

# Shorebird Survey Manual



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# Planning the Shorebird Surveys

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## 1.1 Determining wetland and beach coverage in your country

The first step to plan your surveys is to create an overview of the potential habitat available for shorebirds. The process involves roughly estimating how many, where and how accessible are the coastal wetlands of your country. Doing this will also help you gain some insights into, among other things, how much rocky and sandy beach there is your country's coastline. While it may seem daunting to realize that there are thousands of km of beach and hundreds of wetlands, you should keep in mind that surveys are focused only on the coast (maximum 5 km inland) and that just a sample of the wetlands and beaches will be surveyed.

### 1.1.1 Determining the extent of beaches:

During this process you need to determine via remote sensing *how many km of rocky, sandy and estuarine beach are there are in your country*. These results will be used directly during the analyses.

While you can determine your beach extension at a later stage, doing it beforehand will save you a lot of time. For example, while scanning and classifying the beach in Google Earth you will come across most of the important coastal wetlands for shorebirds and you can already drop a location pin, thus completing section 1.1.2. When classifying, the best results are acquired using [Google Earth pro](#), zooming into a beach segment, drawing a line and manually classifying the beach segment into one of four categories:

- *Rocky Beach*: includes all gravel, boulder, and rocky platforms.
- *Sandy Beach*: Continuous stretches of sandy beach.
- *Estuarine beach*: Sandy beach stretches of up to 3 km along the coast from an estuary. This includes sand bars, river mouths and beaches adjacent to an estuary.
- *Unsuitable*: urban developments without beach, industry, cliffs, etc.

This task can be tedious and involves about a week to fully classify around ~3,000 km of coast with a decent level of accuracy. If you have long stretches of sandy or rocky beach, the process is can be fairly quick. Due to irregular terrain, islands and complex geography, some locations might take longer to digitize.

*End product 1.1.1 A Google Earth folder with polylines that can be converted into a single line shapefile in ArcGis with your classified coast and will help you estimate how many km of each category there is.*

### 1.1.2 Determining wetland coverage:

This is the next step before selecting your survey sites. At the end of this process, you should have pinpointed in Google Earth potential shorebird sites along the coast (estuaries, river mouths, intertidal planes, etc.). This process will give you a broad idea of how many sites are feasible to survey (due to their location and accessibility) and the number of volunteers that you will need to conduct the surveys. If you already determined the extent of your beaches, then you should already have scanned the entire coast via Google Earth, which means that you should have already pinpointed most potential sites for shorebirds.

The easiest way to locate these sites is to find your *national wetland inventory* (if there is one). Most inventories come with a shapefile that can be overlaid on top of imagery from Google Earth. If there is no inventory available, another option is to download a *layer of rivers* for your country and plot it in Google Earth. Most rivers that converge into the ocean will have an associated estuary or wetland with potential shorebird habitat. In any case, you need to assume that the national inventory will not be complete and will not include small estuaries and all river mouths. Because of that, you can complement your wetland coverage by consulting the following options:

- International frameworks: [WHSRN sites](#), [Ramsar sites](#), and [Important Bird Areas](#)
- Neotropical Waterbird Census reports
- Technical reports for your country
- Expert opinion
- Remote sensing

Remote sensing will be the last option and will be the best technique to detect those remote coastal wetlands that are not being reported in any of the above options. The technique involves downloading publicly available Landsat / Sentinel satellite images and opening them in Arcgis/QGIS. These images come with different numbers of spectral bands. When the bands are used in a [certain combination](#), they can be useful to differentiate wetlands from other habitats.

*End product 1.1.2: A Google Earth folder with point locations of (ideally) all sites with potential shorebird habitat (estuaries, river mouths, intertidal planes, etc.).*

## 1.2 Spatial planning

The goal of this section is to define—with a hierarchical approach—the area where your surveys are going to take place. You should start by defining a study area. If your study area is very large, you will have to divide it into regions. Each region will contain a set of sites. Within each site, you will then select the survey plots for each habitat and the different type of beach transects to survey (fig. 1). Creating all of these layers of information beforehand will help you immensely with the planning, survey implementation and result analysis.

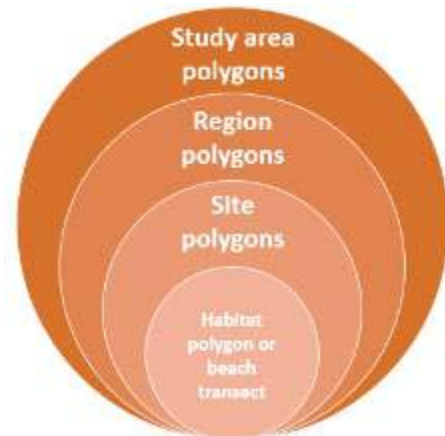


Figure 1. Use a hierarchical approach to organize your study area.

### 1.2.1 Determining your study area

Now that you have a spatial overview of the wetland and beaches available to be surveyed, you need to think about what your overall study area will be. Ideally you will want to include the whole country's coastline. In reality this might not be possible or even necessary—because there might be a lack of potential shorebird habitat in large stretches of the coast— or it might not be even possible to survey—due to the remoteness or lack of trained volunteers in certain regions. In any case, the combination of the wetland coverage, accessibility and number of available volunteers will determine which sections of the coastline to cover.

In the case of Chile, our study area was defined as extending from the northern tip of Chile to southern tip of Chiloe Island. It would have been ideal to include the entire coastline, but based on expert opinion and remote sensing, we concluded that the fiords south of Chiloe Island would be logistically and economically complicated to survey; there would not be enough trained volunteers, and, most importantly, it might not even host many shorebirds.

*End product 1.2.1 A layer of your study area. You can begin by using a shapefile of your country's borders and custom-clip it to cover only your study area.*

### 1.2.2 Selecting and digitizing the regions:

If your study area is very extensive, you will most likely need subdivide it into regions. The rationale behind regionalizing is to account for the variability of climatic and vegetation gradients across the study area. This is important because each climatic zone has specific vegetation that registers different remote sensing signatures that will affect your habitat classification and ultimately your shorebird estimations.

