Shorebirds from “Playa Norte”

Is there a difference in shorebird abundance between Lagoon Quatro and Lagoon Tortuguero based on environmental differences and human impact?

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Photo cover: *Black-Bellied Plover*, lagoon Quatro (Gijs Bouwmeester)

Foreword

In the third year of the study Forestry- and Nature Management at Van Hall Larenstein University of Applied Sciences two technical profession internships has to be carried out. For the first, three month during, internship I have choosing for a project research for the Canadian Organization for Tropical Education and Rainforest Conservation (COTERC) in Costa Rica. There field-station, Cano Palma Biological Station, is located in the Caribbean lowland rainforest nearby the Caribbean ocean. The purpose of this research is to better understand the dispersion and ecology of shorebirds that use dynamic lagoons and beaches to forage or spend the winter in case of migrant birds. Which birds use these beaches and lagoons and what is their abundance?

At first, I would like to thank COTERC to make this magnificent field- and research internship possible. Then I would like to thank my supervisor and good friend Emily Khazan for her critical supervision during this internship. Emily made it possible for me to carry out research on a higher level and brought me in touch with unknown analysis methods and data processing. Furthermore I would like to thank station manager Charlotte Foale for sharing her knowledge about (shore)birds and being my shorebird-buddy during all the shorebird surveys. Lastly I want to thank research coordinator Luis Fernandez being the best desire in company and sharing stories, also all the volunteers and long-term interns make part of this.

Summary

Playa Norte is a dynamic coastal beach positioned in the Barra del Colorado wildlife refuge in Northeast Costa Rica. The beach contains two coastal lagoons, Laguna Quatro and Laguna Tortuguero. These lagoons are very popular by either resident and migrant shorebirds. The differences in abundance between these lagoons are never examined before.

The goal of this research project is to better understand the dispersion and ecology of shorebirds that use these dynamic lagoons to forage. The overall objective of this research is providing Caño Palma Biological Station more information about shorebirds in addition to their existing shorebird transect. Besides measuring the abundance of present shorebirds environmental variables are collected in order to better understand differences between the lagoons. These variables include: general water conditions, human impact, tidal influences and weather conditions. The main question of this research is: *Is there a difference in shorebird abundance between Lagoon Quatro and Lagoon Tortuguero based on environmental differences and human impact?*

Several methods could be used for counting (shore)birds. For this research two fixed transects of 2,5 km where surveyed. In addition to the existing transect at Laguna Tortuguero the Laguna Quatro transect was added to the shorebird survey. The same methodology applied for Laguna Tortuguero was used for Laguna Quatro, making data comparison possible. The surveys were carried out every Sunday and Wednesday. The morning survey starts at 6:00 PM and the afternoon survey at 15:00 AM. Gathering the additional data, like water- and weather conditions, where taken using an EC-meter and pocket climate device. Human impact was recorded during the surveys. Tidal information was sorted out afterwards using special tide-tables.

The difference in result of all the encountered birds in total, between the two lagoons, is very small (41 individuals). That results in the following answer for the main question, no difference in abundance is found between the both lagoons. However, a difference is shown with the results of the Shannon-Wiener Index. A higher number of species and evenness is found at Laguna Tortuguero. Also the results of the water measurements indicates a higher gradient in water conditions which attract specific Functional Feeding Groups. These FFGs are related to diet preference of specific shorebirds which then is related to water condition. The human impact shows a positive correlation to quantity of birds. No significant correlation is found between number of birds and tidal conditions. Significant positive correlations (related to number of birds) are found for an increasing wind-speed, wind-direction East and time of the day.

This research is a two months sample for abundance of resident and migrant shorebirds. Further research needs to do a longer period of data collection, preferred at least one year. A separation can be made between the residents and migrants which could show the importance of this beach for stop-over migrants and year-round residents.

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1. Introduction

During the non-breeding season (September – March), large numbers of shorebirds use lagoons and intertidal areas for feeding. Resident birds also use these dynamic lagoons for feeding. In the spring migration more shorebirds are attracted by this nutritious areas for fatting up to overpass the next stop on their way to their breeding grounds.

In addition to the long term coastal- and shorebird inventories carried out by interns of Caño Palma, more research is necessary to improve the knowledge of the ecology and usage of coastal lagoons by shorebirds. For this purpose, this research encompasses two coastal lagoons located in the Barra del Colorado Wildlife Refuge in Northeast Costa Rica.

The lagoons drain off fresh water from the surrounding rainforest. This creates fresh, brackish and salt environments. Tidal influence on the lagoons will be assessed within this research to determine salt levels which might prove to be an important environmental variable influencing coastal- and shorebird numbers.

There are different methods to measure abundance of shorebirds. This research utilizes long transect counting. Transect counting takes about an hour and is carried out twice a week; once in the morning (06:00) and once in the afternoon (15:00). Not only quantities and species of present shorebirds are counted, human impact is getting observed as well. This provides information about the disturbance of the shorebirds during the surveys. Tidal information, which may influence shorebird abundance at any given time, comes from tide-schedules from Limon. The outcome of the collected data will examine differences in numbers of birds between the two lagoons.

2. Project description

This research was carried out at two lagoons in the Barra del Colorado Wildlife Refuge. This refuge is located in Northeast Costa Rica on the Caribbean coast bordering Tortuguero National Park to the north. The coastal zone is characterized by lowland-rainforest and is dominated by palm swamp. The study was done from Caño Palma Biological Station. The nearest lagoons to the station, Laguna Quatro and Laguna Tortuguero, were researched. The first weeks were used for collecting sufficient data to reveal significant differences.

2.1 Goal of the project

The goal of this research project is to better understand the dispersion and ecology of shorebirds that use these dynamic lagoons to forage. The environmental variables collected in order to better understand differences between the lagoons include:

- Water quality: using an EC-meter. Conductivity will be measured which shows the difference in sweet, brackish and salt water.
- Abundance of birds (all birds identified to species)
- Weather conditions.
- Level of disturbance by human impact.
- Tidal influences

2.2 Research questions

The central question is defined as follows:

- **Is there a difference in shorebird abundance between Lagoon Quatro and Lagoon Tortuguero based on environmental differences and human impact?**

Followed by the sub-questions:

- *Does human impact influence the abundance or presence of shorebirds?*
- *Are there differences in (global)water quality between the lagoons, and could this be related to specific feeding-groups of shorebirds?*
- *Do the different tides influence the presence of shorebirds?*
- *Are different weather conditions related to presence or absence of shorebirds?*

2.3 Research area

The lagoons where the research is carried out are located in two different areas, *image 3*. The southern Lagoon, Laguna Tortuguero is located on the north border of the Tortuguero National Park (TNP). The national park is located on the southern border of the Barra del Colorado wildlife refuge and covers an area of 26,156 hectares in the terrestrial part and about 50,160 hectares of marine area, this is mainly for the protection of sea-turtles. This area consists predominant tropical wet forest, with an annual temperature of 26ºC and an annual rainfall of between 4,500 and 6,000 mm each year (Fallas, 2015). The park contains many rivers, canals and lakes. Which eventually are connected with the river: Rio Tortuguero and the Canal of Tortuguero.

The other lagoon: Laguna Quatro, is located about five kilometres north of Laguna Tortuguero. The differences between the two lagoons are explained in further detail below.

Laguna Tortuguero

This lagoon is the biggest and most densely populated area in the region. Laguna Tortuguero could be defined as a river-mouth lagoon or coastal lagoon. The amount of fresh water carried off by the river as well as tide and wind direction determine the salinity of the water in the river mouth. This lagoon drains of mainly the water from the Rio Tortuguero and local fresh water from the surrounding forests. The lagoon/river-mouth is always in contact with the Caribbean Ocean.

