour and adaptations of the different prey species (Rosa *et al*. 2007). But the accessibility of the prey does not only depend on its activity but also on the abundance. My results would then suggest that the prey of the purple sandpipers are most active or most abundant between low tide and half an hour later. Another explanation for the peak numbers of sandpipers occurring around low tide would be according to the hypothesis of most waders feeding at the estuary when the biggest area is exposed. At the same time this rejects the proposed peak time by Luukkonen (2009) being at about two hours after low tide.

Comparing the number of purple sandpipers to other variables

The fact that the number of sandpipers at the previous counting event was highly influencing the number of sandpipers on the day of the next counting event was expected, since the birds are probably not totally leaving the area after just one feeding session but coming back to the estuary the following days at low tide. It is neither surprising that the number was also significantly influenced by the day of the year, because it was possible to see already from the graph that the number of birds are not changing abruptly from day to day but instead varying throughout the season. The individual data points are thus non-independent.

That there was a negative number for the estimate of the day given means that the number of purple sandpipers is generally decreasing from May to October. Although my data (figure 4) shows that the number of birds is not just steadily decreasing towards the fall, there are on average more birds at the start than in the end of the season with the main peak being in the beginning of June.

The influence of the height of the low tide was also shown to be significant. The amplitude of the tide varied during the studying period between -18 and 208 cm (Statens kartverk Sjø). The relationship between the amplitude and the amount of purple sandpipers was positive, which means that the higher the tide, the more sandpipers were at the estuary. That does not fit the expectation that there should be generally more sandpipers when the tide is low and more area for feeding is exposed in the estuary. Hence this contradictory and unexpected result rejects the theory that more sandpipers are coming for feeding when the tide is especially low. One hypothesis for explaining this could be the higher possibility for the sandpipers to find food even outside the estuary along the shore of the Advent Fjord when the tide is low. So the lower the low tide is, the more area is exposed also in other areas, and the more the sandpipers are spread out over different areas, the fewer individuals feed at the particular area of the Advent delta.

Further studies

To know when during the low tide period the most sandpipers are feeding at the estuary could help in planning further studies that look for maximum numbers. Together with the study of Luukkonen (2009) it could be part of a long-term study of sandpipers occurring at the Advent estuary. With a long-term study it would be possible to tell, whether the phenology of purple sandpipers in Svalbard is changing or not. Maybe there are significant changes in the dates for migrating and breeding. This possible change could be related to the ongoing climate change.

Repeated total counts would even tell if the numbers of sandpipers visiting the Advent estuary every year are stable or not.

Another interesting study would be to also include more data about the sandpipers rather than only the number. This information should include sex, older and possible moulting stages of the birds counted. Additionally it would even be good to know about the residence time of the individuals. By marking enough sandpipers the data could be analyzed for how long sandpipers tend to stay in the estuary. All this additional data would help to even better understand the phenology of the purple sandpipers. If possible, it would also be good to include a study on the occurrence along the shore of the Advent Fjord outside the estuary, to see in how far and at what height of the tide this area is included in the feeding grounds for purple sandpipers.

If total counts throughout the low tide period should be performed again, it would be good to be able to eliminate the source of error of predicted low tide not being correct.

Conclusion

Phenology

My results show how the numbers of sandpipers vary throughout the season in the estuary. Birds are arriving at the end of May and leaving in the middle of October. Their varying numbers throughout the season can partly be explained by the height of the tide, with higher numbers of sandpipers occurring at higher low tides.

Varying number of purple sandpipers throughout the low tide period

The highest numbers of sandpipers were present at the estuary half an hour after low tide. On average there were about 10%, or 13 individuals, more at half an hour after low tide at the estuary than at the time of the low tide. But since the predicted time of the low tide was not exact, the time of the highest number of sandpipers seems to be closer to the time of low tide than the results had shown in the statistics.