To select regions with similar characteristics you can overlay layers such as your country's bioclimatic zones and biogeographical units (Rivas-Martínez, Navarro, Penas, & Costa, 2011); your country's land cover shapefile; and your country's administrative regions. The objective is to find the coastal areas of overlap that have most similarity in terms of vegetation and spectral characteristics. Once you have defined a potential set of regions, use the multispectral images to see if the spectral characteristics (the palette of colors) in each region are uniform across the region. Using the administrative state/department lines to divide your regions is useful when these divisions fit the biogeographical boundaries between the regions.

*End product 1.2.2: A layer (polygon) of your study area subdivided into several representative regions.*

### **1.2.3 Selecting and digitizing sites:**

In section 1.1.2 you pinpointed most potential sites to survey. Using these locations and Google Earth, you will have to digitize a polygon that covers the entire site. In some cases, this will be a small wetland with clear boundaries and in others the polygon will cover wetland complexes with uncertain borders. Use your best judgement to digitize these polygons. **IMPORTANT:** The spatial configuration of wetlands may change dramatically with flooding and seasons. When digitizing, make sure to select current Google Earth imagery close to the survey month. For example, if the surveys will be carried out on February, then you should try to select imagery  $\pm 1$ -month difference. If there is no imagery on those dates, you can also go back some years.

When naming your sites use meaningful simple names that link your site with the region. Avoid spaces, long names, accents or uncommon symbols which cause problems when using GIS. Try to stick to your desired naming system throughout the study. E.g. A1RioLluta (Region=A, SiteNum=1, SiteName=RioLluta). This is particularly important to avoid confusion during data handling and analysis.

You should also start thinking which of these sites are feasible to survey. Keep in mind that each team might have to visit several wetlands separated by many km from each other and drive dozens of kilometers per day. Given those considerations, try to include wetlands that run along a linear route and if there are plenty of wetlands to choose from, avoid long detours.

*End product 1.2.3:*

- *A layer (polygon) with the boundaries of all (preferable) sites with potential habitat.*
- *A list of the selected sites to survey.*

### **1.2.4. Selecting and digitizing habitats within a site:**

In this section, we use the habitat categories used for Peru and Chile surveys as example. Study your sites layer (End product 1.2.3) and assess if these categories will apply to your country's coastline. If you add new categories, you may need to make sure that those categories have enough spectral differences in the multiband satellite images to be able to be classified automatically.

**Sandy beach:** Draw a transect of 0.5 km parallel to the coast. Keep in mind that we only consider those sandy beaches NOT adjacent to an estuary.



Figure 2: A typical sandy beach habitat (left). A 0.5 km transect is digitized using Google Earth (right).

**Estuarine beach:** A transect of 0.5 km parallel to the coast. This are sandy beaches associated with a river mouth, delta or watershed outlet.



Figure 3: A digitized 0.5 km estuarine transect at a sandy bar (left). Aerial image of a river mouth (right).

**Intertidal planes:** The extension of these habitats varies with the tides. Draw a polygon in between the area covering the high and middle tide. Usually, scopes can be used to cover large areas of the intertidal area, however, keep the polygon area realistic.



Figure 4: A digitized polygon of an intertidal mudflat at low tide (left). An intertidal plane during low tide (right).

**Low vegetation (emergent vegetation <0.5 m):** This is probably the most challenging habitat to remotely sense because it is tricky to assess what constitutes low vegetation and because the spectral signature of low vegetation can be similar to other kinds of land covers such as agriculture. Draw 100 x 400m polygon(s) on the vegetation near the wetland that “seems” like low vegetation. Use your best judgement and available Google Earth images to aid the process. Remember that your polygons will represent your training areas that will train the classification algorithm as to what—spectrally—constitutes a given habitat during the supervised habitat classification. The best results are obtained when you choose polygons that cover homogenous patches of low vegetation. The land cover will need to be verified in the field and if necessary, a new polygon re-drawn while observers are on site.



Figure 5: Two plots of 100x400m in what it appears to be low vegetation. One of those plots can be used to perform the zig-zag double counting (left). You should corroborate on the field that the plot contains low vegetation (right).

**High vegetation (emergent vegetation > 0.5 m):** This refers to those habitats that include vegetation > 0.5m high and all areas covered by arboreal vegetation. The vegetation areas will be delineated on the site map and we will assume that the density of waders is zero.





Figure 6: High vegetation is easier to detect than low vegetation (Left); It usually doesn't contain suitable habitat for shorebirds (right).

**Shallow water (water <0.5m deep):** Mostly associated with wetlands, river edges, shallow ponds and lagoons. Draw a polygon around one or more areas of shallow water. This habitat can be identified by the different tonalities on water depth in satellite images. Water levels can be very dynamic; the boundaries of what you delineate as shallow water can change dramatically overnight so you should corroborate your polygon boundaries in the field.



Figure 7: A shallow water polygon example. As with low vegetation, validate the map during the field surveys.

**Rocky coast:** Draw a transect of 0.5 km parallel to the coast. This category includes rocky platforms, boulder beaches, gravel beaches, etc.



Figure 8: It's difficult to differentiate between the different types of rocky coast from Google Earth images.

**Deep water (water > 0.5m deep):** This is also a tricky habitat because water depth may vary with the season. Further, the boundaries between shallow and deep water may not be very apparent. If you have multispectral images using the 7,5,3 band combination will highlight deep water as black and dark blue. (e.g., deep channels, the center of large lagoons).



Figure 9: Deep water corresponds to any waterbody where shorebirds cannot wade. An exception are phalaropes which can swim.

*End product 1.2.3: A polygon layer with all representatives habitats to be surveyed.*

### 1.2.5 Selecting your random segments:

Determine the number of 0.5 km rocky and sandy beach segments that occur along the coastline of your country. Within each region, assign each rocky or sandy beach segment a number. Then, with a random number generator (e.g., [www.random.org](http://www.random.org)), generate a suite of random numbers that can be aligned with your numbered rocky and sandy beach segments. Those beach segments whose number was chosen by the random number generator have been selected to be surveyed. Be sure to choose more segments than you can actually survey, as some segments may not be accessible.