The abundance of water and high biodiversity sightings attracts many tourists. In combination by the using of residents this lagoon is a bustling place. Also because two little villages surrounding the lagoon. The famous and touristic village of Tortuguero and the village of San Fransisco. However, this research is limited to the river-mouth and a long stretch of beach. The river mouth is a dynamic place with strong currents and high waves. It is not the ideal place for tourists, but often visited by fisherman. The shorebird transect is shown with the red line in *image 1*.

Image 1 Overview Laguna Tortuguero, the red line shows the shorebird transect. (Google Maps)

Picture 1 Impression of the lagoon in the morning. (Pic. Gijs Bouwmeester)

Laguna Quatro

As opposed to laguna Tortuguero, this lagoon is placed quite remote with less human activity. It has irregular contact with the sea; defined as a semi-isolated lagoon. The lagoon is not fed by a big inland river, but from small canals and streams which are fed primarily by excessive rainfall. In the ‘dryer’ season, the lagoon is not in contact with the sea. Only high waves or springtides will bring salt water into the freshwater basin which creates a higher salinity or more brackish water. The remaining tidal sandbar seems to be an attractive site for shorebirds.

When the lagoon is crossable (not connected to the sea) some people cross it with motorbikes or by foot. There is only one house next to the lagoon. However, located about one kilometre to the south is a big resort, Turtle Beach Lodge. This resort attracts a lot of tourists which often visit the beach and the shorebird-transect, *image 2*.

icture 2 Impression of the lagoon, conditions at a low water level. Pic. Gijs Bouwmeester)

Image 2 Overview Laguna Quatro, the red line shows the shorebird transect. (Google Maps)

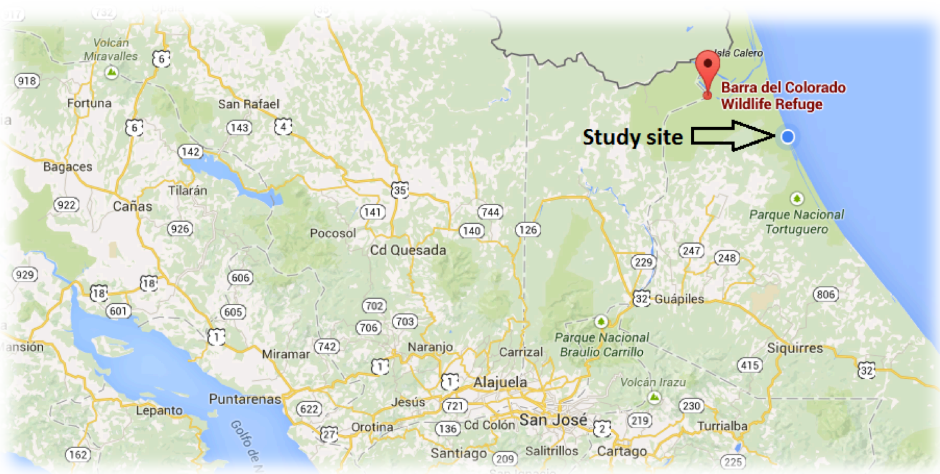


Image 3 Location study site, Playa Norte. (Google Maps)

3. Methodology

This research in an extension on the long-term Shorebird Monitoring Program which has been carried out for several years. Usually only the Laguna Tortuguero survey is completed twice a week. The Laguna Quatro transect was added to the shorebird survey and was carried out using the same methodology as Laguna Tortuguero, making data comparison possible. The surveys were carried out every Sunday and Wednesday. The morning survey starts at 6:00 PM and the afternoon survey at 15:00 AM. Both surveys takes about an hour and were carried out in a similar fixed transect along the lagoons/river-mouth and a long stretch of beach.

3.1 Research methodology

Measuring the abundance of shorebirds:

The counting of shorebirds was carried out using a fixed transect of ≈2500 m Divided into thirteen sub-transects of an eight of a mile (≈200 meters). Only birds visible with the naked eye and identifiable with binoculars were counted and written down on a special form (*appendix A*). The birds must be above or in the sea, on the beach or flying by. Any birds in or beyond the edge of the vegetation were not counted. Number, plumage, ID on juvenile or adult bird were documented as well. This to prevent double counting. The fixed label features are:

- Date
- Start/end time
- Wind, direction and strength
- Tide, low or high
- Rain
- Cloud cover

The presence of fisherman, humans and dogs is written down each section. This could be linked on the quantity of disturbance afterwards. Several types of analysing models will be used to show significant differences or relations. Besides differences in abundance, also differences in biodiversity are analysed using the Shannon and Wiener. The Shannon diversity index (*H*) is an index used to characterize species diversity in a community. Like Simpson's index, Shannon's index accounts for both abundance and evenness of the species present. The proportion of species i relative to the total number of species (p_i) is calculated, and then multiplied by the natural logarithm of this proportion ($\ln(p_i)$). The resulting product is summed across species, and multiplied by -1 (DIVERSITY INDICES: SHANNON'S H AND E). Differences in abundance between the two lagoons differences was analysed with T-tests.

Influence of human impact on shorebirds:

One factor that may have a large influence on presence/abundance of shorebirds is human impact, including pets. At each survey the human impact was be noted. Only human activities which influence the survey are recorded, this was carried out in each section. For example, if there is a dog that follows the surveyors it doesn't effects the birds in front of the persons. If the dog comes towards the persons it could influence presence of shorebirds in that section, in that case it will be recorded as one dog in the relevant section. The outcome of this data will be analysed with the "Generalized Linear Model" . This method is a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models. This means that the GLM breaks up explanatory variables in an explanation what their effects are on the response of the main input (Nelder & Wedderburn, 2015). The following forms of human disturbance are recorded:

Fishermen
Especially the river mouth but also some parts of the beach are often used by fisherman including commercial and recreational fishing practices. Mostly they use one spot from where they fish. That makes the disturbing factor fairly low, but it forms an obstacle for a group of foraging Sanderlings or Semipalmated Plovers, for example.

Dogs
Almost every local resident has at least one dog as a pet/watchdog. Yard boundaries are unknown to most dogs. Therefore they are regularly on the beach, chasing birds or other wild life. The disturbing factor of dogs is high. They can chase or scare of birds for multiple sections.

Boats
Several types of boats could be encountered during the shorebird survey. Most are boats from fisherman, and occasionally tourist boats. The highest disturbance of boats is likely to encountered in the river mouth at the southern transect. The disturbing factor is relatively low, for example passing boats might scare of a group of Royal Terns or several Neotropical Cormorants who are resting on a sand plate, but often the birds will return after the boat(s) passed.
Note: Boats and fisherman, could also attract birds. Leftover baits or pieces of fish are often dumped in the ocean which attracts birds like Laughing Gulls, Parasitic Jaegers and Magnificent Fregatebirds.

Other humans

Among "other humans" we consider the following: locals, tourists and scientists. Because virtually no roads exist along the coast, the beach is often used as a path/road. Along both transects there are several houses, as well as touristic lodges including Vista Al Mar (southern transect) and Turtle Beach Lodge (northern transect). Both places are true tourist destinations. The tourists use the beach often for a stroll or walk. Even the early morning tourist are often on the beach to watch the sunrise. The disturbing factor of humans on the beach could be high, especially if people walking in front of the counters during the survey.