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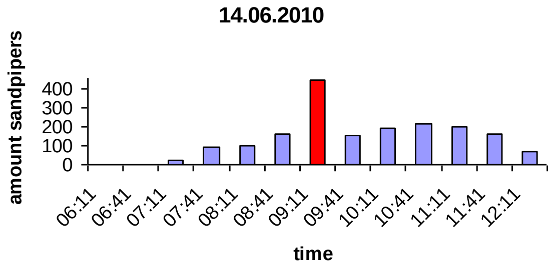
APPENDIX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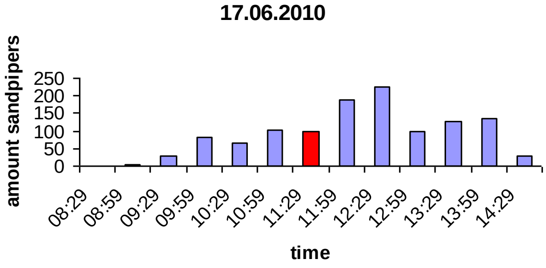
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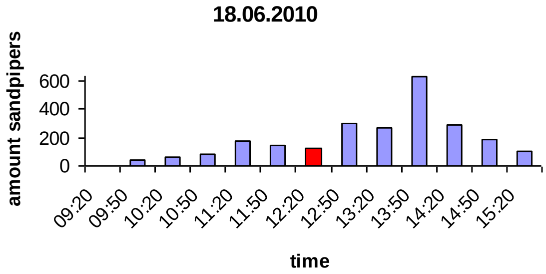
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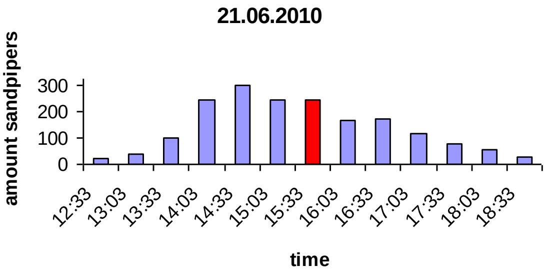
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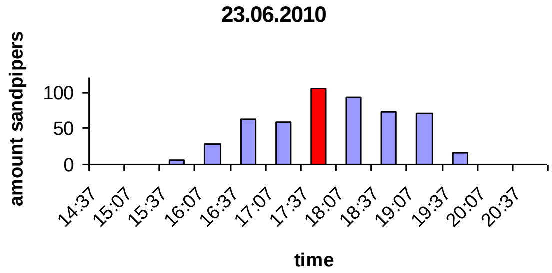
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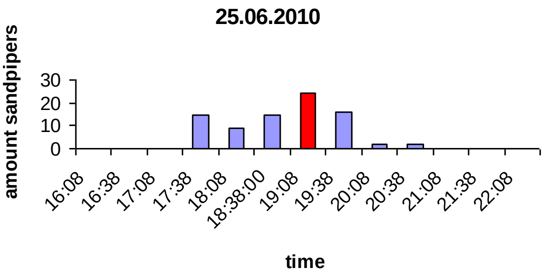
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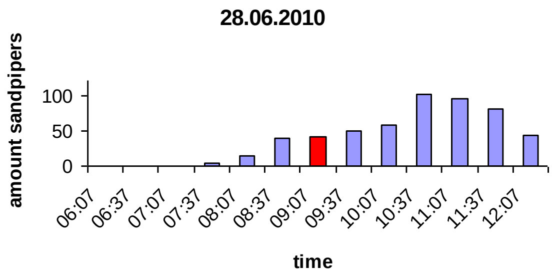
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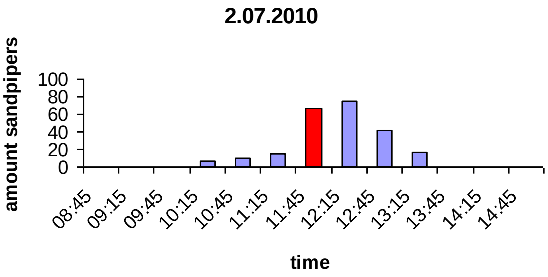