*End product 1.2.5 A layer with all your random beach transects for rocky and sandy beach habitat.*

### 1.2.6 Preparing maps for observers:

Using End product 1.2.4, print maps for each team observers that include their sites to be surveyed, with the habitats delineated by separate colors. These maps (fig. 10) make it easier for the teams to determine which parts of the site need to be surveyed and then to record how much of each habitat they actually surveyed.

*End product 1.2.6 Map printouts with the habitats and transects to survey delineated. Maps will be given to each team.*



Figure 10. Example of a map with the habitat polygons and beach transects to be surveyed.

### 1.2.7 Selecting your Zig-zag polygons:

You have already predefined 100 x 400m polygons for low vegetations habitats (section 1.2.3) In each site, you should select one of those polygons to calculate a detectability ratio. This is done by walking a straight line along the edge of the area (400m side) and counting all birds that use the area. Afterwards, two observers will walk the area in a zigzag. They will record species and number of birds that can be chased away while traversing the area. This procedure just needs to be done once per site. Additional low vegetation counts can be done only along the outside of the polygon (to avoid bird disturbance) because the ratio of birds seen during the two counts can be used to correct further counts in this habitat.

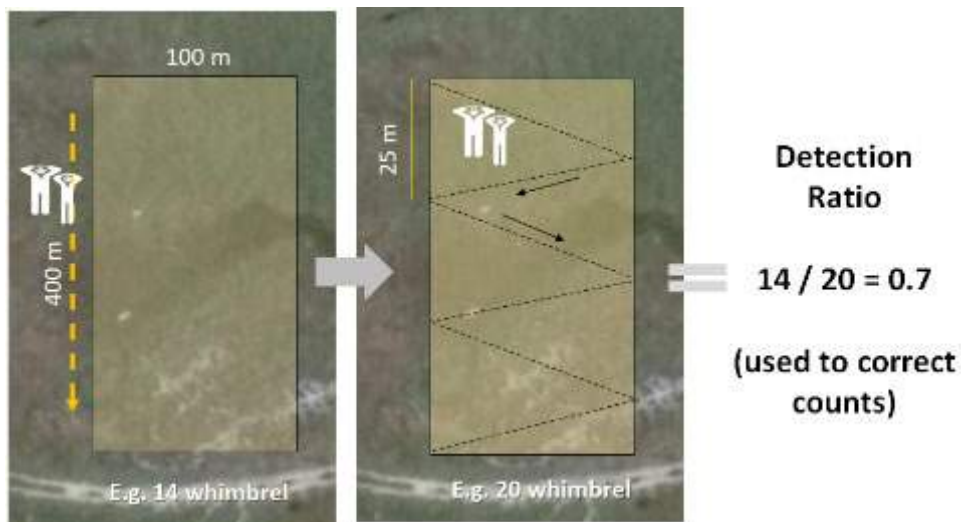


Figure 11. Double counting technique to estimate detection ratio. This procedure only needs to be done once per site.

*End product 1.2.7 A selection of low vegetation zig zag polygon on the survey map of each site.*

## 1.3 Call for volunteers

One of the goals of this project is to encourage the participation of citizen scientists with all of levels of expertise in the collection of data about shorebirds. In both Chile and Peru we have used all manners of formats to invite volunteers to join our surveys, including social media, stories in local newspapers, and collaborations with local universities. The more people involved, the merrier!

### 1.3.1 Organizing training workshops

Plan to organize as many day-long training workshops as needed to adequately prepare teams of observers for the surveys. In Peru, we have held three workshops prior to the surveys, one for each region. In Chile, we have held fewer, but had trained leaders then disperse the length of the country to subsequently help train others more informally. I (Nathan) will plan to help with these workshops in person (if possible).

# Implementing the shorebird surveys

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The following protocol was developed based on Peruvian and Chilean habitats. You might need to adapt this protocol to work in other kinds of habitats that are present in your country and that were not considered in this protocol.

## 2.1 Site selection

We will sample a set of known estuarine sites along the coast. During the planning phase, we created a set of 0.5 km segments (end product 1.2.5) of sandy beaches and rocky coast to be used to estimate the density (individuals / Km<sup>2</sup>) and the total number of shorebirds outside estuaries. The average and variances for the sandy beach and rocky coast habitats will be generated through stratified sampling estimators. The totals and variances for regions, as well as the entire coast, will be the sum of the complete counts from all the designated sites and randomly selected segments of sandy beach and rock coast (sensu Andres *et al.*, 2009).

## 2.2 Habitats to be sampled

During the planning phase you have already defined which habitat types will be sampled and you pre-defined habitat polygons in each site. Each habitat will have a specific protocol to follow. As an example from Chile, the following habitats were sampled:

- Sandy beach
- Intertidal planes
- Low vegetation (emergent vegetation <0.5 m)
- High vegetation (emergent vegetation > 0.5 m)
- Shallow water (water <0.5m deep)
- Deep water (water > 0.5m deep)
- Rocky coast

## 2.3 Field Mapping of the surveyed habitats

The field mapping consists on using the pre-defined habitats maps that you created during the planning phase (*End product 1.2.5*). Since your maps were based on satellite images created prior to the survey, it is **VERY** important to accurately confirm that the habitat and surveyed extension corresponds to that of the predefined map.

To do this, use the prepared map to **accurately** delineate the area actually surveyed and, if possible, take GPS coordinates at the corners of a surveyed area. After the survey, we will measure the surveyed and non-surveyed areas for each habitat type. We need to be as accurate as possible about the extent of the area surveyed because we will use bird densities to estimate the number of birds occupying non-surveyed areas within the sites. We will use a combination of GPS points and maps to delineate the surveyed areas.

## 2.4 Land cover validation

In each surveyed habitat, you will have to gather validation points (preferably more than one). This will help you perform an accuracy assessment during the analysis phase to compare the habitat classification that you will create in a later stage to the points you are validating in the field. In order to obtain validation points you will need to download the "[panorama](#) app" into an android phone.