Making a general pronouncing of the water condition/origin:

Using an EC-meter (Electrical Conduction) the condition of the water can be shown. This is linked on the following values:

- Seawater ≈ 20.000-50.000 µS/cm
- Brackish water ≈ 1.000-20.000 µS/cm
- Fresh/sweet rainwater ≈ 0-50 µS/cm
- Fresh/sweet groundwater ≈ 50-1000 µS/cm

The outcome of these measurements could be linked on functional feeding groups (*appendix B*). Various shorebirds have a different diet depending on where there feeding on related to the water condition. The food supply varies by different water types, which influence the present of birds. Taken into account is that the water measurements could be unreliably because the used device isn't very accurate and don't represents variables like pollution etc. However, it should show a global view of the origin and condition of the water. The water samples are taken at each beginning from a new section. An average of the most represented and similar water data-collections are linked on functional feeding groups and there abundance.

Does tide influence the presence of shorebirds:

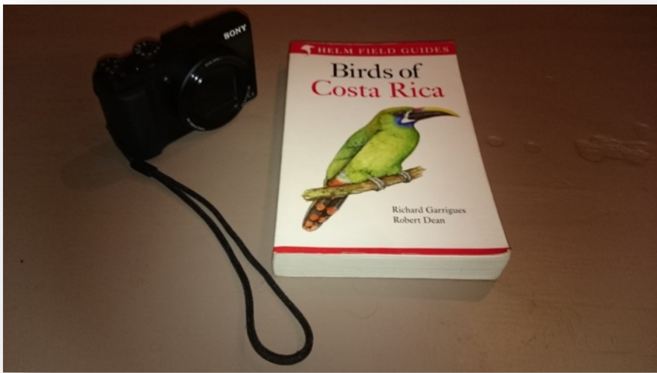
The tidal conditions are very important as they affect shorebird (feeding) behaviour and ecology . The most accurate and closest tide tables are from Limon (2015 Tide Table for Limón, Caribbean Sea Coast for fishing, 2012). These schedules (*appendix C*) will be used to determine the tidal condition. The tidal differences only vary several decimetres, But this minor difference could affect the quantity of available feeding area for shorebirds which could be related to their presence. With the help of T-tests differences in abundance will be examined.

Are different weather conditions could be related to presence or absence of shorebirds:

Just like any other animal, birds react to certain types of weather. For every survey, weather conditions were measured with a small pocket weather meter at the end of the survey. Temperature, wind-speed, wind direction (with a compass), humidity, cloud cover and rain are recorded. To answer this question only wind-speed, direction and temperature are tried to relate on the abundance of shorebirds. Also the difference in quantity related to the time of day is herein included. Analysing this data is elaborated with a GLM test.

3.2 Materials

For the weekly surveys a Bushnell 10x42 binocular is used. A compact digital camera with a big 30x zoom function was used for taking pictures of unidentified birds for future identification. Weather measurements were taken with a pocket climate/weather meter (Kestrel 3000). This device measures humidity, temperature and wind speed. Wind direction is recorded with a digital compass. Water conditions are measured with a simple EC-meter that measures all dissolved salts and minerals in the water. The observations during surveys are recorded on a special form made of waterproof paper, and a protecting clipboard is used for carriage.



Picture 3 Used materials: left binoculars, top field guide and camera, right EC-meter, middle pocket climate device (Pic. Gijs Bouwmeester)

4. Results

- **Is there a difference in shorebird abundance between Lagoon Quatro and Lagoon Tortuguero?**

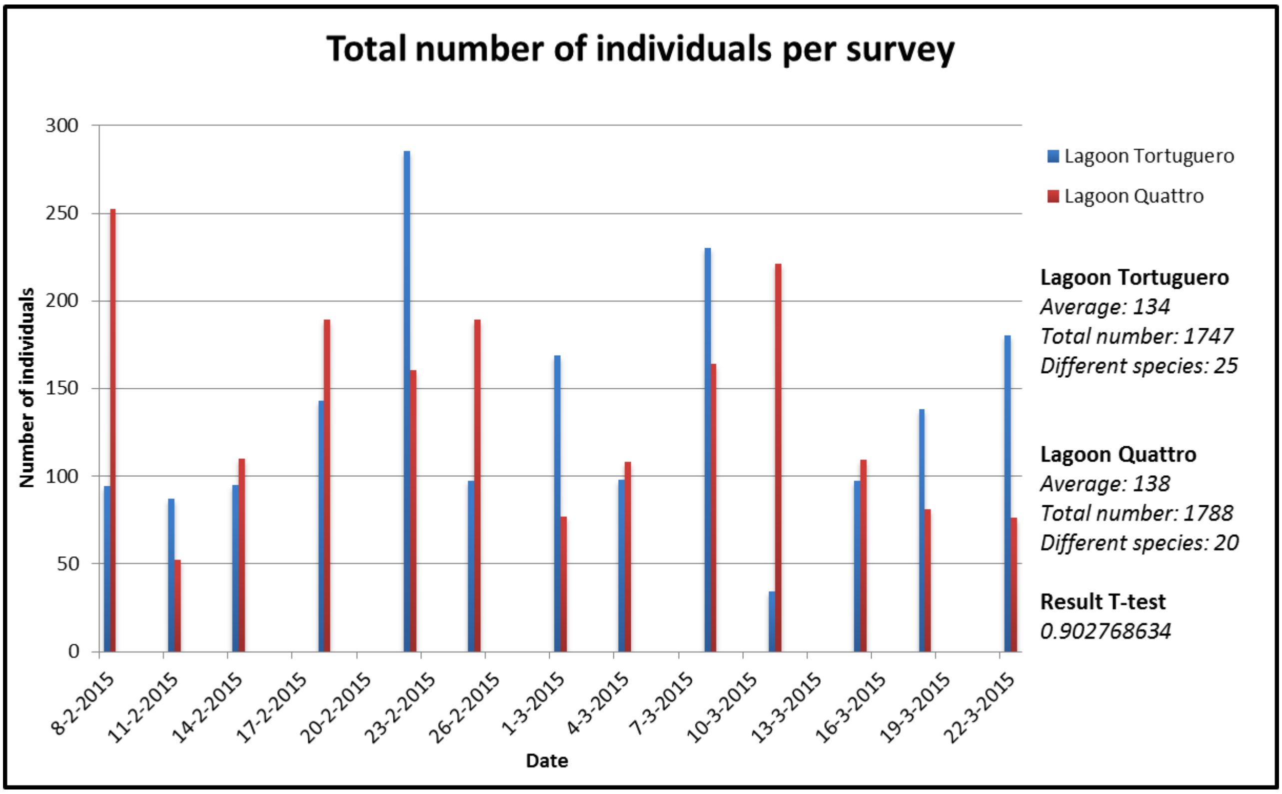


Table 1 Total number of birds per survey.

Results LQ:	Results LT:
Diversity	Diversity
1,325770038	1,935041155
Max diversity	Max diversity
2,995732274	3,218875825
Evenness	Evenness
0,442552911	0,601154335

Figure 2 Results Shannon-Wiener diversity index.

Shannon-Wiener Index denoted by **H = -SUM[(p_i) × ln(p_i)]**

SUM = summation

p_i = proportion of total sample represented by species *i*

Divide no. of individuals of species *i* by total number of samples

S = number of species, = species richness

H_{max} = ln(S) Maximum diversity possible

E = Evenness = H/H_{max}

Figure 1 Shannon-Wiener biodiversity index, formula.

Table 1 shows the total number of recorded birds from each survey. Herein no distinguish is made between different species and there abundance. Total numbers and average show major similarities as supported by the T-test which indicates no difference between abundance of shorebirds across the two transects. Data setup and overview, *appendix D*.

