TECHNICAL MANUAL FOR MONITORING AVIAN PREDATORS OF THE ARCTIC TUNDRA

Version 1

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HAWK MOUNTAIN



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Photo credit of cover page: Yannick Seyer (snowy owl & long-tailed jaegers)
Alexandre Paiement (rough-legged hawk nest with young and prey remains)

Table of content

1. INTRODUCTION

Predators play a key role in the functioning of ecosystems and could potentially control the abundance of their prey. As predators are at the top of the food chain, they can be good indicators of the state of the tundra ecosystem. Avian predators, mostly raptors and seabirds, are the most diverse groups of predators in the Arctic tundra and range from specialists to generalists in terms of their diet. Most species of avian predators are migrants and are only present in the Arctic during the summer to reproduce. During the short Arctic summer, they can encounter harsh conditions that could affect their breeding effort, reproductive success or even their survival. Furthermore, these species are exposed to climate change, which is predicted to be most severe at northern latitudes. For instance, raptors have already started to experience loss of breeding habitats in some regions due to the collapse of their nesting structures cause by permafrost thawing. Changes in prey distribution can also impact avian predators, especially those that are diet specialists. Hence, implementing a monitoring program of avian predators can provide useful information on the status of these species, some of which are considered vulnerable, as well as on the health of the whole tundra ecosystem.

In this manual, we present sampling techniques to monitor the abundance, reproductive success and food habits of the most common species of avian predators present in the Arctic tundra of North America. The species covered in this manual include raptors, tundra-nesting seabirds, cranes and ravens. The latter two groups are included here because, even though they are not considered birds of prey per se, they nest in the same habitats and have similar food habits as raptors and seabirds, especially during the breeding season in the Arctic summer. Seabirds nesting on cliffs and feeding exclusively at sea are not considered in this manual.

Techniques presented here can be used by any research team wishing to implement monitoring programs for these species, whether it is a simple or a more elaborate one. However, prior to going into the field, research teams must obtain all required federal and/ or provincial/territorial permits as they are mandatory to apply most of the techniques described in this manual. Approval by an institutional animal welfare committee is also required in most cases.

Peregrine falcon pair.

2. Monitoring raptor and raven abundance

Due to their highly territorial behaviour and need for a large territory, raptor species are usually found in low density in the field. Their numbers can also be influenced by food and nesting sites availability. Competition among individuals of the same species ('intra-specific competition') or of different species ('inter-specific competition') present at your study area can also affect their abundance and nesting distribution.

2.1. Field methods

Since most raptor species present in the Arctic are migrants, the best period to determine their annual abundance is during the summer breeding season by counting the number of occupied nests or territory found over pre-defined areas. Monitoring non-breeding individuals is exceedingly difficult and there is no reliable method to monitor this component of the population.

2.1.1. Defining areas to survey

Raptor species typically build their nests in rugged terrain, from low hills and mounds to steep cliffs. You need to define suitable habitats for nesting raptor at your field site using 1:50 000 topographic maps. The size of the areas to be searched may vary considerably depending of the species and nesting density in your area and could range between 50 and 1000 km^2 or more. Because large body size species have larger home range, a larger study area is usually needed to obtain decent sample sizes compared to species of smaller size. Suitable nesting habitat will vary according to the species considered. Here, we present a general description of nesting habitats and sites for the most common raptor species found in the Arctic. Note that all raptor species except owls show fidelity to their nesting territory and will often reuse the same nesting structure year after year.

Typical cliff where raptors and ravens nest on Bylot Island, NU.

Snowy owl

Their nest is generally located on a ridge, a small mound on a gentle slope or along a ravine or a deep gully on dry terrain. The eggs are laid directly in a shallow depression scraped out of the ground. Nest material is not used to line the nest bowl. Incubating females are easy to spot at a distance due to the white color of their plumage. Furthermore, at some field sites, other bird species such as geese and ducks can be found nesting around owl nests and their presence in relatively high numbers can help locating snowy owl nests. Owl nests are generally easily accessible. Snowy owls are highly nomadic and show no fidelity to their previous nesting site.

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Rough-legged hawk

This species nests on cliff edges, outcrops, rocky pinnacles such as hoodoos, steep slopes and river banks. The nest consists of a large bowl made out of branches and roots. Vegetation such as forbs, sedges and grasses can be used to line the nest bowl. Although more than one nesting structure can be found close to another, only one is usually occupied within a territory and the structure selected to breed may change each year. Similar to the snowy owl, other bird species can nest in association with this hawk in some areas.

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Peregrine falcon

This wide-ranging species typically nest on ridges along cliff walls in the Arctic. Their nest is most often simply a shallow depression scraped in substrate with no lining material, sometimes with an overhang. However, they are also known to use pre-existing nesting structures built by other species such as those of rough-legged hawks or common ravens.


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Gyrfalcon

This raptor typically nest on rocky ledges, cliffs or steep river banks. Similar to the peregrine falcon, they do not built nest structure per se. The nest bowl is simply a shallow depression scraped on the ground often protected by an overhang. They are also known to sometime use pre-existing nesting structures built by other raptor species or common ravens.