The procedure is simple. Stand inside the surveyed polygon. Open the [Panorama](#) app and take a 360 degrees picture of the point location. Record the GPS location with the built-in feature. Name the picture with the corresponding site name and validated habitat or landcover. For example, BahiaYavaros-lowvegetation.

## 2.5 Counting the birds

All habitat types in a site should be delineated on a map. Observers should act as quickly as possible to minimize bird movement between habitats within the site (this will depend on the density of the birds, but a rule of thumb is that sites should be counted at a rate of approximately 15 hectares per hour).

The surveys should be done on either a rising or falling tide (or if necessary at low tide) to minimize the number of birds resting in areas near or adjacent to wetland sites. The optimal survey period is 1-3 hours before or after low tide (tide tables will be available).

Only the birds that are using the survey area should be counted. That is, those actively feeding, resting, swimming or within the borders of the surveyed area (this may include birds that arrive at the surveyed area during the count, as long as they have not been previously counted). All birds that are identifiable to genus and that are seen outside the counting area or flying over must be counted separately.

Here is the counting protocol for each type of habitat:

### Sandy beach

Take a GPS point at the beginning and end of each 0.5Km segment. Walk the designated 0.5 km segment and record all individuals by species that are **using** the area (as explained above). The surveyed areas will be used to estimate the density and the total number of individuals for all of the sandy beaches in each coastal region.

### Intertidal Mudflats:

*Open - Broad Visibility* - This category refers to muddy intertidal flats or sandy planes adjacent to lagoons. Walk across the flat or to one side of it. If there is no vegetation, stop every 400m and count all individuals within a radius of 200m. Be alert to groups moving between different parts of the survey area or being pushed forward from the observers' transect.

*Open-Inaccessible* - Will not be counted. The density generated in census areas will be applied to inaccessible areas within the site.

### Low vegetation:

*Accessible* - Areas of 100m x 400m will be previously defined on a map. Observers will walk a straight line along the edge of this area (400m) and count all birds that use the area. Afterwards, two observers will walk the area in a zigzag. They will record species and number of birds that can be chased away while traversing the area.

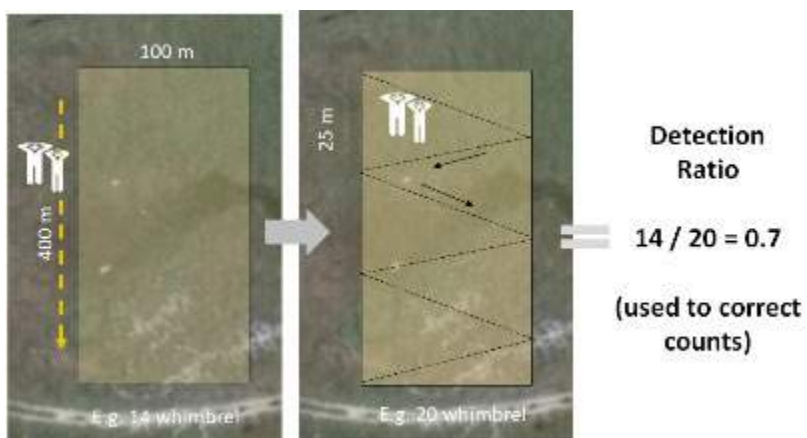


Figure 12. Double counting technique to estimate Detection ratio. This procedure only needs to be done once per site.

*Inaccessible* - The density obtained in the previous method will be used to determine the density in the non-surveyed areas within a site.

### High vegetation

This refers to those habitats that include vegetation > 0.5m high and all areas covered by arboreal vegetation. The vegetation areas will be delineated on the site map and we will assume that the density of waders is zero and thus that these areas do not need to be surveyed.

### Shallow water

*Without Vegetation* - This refers to all open lagoons or estuarine areas that are permanently covered by <0.5 m of water (i.e., not tidal), but without emergent vegetation. These sites should

be counted by a transect directly adjacent to the habitat and stopping every 400m to count all visible individuals within 200m of the transect line.

*With Vegetation* - This refers to areas covered by <0.5 m of water and sparsely populated by emergent vegetation. These areas should be surveyed by walking a transect parallel to the habitat and stopping every 400m to count all visible individuals within a distance of 200m from the transect line. If possible, a circle should then be used (e.g., a circle of 200m radius around a census point) which should be walked through the center to make a count of birds that are flushed (similar to those made in a low vegetation area). This will provide an estimate of detection of areas with vegetation.

### **Deep water**

This refers to all deep water habitats in which the depth of the water is greater than that in which a small shorebird or wader can feed (e.g., deep channels, the center of large lagoons). Habitats will be delineated on the site map, but it is assumed that the density of shorebirds or small waders is zero and thus that these areas do not need to be surveyed.

### **Rocky coast**

Take a GPS point at the beginning and end of each 0.5 km segment. Walk the 0.5 km delineated segment and record all the individuals of each species that are using the area. The surveyed areas will be used to estimate the total number of birds on the rocky coast by coastal region.

## **2.6 Data entry**

We will use the *Censo Costero de Aves playeras* in eBird for all the data entry that corresponds to the census. All data will be accessible through the Avian Knowledge Network (Avian Knowledge Network [www.avianknowledge.net](http://www.avianknowledge.net) ) where you must search for the correct protocol.

Below the necessary steps to enter the census data in the Coastal Shorebird protocol:

1. Visit the website [ebird.com](http://ebird.com)
2. Register in eBird, if you have not done it before.
3. After you have registered, go to the "Send your observations" button
4. Then choose "Find it on the map." Choose the appropriate department for your survey site (eg Los Lagos, etc.) and then your country in the "Country" tab. Doing this will open a map in the chosen department. Find your site on the map and try to put the point in the most exact place possible where you have taken the data. Please name the site **in the same way** as it appears above on your site map. Do not use pre-existing hotspots when submitting your data.
5. Once you have identified the site, proceed to the next page. Here you will find the Coastal Shorebird Survey (Shorebird Coastal Survey) as the protocol that you will be using to enter the data. On this page, enter the total size of the area you have surveyed



or, for each beach or rocky coast, the total distance you have walked. For the beach and rocky coast you must enter the starting coordinates (GPS) of the census. Input the start time, the duration of the survey, and the number of observers present. Next, choose the type of habitat present in the census area - You must enter a new list (checklist) for each different habitat (polygon) that you have surveyed at a site. Additionally, you must enter a separate list that includes the birds flying over the area, but not found within the surveyed area itself. Finally, at the bottom of the page there is a comments section. In this section you must list all the GPS coordinates demarcating this site (for a beach census, the start and end coordinates) You should also list any other information of interest that may help later when we are reviewing the data (e.g., car moved along the beach during the census and scared the birds).