The Shannon and Wiener diversity Index (*figure 1*) shows a higher biodiversity in the southern transect of Laguna Tortuguero (*figure 2)*. In this model not only the total number of birds is calculated but also the proportion of number of species and the evenness, this means the ratio between the species and number of birds. The setup and calculation of the data is shown in a*ppendix E.*

- *Does human impact influence the abundance or presence of shorebirds?*

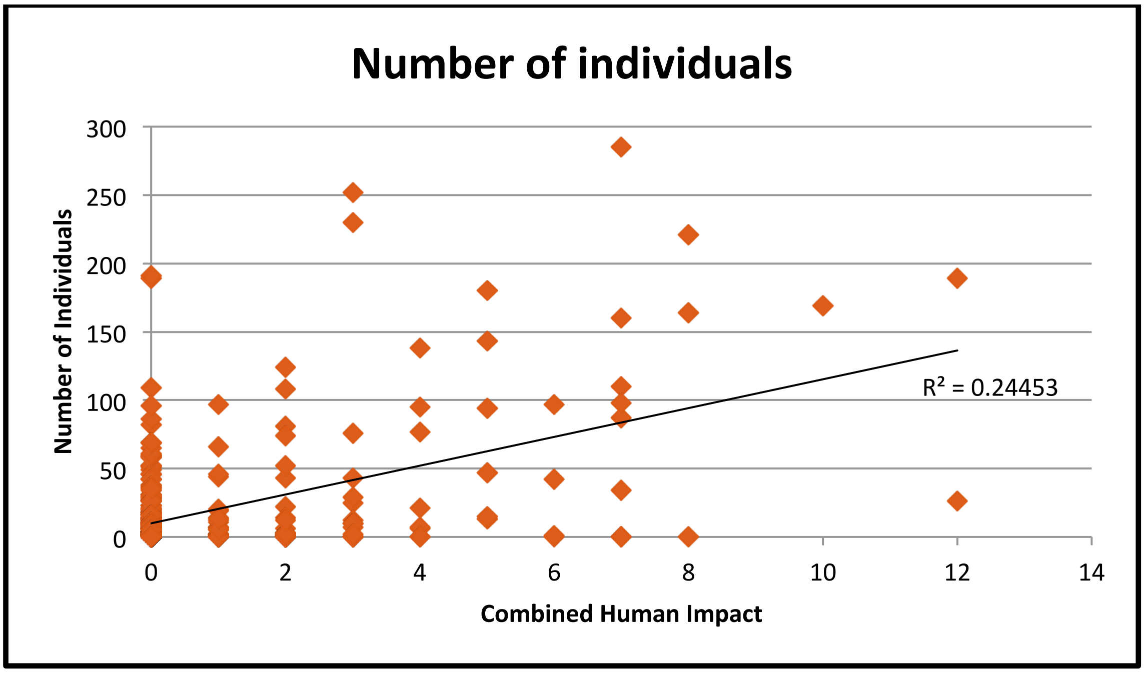


Table 2 Combined Human Impact related to number of birds/individuals.

Table 2 with regression line shows the relation between number of individual shorebirds from both lagoons and the combined number of human impact (cumulative number of dogs, fisherman, boats and other human per section). Each data point represents one section from one survey and includes the total number of birds seen in that section coupled with the total human impact. The linear regression line shows a positive relationship between the abundance of shorebirds and the amount of human impact. *Table 3* and *figure 3* shows the separate result per factor (GLM-analyse). All factors show a strong positive correlation (***) to quantity of encountered birds.