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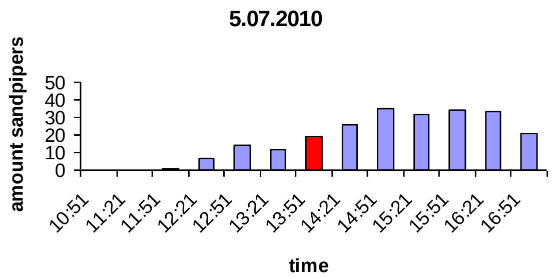
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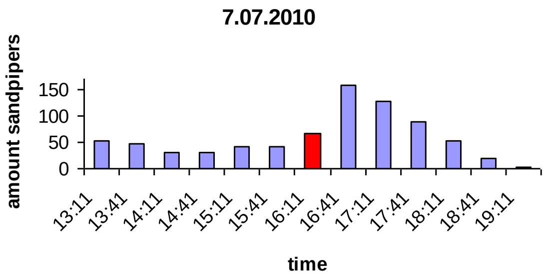
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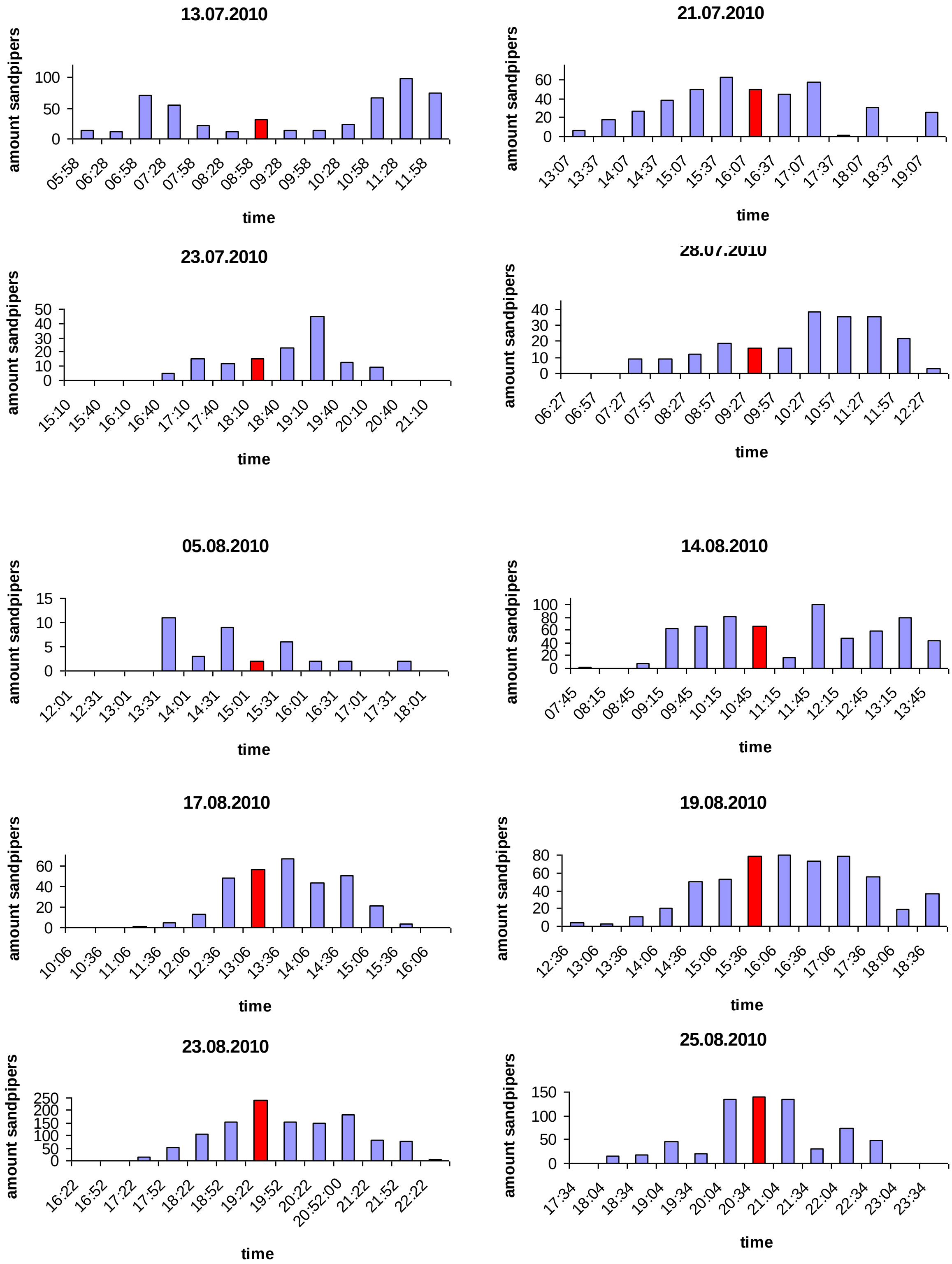

Supplementary figure 1: Figures of all the twenty six-hour-counts of the purple sandpipers at the Advent Fjord in 2010. The figures have a different scale on the y-axis depending on how many birds were counted. The red bars indicate the number of sandpipers at the time of predicted low tide.

Supplementary calculation 1

(1) $y'=0;\ x=\dfrac{-1.8*10^{-3}}{2*(-2.7*10^{-5})}=33.21$

Supplementary calculation 2

(2) $y=-2.71*10^{-5}*33.21^{2}+1.8*10^{-3}*33.21+1.07=1.1$