6. When you have completed this page, you will move to the next page that contains the list of all potential birds in your department. Here you can enter the exact number of species counted in your surveyed area- remember that birds flying over should be counted in a separate list.
7. For those areas where two counts are made (e.g., short vegetation without water), you must enter the birds that you observe from the transect along the edge of the habitat in the box next to each species name. Then, next to each species' name you will also see an 'add details' button. Press this and, in the notes section, add the number of individuals seen while performing the 'zigzag' transect through the survey area.
8. After you have entered the number for the second transect and pressed "send," you will go to a summary page that includes the numbers of all the species that you have entered, as well as the notes for each one. Be sure to double check all of your numbers to make sure they are correct.
9. When you have finished "send", if you have surveyed other sites or habitats, return and start the process again.

## 2.7 Important considerations:

- a) If you are surveying multiple areas that are influenced by the tide over the course of the day, be sure to plan your day so as to survey each site  $\pm 1-3$  hours around the low tide.
- b) We cannot emphasize enough that observers need to demarcate on their maps the areas that they actually surveyed while still in the field.
- c) Make sure observers are only counting those birds actually 'using' a survey area!
- d) Make sure to enter checklists from sites at which zero shorebirds were observed. Zeroes are important data points!
- e) If a site contains multiple sections of the same habitat type (e.g., multiple shallow water lagoons), it is important to try to survey at least two of these separate sections so as to determine the amount of variation that exists within a site in the number of birds using each type of habitat.

# Conducting the analysis

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In this section, a general overview of the main steps to conduct the analyses are given. If you gathered accurate data and properly organized it during the previous phases, you should have avoided many potential problems in these next steps.

## Step 1: Data Organization - Ebird data and spatial data in one dataset

After you have performed the field surveys, confirm that all your team leaders have uploaded the survey data in the ebird portal and handed in other materials such as their delineated maps and 360° panorama land cover validation pictures.

Once all the relevant data is gathered together, you will integrate it together into one dataset. Start by [downloading your ebird data](#) into a .csv excel sheet. This file is a “life list” that contains a compilation of every list and bird observations from the shorebird surveys since 2010 (this includes the surveys in Chile 2014 and Peru 2010/2014). Before having a usable dataset you will need to clean it, leaving only the relevant observations and adding some extra information. Open the .csv file in Microsoft Excel and use Excel filters to:

- **Discard observations** done outside the country and dates of interest (for example, any observation done in Chile and Peru or added during the training sessions).
- **Discard species which are not shorebirds.** Define which species are going to be included in the analyses, use the Excel filters and keep only your chosen shorebird species.

- **Mark observations of birds not using the area** but that were counted flying or located outside of the area (so you can make sure you exclude them during the extrapolations)
- **Include birds lists with “0” birds.** Make sure that sites that were surveyed but had “0” shorebirds are included in the Excel database (often team leader forget to include lists that had 0 shorebirds)
- **Input consistent habitats.** Make sure that all the habitats categories are consistent in the dataset (e.g. observers often write “river shoreline” when this could mean “shallow water”, “deep water” or even “low vegetation”)
- **Matching names.** Make sure that your “site polygons”, “habitat polygons” and “beach transects” have matching and consistent names with your GIS data. The names need to match exactly in order to make a “spatial join” between your spatial data and your excel tabulated data.
- Compare your database to our [sample database](#)

There is other data that will need to be calculated and added to the dataset:

- **Add the area extent of each surveyed polygon.** Use your field maps to corroborate the surveyed area. If the areas are different from the original map, you will also need to modify your GIS polygon. Some eBird lists might already have area data; corroborate that the units are hectares.
- **Calculate the detection ratio for each species in each habitat:** During your surveys, your teams did a double counting procedure (Fig. 13) where they counted birds from outside a polygon and then re-counted them as they walked a transect inside the polygon. Use these results to calculate the detectability ratio per species per habitat.
- **Count correction.** Using the detection ratios per species and habitat, correct your counts and account for undetected birds in polygons that were surveyed only once.

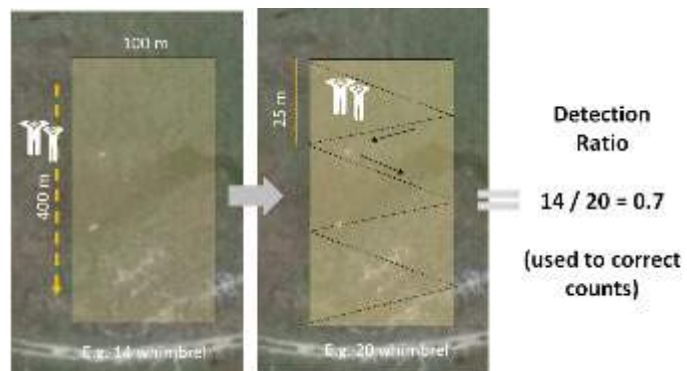


Figure 13 Double counting technique to estimate Detection ratio. This procedure only needs to be done once per site.

## Step 2: Obtaining and mosaicking satellite data.

There are several ways in which you can [download Landsat](#) images or [sentinel images](#) and countless tutorials on YouTube and the web to do so. Decide [which of the two types of imagery you will use](#) and stick with one kind throughout the entire study. Each satellite image is called a tile. Tiles have small overlaps with the neighboring tile, allowing you to join tiles as a mosaic. Download all the tiles that give you complete coverage of your study area (Fig. 14). The tricky part is that the chosen tiles should:

- Preferably have the same acquisition dates
- The dates should be no more than  $\pm 1$  month apart from each other and the date of your survey. If you cannot find suitable tiles then, go back to 2018 or earlier dates and choose the same month as the survey dates.
- Tiles should be cloud and haze free (at least on the immediate coastline).
- If you cannot find tiles with the same dates, then try at least to have the same dates within your regions.