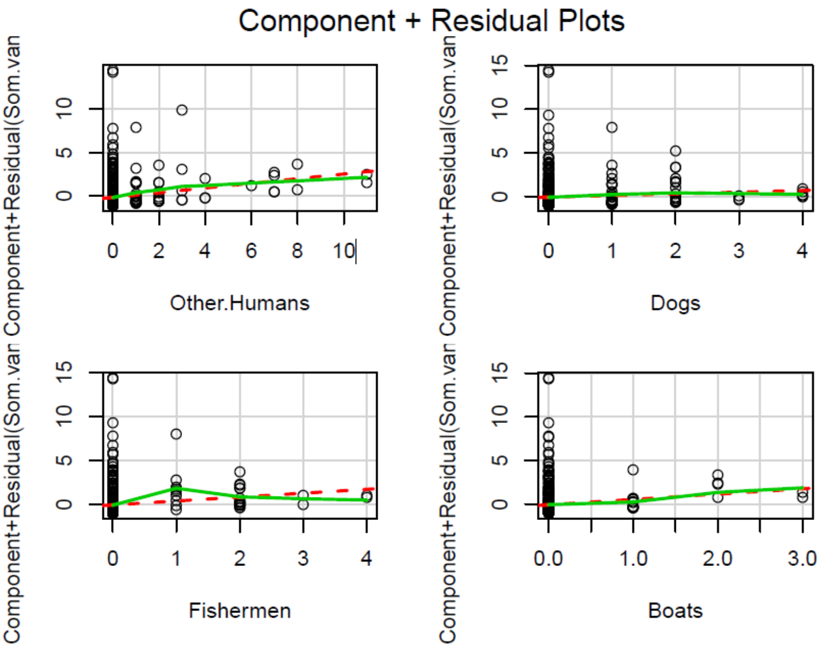


Table 3 GLM output per factor of Human Impact.

```
GLM (formula = Som.van.Quantity ~ Other.Humans +
Dogs + Fishermen + Boats, family = poisson(), data =
hum.impact, na.action = na.omit)

Deviance Residuals:
     Min        1Q    Median       3Q       Max
-14.7757   -4.9694   -3.6625   0.1841   26.8263

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)    2.51344    0.01570  160.07  <2e-16 ***
Other.Hum      0.22845    0.00413   55.31  <2e-16 ***
Dogs           0.20139    0.01255   16.05  <2e-16 ***
Fishermen      0.33225    0.01381   24.05  <2e-16 ***
Boats          0.57825    0.01904   30.37  <2e-16 ***
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Figure 3 GLM results per factor. Formula, deviance residuals and coefficients.

- *Are there differences in (global)water quality between the lagoons, and could this be related to specific feeding-groups of shorebirds?*

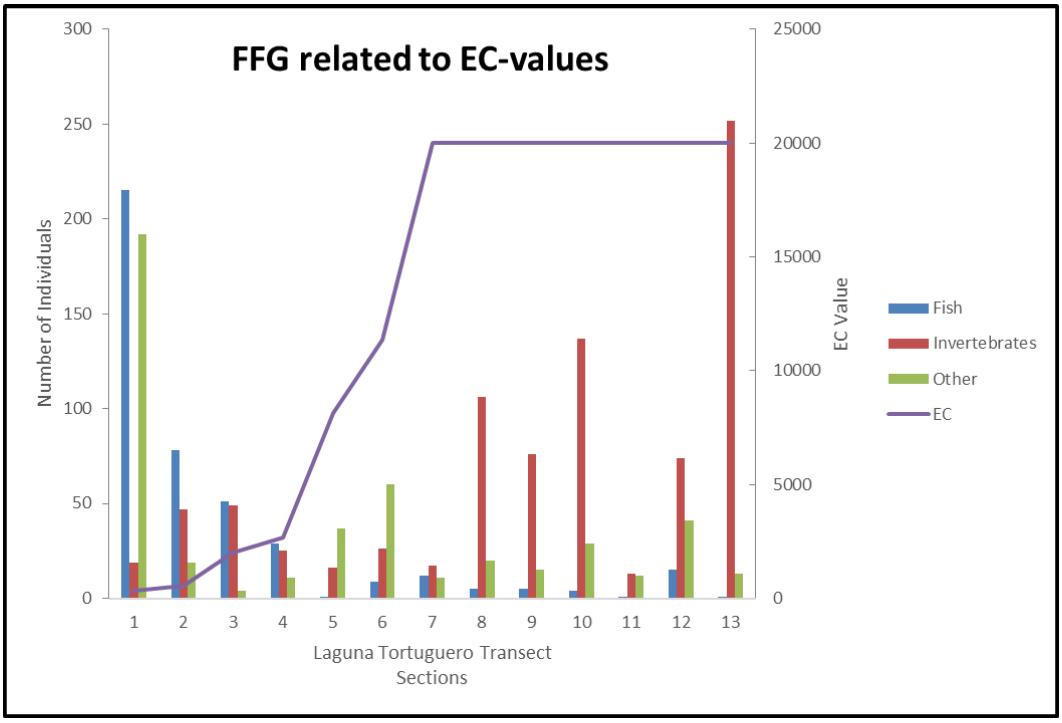

Table 4 Functional Feeding Group per section related to quantity, purple line shows gradient in EC-values.

Table 4 shows the number of shorebirds belonging to a specific or functional feeding group (FFG) related to EC-values from Laguna Tortuguero. The FFGs are based on diet which, as demonstrated in the figure, is related with salt or fresh water preference (*appendix B*). While these FFGs correspond with salinity, there is a variation within FFGs. For example, there could be two types of fish eaters whereby an Amazon Kingfisher strictly hunts in fresh water and an Royal Tern prefers to forage in salt water. Fish eaters are therefore classified as fresh water birds, invertebrate eaters are classified as salt water birds. Other is classified as fish, invertebrates or insect eaters, with an overlap in water condition preference. The EC-values are based on three similar and most representative sampling events (*appendix F*). These are selected because the overall data shows large variety's in value. The structure of this transect supports it as well, it starts at the riverbank and walking along the transect you will see the river mixing with the sea and eventually you will and op a long stretch of beach which contains seawater. Thereafter the average is taken and classified as follows:

- Sea water ≈ 20.000-50.000 µS/cm
- Brackish water ≈ 1.000-20.000 µS/cm
- Fresh/sweet rainwater ≈ 0-50 µS/cm
- Fresh/sweet groundwater ≈ 50-1000 µS/cm

From section seven the remaining sections are classified as pure salt- seawater. This is caused by the similarity of the remaining beach sections and the range of the EC-meter which reaches to 20.000 µS/cm. That results in a horizontal line from section seven to section thirteen.

- *Do the different tides influence the presence of shorebirds?*

For this question a T-test was carried out. All of the individuals of both transects were combined in the adjacent table. There separated afterwards between high and low tide according to the tide-tables from Limon, shown is *appendix C* (2015 Tide Table for Limón, Caribbean Sea Coast for fishing, 2012). The total numbers between high and low tide show a small difference of 192 individuals. Whereby Royal Terns represent the biggest difference.

The results of the T-test don't show a significant difference between abundance in shorebirds related to low or high tides.

Result T-test: 0,430115

Species	**High**	**Low**	**Total**
Amazon Kingfisher	11	6	17
Anhinga	1		1
Bare-throated Tiger-Heron	2		2
Black Tern		1	1
Black-bellied Plover	24	22	46
Blue-winged Teal	3		3
Brown Pelican	109	78	187
Cattle Egret	17	15	32
Collared Plover	5	2	7
Great Blue Heron	4	2	6
Great Egret	14	8	22
Green Heron	2		2
Laughing Gull	5	1	6
Least Sandpiper		2	2
Little Blue Heron	6	3	9
Magnificent Frigatebird	15	8	23
Neotropical cormorant	31	32	63
Osprey		2	2
Parasitic Jaeger		2	2
Ringed Kingfisher	3	4	7
Royal Tern	62	404	466
Sanderling	935	775	1710
Semipalmated Plover	141	163	304
Snowy Egret	125	132	257
Spotted Sandpiper	89	138	227
Tricoloured Heron	1	2	3
Whimbrel	26	21	47
Total	**1631**	**1823**	**3454**

Figure 4 Data setup, t-test tide differences.

- *Are different weather conditions related to presence or absence of shorebirds?*

A GLM-analysis was carried out for this question. With the next factors related to quantity of birds, Wind Speed, Wind Direction and Time of Day (AM,PM) and the Transect (Laguna Tortuguero LT, Laguna Quatro L4). The weather measurements, raw-data setup and GLM-output/outcome are shown in *appendix G*. Significant correlations are shown bold and marked with a * (* Weak, ** Normal, *** Strong). A strong positive correlation is found between Wind-Speed, Wind Direction East and the time of day PM/AM and abundance. A strong negative correlation is found by the Wind Direction Northwest. A positive correlation is found by the following Wind Directions: Northeast and Southwest. There aren't significant differences found between the both Transects and Wind Direction West.

5. Conclusion and discussion

There is no significant difference in shorebird abundance between Laguna Tortuguero (LT) and Laguna Quatro (L4). Surprisingly enough the number of individuals and the average number of birds per survey are almost equal. However, the results of the Shannon-Wiener Index demonstrate a difference in species diversity between the two transects. LT had more sightings and recorded species during most surveys species evenness is higher at LT, this means that the diversity between number of species and quantity is better distributed. According to the recorded species, there more fresh water related species found at this transect compared with L4. The lower evenness of L4 is mostly caused by a higher quantity of Sanderlings which occur in large groups on the beach. Sanderlings represent 66% of all recorded shorebirds at L4, compared to a 33% at LT. This is caused by the higher available feeding area at L4. This feeding area include hard-compact sand beaches (Sanderling) Compared to the presence of more fresh water sections at LT, which creates less suitable feeding area for Sanderlings. Thereby there are also less fresh water related birds encountered at L4. The difference in quantity of birds between morning and afternoon surveys are equalized by using the same method for both lagoons. The overall number of migrating birds will decline as the breeding season approaches, from May until August most migrating shorebirds will be absent (HVENEGAARD, 2008). Although there is no distinction made between migratory and resident shorebirds during this study, the migrating effect could have major influence on the number of encountered shorebirds at a specific time of year.

The human impact was combined and related to the total quantity of all recorded shorebirds of 24 surveys. The logical expectation was to find a negative relationship between an human impact and bird abundance, however The results show the opposite. All factors (Other Human, Fisherman, Boats and Dogs) show a positive correlation with number of birds per survey. This implies that more human impact results in more individual shorebirds. In case of the factor Boats it could be explained that birds are attracted due to bait- and fish waste that is dumped from the fisher boats. This unexpected trend can also be partially explained by the data collection method and location of surveys. The first sections from both transects shows the most encountered birds per survey, Section 1: 24% (LT); section 1: 22% (L4). Also the combined human impact is by far the highest in the first section, 58% of all combined human impact. Given that the individual sections do not have a specific value for the number of encountered birds and number of human impact an unreliable conduct of the results was predictably, like the disproportion shown in *table 3*. During the surveys actual disturbance- or flight behaviour on the encountered shorebirds was not documented. The effects on quantity of birds disturbed by human impact or other factors cannot be statistically supported using this method and type of analysing. More and other types of study are needed to understand more about disturbance of human impact and the effect on abundance and behaviour of shorebirds.

differences in water condition between the two lagoons was not reasonable to investigate because of the vastly different morphology of the lagoons for the majority of the study period. At the beginning of this project L4 was still connected with the sea, due to large amounts of rain from the previous weeks. After two weeks the connection with the sea stopped. The water level in the lagoon dropped and the sea created a sand embankment along the shoreline. Only the average from three water samples of the lagoon was still conducted but could not be used for the analyses afterwards. Instead of making a comparison between the two lagoons, the focus was put on the water measurements of LT. *Table 4* shows a clear gradient from fresh to brackish and eventually to pure salt seawater. The encountered birds where divided in specific feeding groups and a relationship between the water conditions and functional feeding groups appeared. The results only show an overall impression of this relation. The water conditions varies a lot in the dynamic river-mouth and the measurements were taken with a simple EC-meter.

Study site "Playa Norte" is a dynamic beach with a strong changing shoreline/beach. This is caused by strong currents and the impetuous Caribbean gulf stream. Tidal differences are on the other hand not big. The difference between low and high tide are just several decimetres *appendix C.* In combination with a fairly steep beach the intertidal proportion of the beach is not big. The results of the T-test confirms there is no significant relation between abundance of shorebirds and tidal differences. Also the number of birds per species does not show large differences, except the number of Royal Terns (High 13%, Low 87%). This is caused by big groups of resting Royal Terns at a sandbar situated at LT.

The outcome of the GLM-test shows several strong and significant correlations. Beginning with the time of the day, a large difference in abundance was found between morning and afternoon surveys. It is generally known that birds are the most active in the mornings, and shorebirds also exhibit this behaviour. Strong sun in the afternoon causes fewer birds to be on the beach and lagoons, especially resident birds (mostly herons) who retreat to the more shady forests to forage. Also a strong correlation was found between an increasing wind speed and higher number of recorded birds, in particular when the wind was coming from the East. With strong wind from an Eastern direction (coming from the water toward the beach), which is right-angled on the beach, more offshore birds like Royal Terns and Magnificent Frigatebirds were encountered because they are forced to forage in the branding. This condition also results in present shorebirds (mostly migrants) to stay on the beach to forage, which is a better strategy than trying to continue flying and spend energy fighting the wind.

6. Recommendations

Recommendations are of great importance for other researchers that will undertake this survey or similar research. In this chapter there some points listed which take into account for more research. The research questions will guide the recommendations:

- The results of this research give an image of only two months. A more representative image between differences in abundance between the lagoons could be created by a longer sampling period, preferably at least one year. Thereby a separation could be made between resident and migratory shorebirds. This could also show the importance of the lagoons and beach for wintering migrants, and for residents. Phenology, arrival and leaving time, could also be researched. This could be linked on stop-over ecology of specific species of shorebirds.

- Measuring human impact and its effects on the presence of shorebirds should be carried out by a different research methodology. Looking to, for example, flight-behaviour and energetic costs can support this topic. Changes in population-scale impact could be carried out with the next method: Sutherland (1998) described how density-dependent mortality and fecundity can combine to determine population-scale impacts of disturbance. This approach describes the change in the total population size (ΔN) that will result from a given level of disturbance within one site: $\Delta N = LM\gamma \, d'/(b' + d')$ (1) where L is the area affected by the disturbance, M is the density within the site prior to disturbance, b' is the strength of per capita breeding output, d' is the per capita density-dependent mortality and γ is the proportional change in the number of animals in the site as a result of disturbance (Sutherland, 1998).

- The relation between functional feeding groups and general water quality is demonstrated clearly in this research. To support this relationship, research to food availability could be carried out. Especially differences in the type of food between fresh and salt water environments could show an even better correlation to the distribution of the FFG.