Figure 14. Schematic view of the overlapping tiles covering the coast of Peru.

After you have downloaded and unzipped all of your landsat images you will see that each tile has different bands that will need to be stacked together. In other words, you will need to go from [single separate bands to a multi-band image](#). Once you have your set of multiband tiles, you can proceed to [create a whole mosaic](#) of your study area.

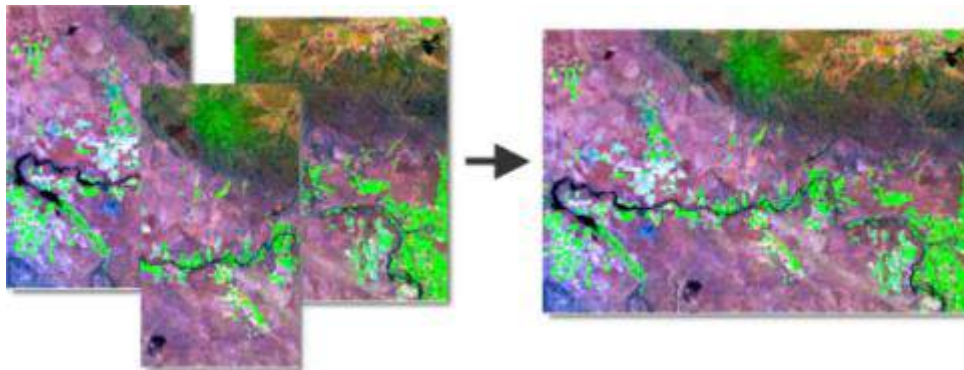


Figure 15. A mosaic consists on joining together several tiles that cover your study area.

### Step 3: GIS - Clipping and preparing your base layers

Notice that your mosaic demands quite a lot of hard drive space (usually more than 5 Gb) and computing power. To be more efficient, a series of clips will be performed in order to get rid of unwanted areas (such as mountains) and to keep only the area of interest.

- **Five-kilometer buffer of the coastline:** The idea is to narrow your study area in the mosaic to only the coastline. Download a shapefile of your country's administrative

borders. Then, convert it from [polygon to polyline](#) and erase all the borders which are not part of the coastline. You should end up having one single line representing the coastline. Now use the [buffer tool](#) to create a 5 km buffer from each side of the coastline.

**End Product 3.3.1** A polygon—5 km in width left and right from the coastline.

→ **Clip the mosaic with the 5 km buffer:** Use the five km buffer to [clip](#) the mosaic. Essentially, you are using the 5-km buffer as a cookie cutter.

**End Product 3.3.2** A layer of your mosaic with only the first five kilometers of the coastline.

**Use your “Regions” layer (endproduct 1.2.2) to clip your 5-km mosaic:** Once you have clipped your mosaic, it will no longer be so “large.” You will still want to clip your mosaiced 5km-buffer-image with your Regions layers so you can work with each region individually.

**End Product 3.3.3** A clipped multiband image of each region of your coastline, 5-km wide from the coast o mainland.

## Step 4: Remote Sensing - Determining habitat extent

From this point onwards, you should commit to using a single GIS program, whether it is QGIS or Arcmap. The methodology shown here is based on Arcmap, but the same tools are found in QGIS, albeit with different names. I will not go in much methodological detail but rather guide you through an overview of the general steps and provide you with links to the references.

At a minimum you should review the following complete [article](#) and also watch a couple of video tutorials to get familiarized with land cover classification techniques. By far, this is the component of the analysis that will take you the longest because you want to make sure that you are creating an accurate habitat classification.

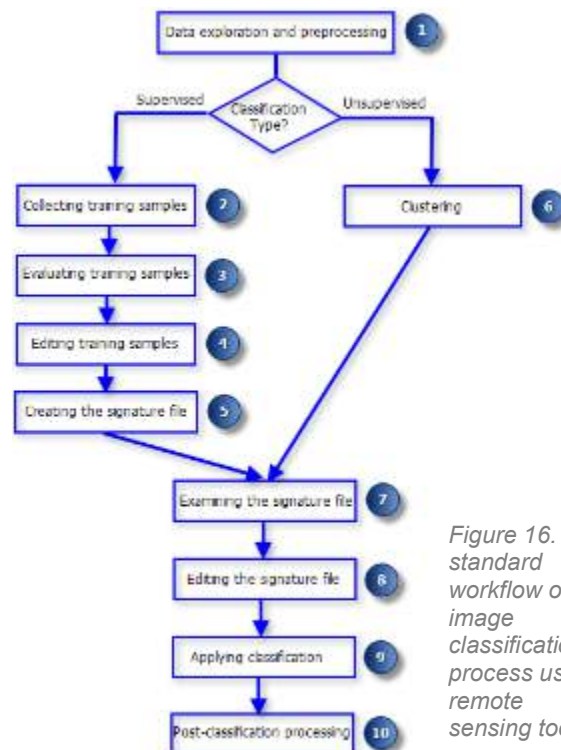


Figure 16. The standard workflow of the image classification process using remote sensing tools.

## The classification process in a nutshell

In previous steps you *explored and processed* your data (1). You will now start classifying each region, one region at a time.

You can start by performing a quick *unsupervised classification* (6) to identify problematic habitats and to develop a glimpse of which landcovers have similar spectral characteristics. Afterwards, you will start your Supervised classification. To do this you will have to [collect training samples](#) (2) or in other words, examples of each habitat of interest that will be used to train the algorithm that will classify the whole region (Fig. 17).

To be sure that your training samples are of good quality and representative of each habitat, those training samples will have to be evaluated (3) with a [bundle of visual tools](#) that will aid the process (fig.18). Based on those evaluations, the training samples might need to be re-edited (4) until you obtain samples that represent each desired habitat and that are spectrally separate from each other.

Once you have finalized selecting your training samples, they will be used to create a signature file (5) that will be used to run the Maximum Likelihood algorithm. The output of this process will be a classified image of your region.