- There were no significant differences found between quantity of birds related to tidal conditions. The tidal differences are not big at the beach, on the other hand some sandbars located at the lagoons show large differences in reclamation surface between low and high tide. Measuring the actual surface of this sandbars and relate it to presence or behaviour of shorebirds could be a nice topic for further research.

- Further research is needed to explain the negative correlation for wind direction Northwest. It is unknown what the birds do and where they are going with this weather conditions. This could be revealed by using data-loggers attached to shorebirds. It would also be nice to know if migrating birds do not use beach to stop over and fat-up during specific weather conditions.

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Appendices

A. Shorebird recording form

Date	Team	Start	End	Tide	Wind Direction	Wind Strength	Rain	Cloud

Section	Fishermen	Other Human	Dogs	Boats	Section	Fishermen	Other Human	Dogs	Boats
1					8				
2					9				
3					10				
4					11				
5					12				
6					13				
7									

Section	Species	Tally	Total	Breeding	Non-Breeding	Adult	Juvenile

B. Functional Feeding Groups

Species:	Abbreviation:	Diet:	Resident or Migrant:
Amazon Kingfisher	AMKI	Fish	Resident
Anhinga	ANHI	Fish	Resident
Belted Kingfisher	BEKI	Fish	Resident
Black Tern	BLTE	Small Fish and Insects	Migrant
Black-bellied Plover	BBPL	Insects and Marine Worms	Migrant
Brown Pelican	BRPE	Fish	Resident
Cattle Egret	CAEG	Grasshoppers and other Insects	Resident
Great Blue Heron	GBHE	Fish, Rodents and Frogs	Resident
Great Egret	GREG	Fish and Frogs	Resident
Green Heron	GRHE	Small Fish and Insects	Resident
Laughing Gull	LAGU	Small Fish, Carrion, Insects and Crabs	Resident
Least Sandpiper	LESA	Insects, Mollusks and Marine Worms	Migrant
Little Blue Heron	LBHE	Small Fish and Insects	Resident
Magnificent Frigatebird	MAFR	Fish and Hatchling Turtles	Migrant
Neotropical Cormorant	NECO	Fish	Resident
Parasitic Jaeger	PAJA	Fish	Resident
Osprey	OSPR	Fish and small Birds	Migrant
Ringed Kingfisher	RIKI	Fish	Resident
Royal Tern	ROTE	Fish	Migrant
Sanderling	SAND	Crustaceans and Mollusks	Migrant
Semipalmated Plover	SEPL	Crustaceans, Mollusks and Marine Worms	Migrant
Snowy Egret	SNEG	Fish	Resident
Spotted Sandpiper	SPSA	Insects, Mollusks and Marine Worms	Migrant
Tricoloured Heron	TRHE	Fish	Resident
Whimbrel	WHIM	Crustaceans, Mollusks, Crabs and Marine Worms	Migrant
A Guide to The Birds of Costa Rica, F. Gary Stiles and Alexander F. Skutch, Cornell University 1989			

C. Tide-tables Limon

Tide table for Limón, February 2015 www.tides4fishing.com

DAY	Moon	Sun	1st TIDE	2nd TIDE	3rd TIDE	4th TIDE	COEFFICIENT	SOLUNAR ACTIVITY
1 Su		05:54am 5:37pm	02:14am low tide (0 m)	08:54am high tide (0.3 m)	5:34 pm low tide (-0.1 m)		72 high	
2 Mo		05:54am 5:37pm	12:11am high tide (0 m)	03:01am low tide (0 m)	10:43am high tide (0.2 m)	8:32 pm low tide (-0.1 m)	78 high	
3 Tu		05:54am 5:38pm	01:28am high tide (0 m)	04:10am low tide (0 m)	11:37am high tide (0.2 m)	7:20 pm low tide (-0.1 m)	82 high	
4 We		05:54am 5:38pm	02:28am high tide (0.1 m)	05:37am low tide (0 m)	12:35pm high tide (0.2 m)	7:58 pm low tide (-0.1 m)	84 high	
5 Th		05:54am 5:38pm	03:08am high tide (0.1 m)	06:54am low tide (0 m)	1:32 pm high tide (0.2 m)	8:23 pm low tide (-0.1 m)	84 high	
6 Fr		05:54am 5:39pm	03:41am high tide (0.1 m)	08:03am low tide (0 m)	2:25 pm high tide (0.1 m)	8:47 pm low tide (-0.1 m)	82 high	
7 Sa		05:53am 5:39pm	04:08am high tide (0.1 m)	09:08am low tide (0 m)	3:15 pm high tide (0.1 m)	9:08 pm low tide (-0.1 m)	77 high	
8 Su		05:53am 5:39pm	04:32am high tide (0.2 m)	10:08am low tide (0 m)	4:01 pm high tide (0.1 m)	9:28 pm low tide (-0.1 m)	71 high	
9 Mo		05:53am 5:39pm	04:51am high tide (0.2 m)	10:57am low tide (0 m)	4:43 pm high tide (0.1 m)	9:50 pm low tide (-0.1 m)	63 average	
10 Tu		05:53am 5:40pm	05:08am high tide (0.2 m)	11:44am low tide (-0.1 m)	5:22 pm high tide (0.1 m)	10:10 pm low tide (-0.1 m)	55 average	
11 We		05:53am 5:40pm	05:27am high tide (0.2 m)	12:30 pm low tide (-0.1 m)	5:59 pm high tide (0 m)	10:30 pm low tide (-0.1 m)	47 low	
12 Th		05:52am 5:40pm	05:52am high tide (0.2 m)	1:17 pm low tide (-0.1 m)	6:38 pm high tide (0 m)	10:53 pm low tide (-0.1 m)	43 low	
13 Fr		05:52am 5:40pm	06:24am high tide (0.2 m)	2:08 pm low tide (-0.1 m)	7:17 pm high tide (0 m)	11:21 pm low tide (-0.1 m)	45 low	
14 Sa		05:52am 5:41pm	07:02am high tide (0.3 m)	2:55 pm low tide (-0.1 m)	8:08 pm high tide (0 m)	11:58 pm low tide (0 m)	53 average	
15 Su		05:51am 5:41pm	07:45am high tide (0.3 m)	3:44 pm low tide (-0.1 m)	9:09 pm high tide (0 m)		57 average	
16 Mo		05:51am 5:41pm	12:50am low tide (0 m)	08:32am high tide (0.3 m)	4:31 pm low tide (-0.1 m)	10:24 pm high tide (0.1 m)	83 high	
17 Tu		05:51am 5:41pm	01:58am low tide (0 m)	09:24am high tide (0.3 m)	5:17 pm low tide (-0.1 m)	11:34 pm high tide (0.1 m)	97 very high	
18 We		05:50am 5:41pm	03:28am low tide (0.1 m)	10:22am high tide (0.3 m)	6:04 pm low tide (0 m)		109 very high	
19 Th		05:50am 5:42pm	12:38am high tide (0.2 m)	05:14am low tide (0.1 m)	11:33am high tide (0.3 m)	6:50 pm low tide (0 m)	116 very high	
20 Fr		05:50am 5:42pm	01:34am high tide (0.2 m)	06:42am low tide (0.1 m)	1:00 pm high tide (0.2 m)	7:34 pm low tide (0 m)	114 very high	
21 Sa		05:49am 5:42pm	02:28am high tide (0.3 m)	08:00am low tide (0 m)	2:27 pm high tide (0.2 m)	8:17 pm low tide (0 m)	107 very high	
22 Su		05:49am 5:42pm	03:18am high tide (0.3 m)	09:15am low tide (0 m)	3:40 pm high tide (0.2 m)	9:00 pm low tide (0 m)	94 very high	
23 Mo		05:49am 5:42pm	04:04am high tide (0.3 m)	10:24am low tide (0 m)	4:40 pm high tide (0.2 m)	9:43 pm low tide (0 m)	78 high	
24 Tu		05:48am 5:42pm	04:48am high tide (0.3 m)	11:23am low tide (-0.1 m)	5:31 pm high tide (0.2 m)	10:27 pm low tide (0 m)	62 average	
25 We		05:48am 5:42pm	05:34am high tide (0.3 m)	12:18 pm low tide (-0.1 m)	6:17 pm high tide (0.1 m)	11:12 pm low tide (0 m)	48 low	
26 Th		05:47am 5:42pm	06:18am high tide (0.3 m)	1:10 pm low tide (-0.1 m)	7:01 pm high tide (0.1 m)	11:58 pm low tide (0 m)	41 low	
27 Fr		05:47am 5:42pm	07:04am high tide (0.3 m)	2:00 pm low tide (-0.1 m)	7:49 pm high tide (0.1 m)		42 low	
28 Sa		05:46am 5:43pm	12:38am low tide (0 m)	07:49am high tide (0.3 m)	2:51 pm low tide (0 m)	8:48 pm high tide (0.1 m)	48 low	

Times in local time UTC -6 | Heights in meters

D. Data setup and overview shorebird surveys

		Lagoon Tortuguero	
Date	Total number each survey	Number of sightings	Number of species
8-2-2015	94	25	14
11-2-2015	87	24	12
14-2-2015	95	39	15
18-2-2015	143	28	12
22-2-2015	285	48	16
25-2-2015	97	16	6
1-3-2015	169	33	15
4-3-2015	98	20	8
8-3-2015	230	35	12
11-3-2015	34	26	9
15-3-2015	97	25	12
18-3-2015	138	18	6
22-3-2015	180	30	12
Total	**1747**	**367**	**149**
	Total number different species 25		

		Lagoon Quattro	
Date	Total number each survey	Number of sightings	Number of species
8-2-2015	252	27	9
11-2-2015	52	24	11
14-2-2015	110	20	8
18-2-2015	189	31	12
22-2-2015	160	22	9
25-2-2015	189	28	9
1-3-2015	77	16	8
4-3-2015	108	25	12
8-3-2015	164	31	11
11-3-2015	221	26	12
15-3-2015	109	16	6
18-3-2015	81	22	11
22-3-2015	76	19	9
Total	**1788**	**307**	**127**
	Total number different species 20		

E. Data setup and calculation Shannon-Wiener diversity index

		Laguna Tortuguero		
Species	Sum	proportion (pi)	ln(pi)	pi*ln(pi)
Amazon Kingfisher	12	0,006868918	-4,98074866	-0,034212355
Anhinga	1	0,00057241	-7,46565531	-0,004273415
Black Tern	1	0,00057241	-7,46565531	-0,004273415
Black-bellied Plover	13	0,007441328	-4,900705953	-0,03646776
Blue-winged Teal	3	0,00171723	-6,367043021	-0,010933674
Brown Pelican	71	0,040641099	-3,202975433	-0,130172442
Cattle Egret	16	0,009158558	-4,693066588	-0,04298172
Great Blue Heron	3	0,00171723	-6,367043021	-0,010933674
Great Egret	12	0,006868918	-4,98074866	-0,034212355
Green Heron	1	0,00057241	-7,46565531	-0,004273415
Laughing Gull	3	0,00171723	-6,367043021	-0,010933674
Least Sandpiper	2	0,00114482	-6,77250813	-0,007753301
Little Blue Heron	4	0,002289639	-6,079360949	-0,013919544
Magnificent Frigatebird	17	0,009730967	-4,632441966	-0,045078142
Neotropical cormorant	53	0,030337722	-3,495363397	-0,106041362
Osprey	2	0,00114482	-6,77250813	-0,007753301
Parasitic Jaeger	2	0,00114482	-6,77250813	-0,007753301
Ringed Kingfisher	5	0,002862049	-5,856217398	-0,016760782
Royal Tern	438	0,250715512	-1,3834364	-0,346848966
Sanderling	584	0,33428735	-1,095754327	-0,36629681
Semipalmated Plover	66	0,03777905	-3,276000568	-0,123764189
Snowy Egret	243	0,139095592	-1,972593867	-0,274379113
Spotted Sandpiper	168	0,096164854	-2,341691331	-0,225188405
Tricoloured Heron	3	0,00171723	-6,367043021	-0,010933674
Whimbrel	24	0,013737836	-4,28760148	-0,058902367
Total	1747			

Results LT:
Diversity
1,935041155
Max diversity
3,218875825
Evenness
0,601154335

Shannon-Wiener Index denoted by

H = -SUM[(p_i) × ln(p_i)]

SUM = summation

p_i = proportion of total sample represented by species *i*

Divide no. of individuals of species *i* by total number of samples

S = number of species, = species richness

H_{max} = ln(S) Maximum diversity possible

E = Evenness = H/H_{max}

		Laguna Quattro		
Species	Sum	proportion (pi)	ln(pi)	pi*ln(pi)
Amazon Kingfisher	5	0,020576132	-3,883623531	-0,079909949
Bare-throated Tiger-Heron	2	0,008230453	-4,799914263	-0,039505467
Black-bellied Plover	35	0,144032922	-1,937713382	-0,27909452
Brown Pelican	128	0,526748971	-0,641031179	-0,337662514
Cattle Egret	16	0,065843621	-2,720472721	-0,179125776
Collared Plover	7	0,028806584	-3,547151294	-0,102181313
Great Blue Heron	3	0,012345679	-4,394449155	-0,054252459
Great Egret	10	0,041152263	-3,19047635	-0,131295323
Green Heron	1	0,004115226	-5,493061443	-0,022605191
Laughing Gull	3	0,012345679	-4,394449155	-0,054252459
Little Blue Heron	5	0,020576132	-3,883623531	-0,079909949
Magnificent Frigatebird	8	0,032921811	-3,413619902	-0,112382548
Neotropical cormorant	11	0,04526749	-3,095166171	-0,140110403
Ringed Kingfisher	2	0,008230453	-4,799914263	-0,039505467
Royal Tern	35	0,144032922	-1,937713382	-0,27909452
Sanderling	1175	4,835390947	1,575961983	7,620392306
Semipalmated Plover	238	0,979423868	-0,02079077	-0,020362976
Snowy Egret	14	0,057613169	-2,854004114	-0,164428221
Spotted Sandpiper	61	0,251028807	-1,382187579	-0,346968898
Whimbrel	27	0,111111111	-2,197224577	-0,244136064
Total	1788			

Results LQ:
Diversity
1,325770038
Max diversity
2,995732274
Evenness
0,442552911

F. EC-values, Laguna Tortuguero and Laguna Quatro

EC-Values														
Laguna Quattro														
Date:	8-feb	11-feb	14-feb	18-feb	22-feb	25-feb	1-mrt	4-mrt	8-mrt	11-mrt	15-mrt	18-mrt	22-mrt	
Section 1	> 20000	> 20000	7600	> 20000	> 20000	2476	5756	2060	3016	1237	2310	1564	2120	
Laguna Tortuguero														
Date:	**8-feb**	11-feb	14-feb	**18-feb**	**22-feb**	25-feb	1-mrt	4-mrt	8-mrt	11-mrt	15-mrt	18-mrt	22-mrt	**Average**
Section 1	**180**	128	1810	**378**	**476**	163	2430	2309	1562	295	1250	1144	3480	**345**
Section 2	**235**	1683	2590	**485**	**880**	2420	3100	3402	1940	5330	12080	1518	4480	**533**
Section 3	**1240**	6080	17690	**1642**	**3160**	1670		3100	12890	13020		3980	4230	**2014**
Section 4	**2570**	8820		**1580**	**3920**	3400		3510	13480	18620		5120	12020	**2690**
Section 5	**6560**			**6470**	**11370**	3800		5800				11000	12020	**8133**
Section 6	**9430**			**11360**	**13250**			6840					12230	**11347**
Section 7								8300						

G. Data setup GLM-analyse, weather condition data overview

Laguna Quatro

Date (day-month):	18-feb	22-feb	25-feb	1-mrt	4-mrt	8-mrt	11-mrt	15-mrt	18-mrt	22-mrt
Temperature (C⁰):	27.3	27.9	24.2	27.5	24.1	27.0	25.2	25.3	24.4	29.4
Wind (Km/H):	2.2	11.3	1.8	16.3	4.4	10.0	3.5	12.2	1.8	8.7
Wind direction:	W	NE	N	NE	NW	E	SW	W	SW	NE
Humidity (%):	98.7	90.6	96.2	91.9	69.3	99.9	100.0	100.0	96.8	87.2

Laguna Tortuguero

Date (day-month):	18-feb	22-feb	25-feb	1-mrt	4-mrt	8-mrt	11-mrt	15-mrt	18-mrt	22-mrt
Temperature (C⁰):	28.4	24.6	26.2	24.3	28.7	23.3	26.4	25.1	27.8	25.5
Wind (Km/H):	10.2	3.1	7.8	4.8	7.1	9.0	11.1	1.1	7.7	1.8
Wind direction:	NE	NE	NE	SW	E	SW	NE	SW	E	SW
Humidity (%):	91.9	96.8	87.6	99.9	86.9	99.9	100.0	100.0	87.1	100.0

(red) = Morning
(green) = Afternoon

Number of individuals	Wind Speed	Direction	AM/PM	Transect		Transect	
189	2,2	7	1	1		L4 =	1
160	11,3	2	2	1		LT =	2
189	1,8	1	1	1			
77	16,3	2	2	1		AM =	1
108	4,4	8	1	1		PM =	2
164	10	3	2	1			
221	3,5	6	1	1		N =	1
109	12,2	7	2	1		NE =	2
81	1,8	6	1	1		E =	3
76	8,7	2	2	1		SE =	4
143	10,2	2	2	2		S =	5
285	3,1	2	1	2		SW =	6
97	7,8	2	2	2		W =	7
169	4,8	6	1	2		NW =	8
98	7,1	3	2	2			
230	9	6	1	2			
34	11,1	2	2	2			
97	1,1	6	1	2			
138	7,7	3	2	2			
180	1,8	6	1	2			

GLM Output, Deviance Residuals:

Min	1Q	Median	3Q	Max
-7.7333	-1.6945	0.4009	1.5828	5.2428

Coefficients:

	Estimate	Std.	Error	z value	Pr(>|z|)
(Intercept)	5.145160	0.074323	69.227	< 2e-16	***
Wind.Speed	**0.053660**	**0.008478**	**6.329**	**2.46e-10**	***
factor(Direction)(NE)	0.272633	0.101452	2.687	0.00720	**
factor(Direction)(E)	**0.699376**	**0.119733**	**5.841**	**5.18e-09**	***
factor(Direction)(SW)	-0.255422	0.088296	-2.893	0.00382	**
factor(Direction)(W)	0.080280	0.095332	0.842	0.39973	
factor(Direction)(NW)	**-0.699131**	**0.122622**	**-5.702**	**1.19e-08**	***
factor(AM.PM)2	**-1.394171**	**0.097960**	**-14.232**	**< 2e-16**	***
factor(Transect)2	-0.005321	0.046375	-0.115	0.90865	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for poisson family taken to be 1)
AIC: 387.25