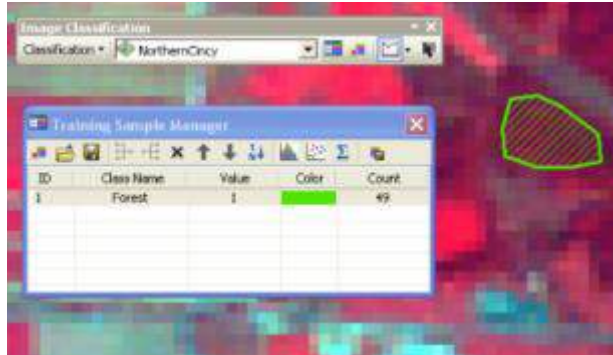


Figure 17. The training sample toolbar is designed to help collect quality training samples on your remotely sensed image.

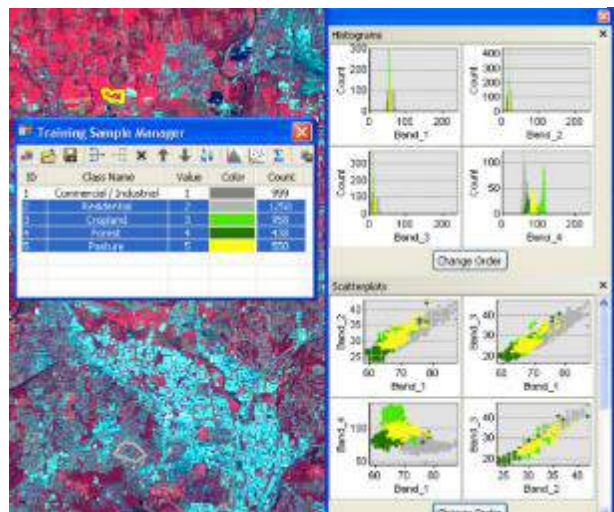


Figure 18. Use the scatterplots and histograms to assess how distinct are your chosen classes from each other. Classes should not overlap with each other.

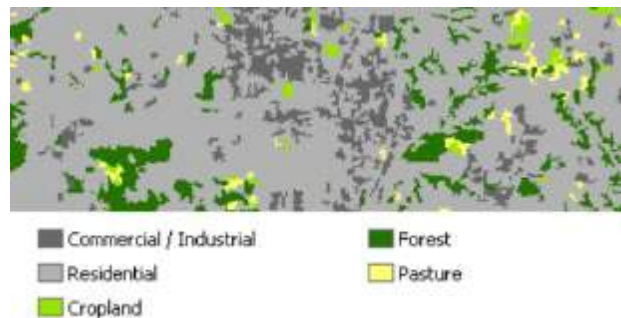


Figure 19. The output of an image classification.

## Post-processing your classification

Your classification will likely not be perfect—due to misclassified pixels and certain problematic areas. To improve the classification, there is a simple workflow that helps you [deal with misclassified pixels](#) with a certain degree of accuracy.

- Filtering the classified output ([Majority filter tool](#)): replaces cells based on the majority value in their contiguous neighborhoods.
- Smoothing class boundaries ([Boundary tool](#)): Used for cleaning ragged edges between zones.
- Generalizing the output ([Generalize tool](#)): This process removes small isolated regions from a classified image.

The last step on a classification is to do a visual check and manual edit of large misclassified areas.

## Step 5: Accuracy assessment - how “good” is your classification?

To provide some quantitative data on how accurate your classification is, you will need to perform an [accuracy assessment of your classification](#). In a nutshell, you will compare your classified image to another data source that is considered accurate. You already collected in the field many points (360° images) that can be used to validate your classification. You can also add a matrix of random points and use high-resolution imagery to interpret the landcover. This process involves three steps:

- Create [accuracy assessment points](#): Creates randomly sampled points for post-classification accuracy assessment. You can choose from different sampling methods.
- [Update accuracy assessment points](#): Updates the Target field in the attribute table in order to be able to compare reference points to the classified image.
- [Generate confusion matrix](#): Computes a confusion matrix that will provide you with an overall accuracy between the classified map and the reference data.

Typically, a good accuracy is considered 80% overall accuracy and above, where 80% represents the percentage of correctly classified pixels.

## Step 6: Extrapolations and confidence intervals

Once you have completed your classification you can easily calculate how many hectares of shallow water, low vegetation, intertidal planes, etc. exists in each region. It is important to calculate the extent of each habitat separately *inside* your “sites polygon” and *outside* your “sites polygon” because the extrapolations should be done separately.

Extrapolations are a lot easier to perform when data is tabulated as in the [example dataset](#) because all the calculations are automatically done in Excel.

### Site Extrapolations:

In this step you will estimate how many birds were present in each site during the surveys (fig. 20). This is important because when your teams surveyed each site, they only counted birds in a portion of each site (surveyed polygons). We thus need to account for the un-surveyed areas within each site. The boundaries of your site are the polygon edges you drew during the planning phase.

To calculate your site extrapolations--or how many birds of each species used the sites within a given region, you will need two pieces of information:

1. Number of hectares of a given habitat (which you calculated using your habitat classification).
2. Your specific density estimates. These density estimates were calculated by dividing the bird counts of each surveyed habitat by the surveyed habitat's total area.

I then used the specific densities to extrapolate to the extent of each habitat type that was not surveyed within a site. The estimate of the number of birds found in each site was composed of the sum of the actual counts and these extrapolations.

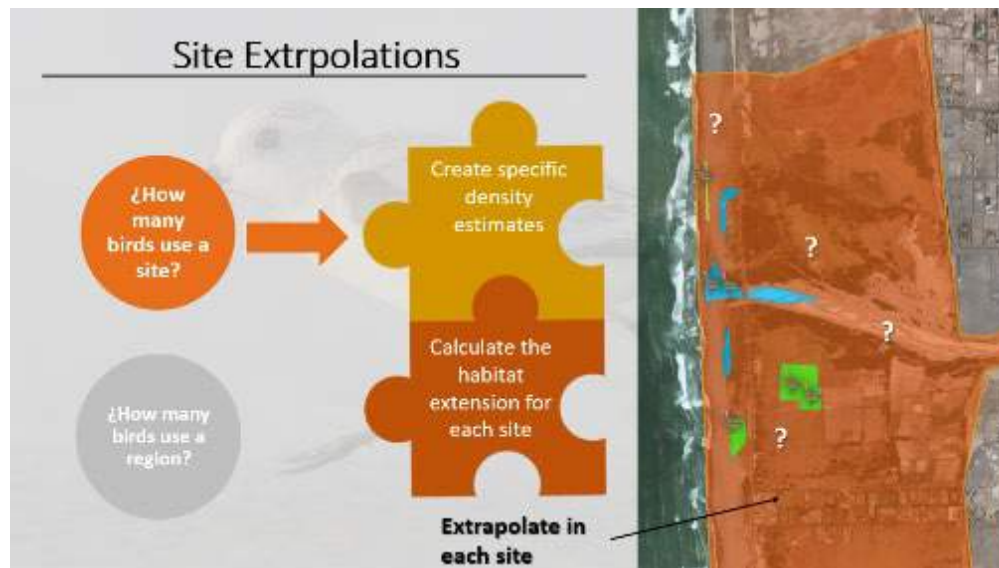


Figure 20. As an example, the observers surveyed four shallow water polygons (blue), two low vegetation polygons (green) and a beach transect (yellow line). We know how many birds are found on those areas, and we will use those counts to create specific density estimates (first puzzle piece) to extrapolate to the rest of the un-surveyed habitats within a site. We can then estimate how many birds use the whole site (orange polygon).



## Regional extrapolations

For your regional extrapolations, you will then need to create regional density estimates by averaging the site-specific densities for a given species in a particular habitat across a region. The regional density was then used to extrapolate the non-surveyed habitats detected **outside** of the site polygon boundaries.

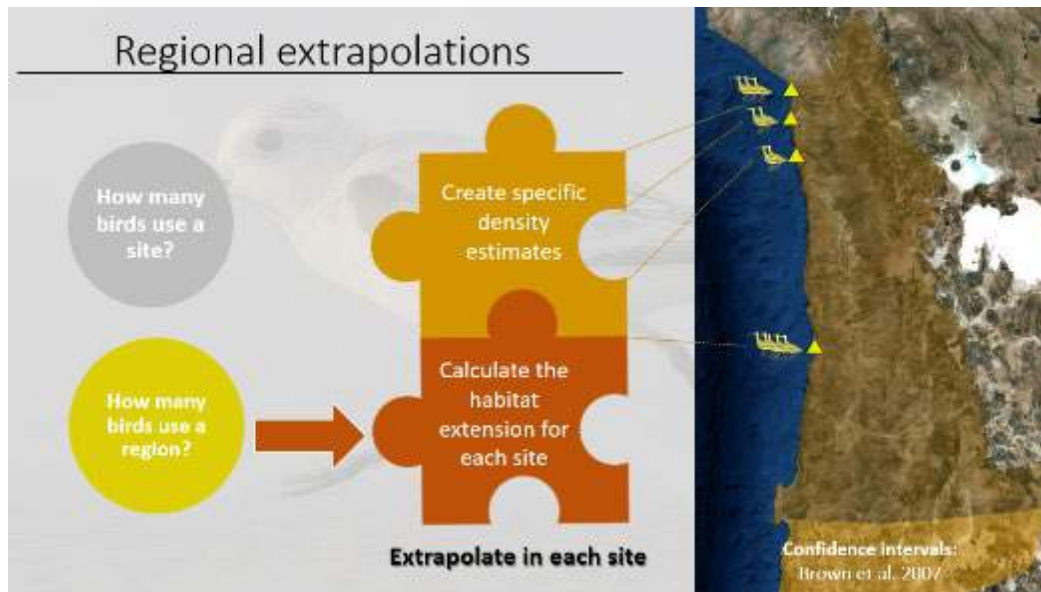


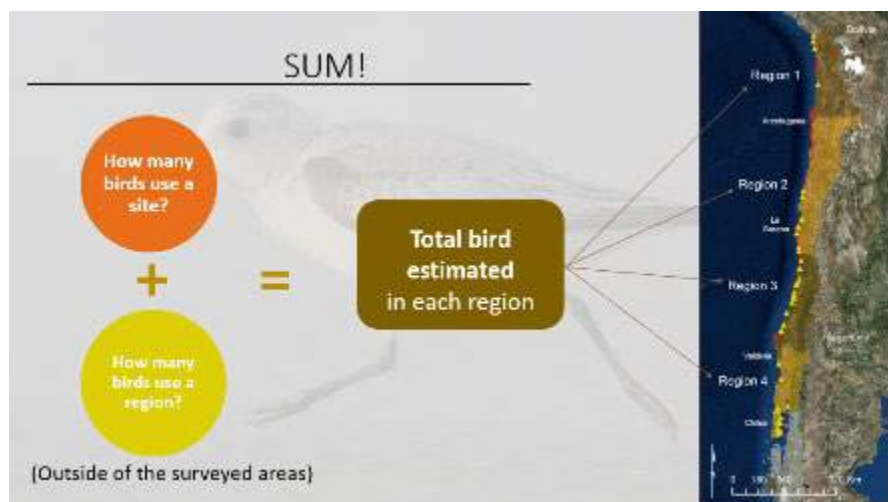
Figure 21. How many birds use ALL the areas outside of our survey sites in a given region? We averaged our site-specific density estimates to create a regional estimate. We used the regional estimate to extrapolate to all the unsurveyed habitat outside of our sites.

Confidence intervals at 95% significance were constructed for the regional estimate from the variance of surveyed sites and randomly selected beach segments (see Brown et al., 2007). See the [sample dataset](#) to study the formula to create your confidence intervals.

## Step 7: Final results

The final step of the analysis consists on simply summing up all bird population estimates on your regions to estimate the total number of shorebirds on your study area.

Figure 22. How many birds use a region? We summed the birds estimated inside all the sites and the birds estimated outside the sites. How many birds use the whole study area? We summed the birds estimated in each region.



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