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Golden eagle

They usually nest on rocky ledges and cliffs. Their nesting structure is built out of sticks and branches and lined with vegetation. They often have more than one alternative nest within their territory but only one will be occupied. In the transitional zone between subarctic forest and tundra, golden eagles can also be found nesting in trees such as white or black spruces. Due to the large size of this species, their nest can get very large compared to other raptors.

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Short-eared owl

This owl uses less rugged terrain than other raptors, including lowland tundra. Their nest can be located on a ridge, a small mound on a gentle slope or along a ravine or a deep gully directly on the ground, in a dry habitat. It consists of a scraped bowl among tall vegetation or hummocks that provides enough cover for the female while incubating but also a good vantage point. The nest bowl can be lined with grasses and feathers.

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Common raven

Although a passerine bird, ravens breed in the same type of habitats than raptors. They build their nest on rocky ledges along cliffs using branches and roots. The nest is often protected by a rock overhang. Near the northern limit of trees nests can also be found in trees.

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2.1.2. Systematic search of areas to survey

Raptors nests will be found by conducting systematic searches in suitable nesting habitat in your study area. Depending of the raptor species and habitat types present at your field site, your whole study area may become your search area. However, depending on the resources available, priority should be given to areas that can be searched most easily and repeatedly over the years. Indeed, it is important to be able to survey the same area each year to ensure a good monitoring program that will allow detection of annual variation in abundance or temporal trends.

Preliminary searches can be done by boat or helicopter to locate suitable nesting habitat worth searching more thoroughly, especially if an area is searched for the first time. If nests or raptors are observed during these preliminary searches, their location should be recorded with a GPS receiver for further investigation on the ground. Search areas should then be surveyed on foot, following survey route determined beforehand in order to maximize the coverage of the area. If an area has been surveyed in previous years, it is advisable to use the same route (see Section 2.1.3). Survey route should take into account the local topography, for instance by walking on high ground (e.g. ridges) to obtain a good view of the surrounding.

You should stop at each vantage point along the way and thoroughly scan the surrounding landscape. In most cases, raptors will reveal their presence to the observer by alarm calls, often a hundred meter or more from their nest. Hearing an alarm call is a sure sign of a breeding pair occupying a territory and extensive searches should be conducted in those areas. Alarm calls will also intensify when you get closer to the nest itself. Similar searches should be conducted when a raptor is found perched on the ground. Usually, the partner that is incubating the eggs will be the last one to start calling right after it leave the nest. Be vigilant in order to see it fly off its nest.

Cliff-nesting species will sometime select nesting sites that are oriented toward the south and/or are protected by an overhang. These characteristics are often associated with higher reproductive success due to increased protection against adverse weather conditions. This should be kept in mind when looking for nests. The presence of white streaks of dried bird excrement on rocks or cliff walls, called 'whitewash', is a good indicator of the presence of an occupied nest above. Note, however, that a small amount of whitewash can also indicated a resting perch.

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Hoodoo formation with whitewash, Bylot Island, NU.

During surveys, all raptor sightings should be recorded with the following relevant information:

- Species
- Behavior: in flight, on the ground, alarm call, attacks by the bird, on a nest
- Geographical coordinates of the sighting recorded with a GPS receiver

Nest defence behaviour (i.e. alarm calls, attacks, etc) are important to record because even if no nest are found, these individuals can still be counted as a pair occupying a territory.

When a nest is found, it should be positioned with a GPS receiver, the species recorded and, if necessary, its nest content checked (see Section 4 for details on checking nest content). If a nest cannot be reached, you should try to get to a vantage point from where you could see the content of the nest with binoculars. Taking pictures can also be an option to zoom in the nest content.

Search areas need to be surveyed only once. However, if a bird was seen exhibiting nest defence behaviours but no nest was found, you should schedule another visit to the site a few days later and search again.

2.1.3. Recording GPS tracks

It is important to have a log of areas that have been searched for raptor nests every year. Nowadays, all research personnel carry GPS receivers with them while working in the field. Hence, the best way is to record the tracks of their daily route in their device. The

Rough-legged hawk.

*** CAUTION! DANGER! ***

Search and inspection of raptor nests should be done with great care. Be careful when walking on steep hills or along cliffs and do not take any undue risk that could result in a fall. Slopes may be unstable and the substrate brittle. Furthermore, raptors often attack people approaching their nests and their claws can cause severe injuries. Always be alert when checking those nesting sites, especially when you bend over nests or when you are in an unstable position (e.g. along cliffs). Make sure to keep an eye on both individuals because both can attack. Whenever possible, we recommend that the field work be done in teams of two where one person can stand alert of bird attacks while the other person can inspect the nest. Wearing a hard hat when visiting those sectors is also a good idea.

easiest way is to program the GPS to record automatically and continuously during the searches. If the GPS memory does not allow such daily recordings, then you should ask your staff to record points periodically during the day. These tracks should be saved and downloaded daily into a computer for safe keeping (see Figure 2.1 for example). This information can also be useful to determine the route to follow in the field when the same areas are surveyed in subsequent years.

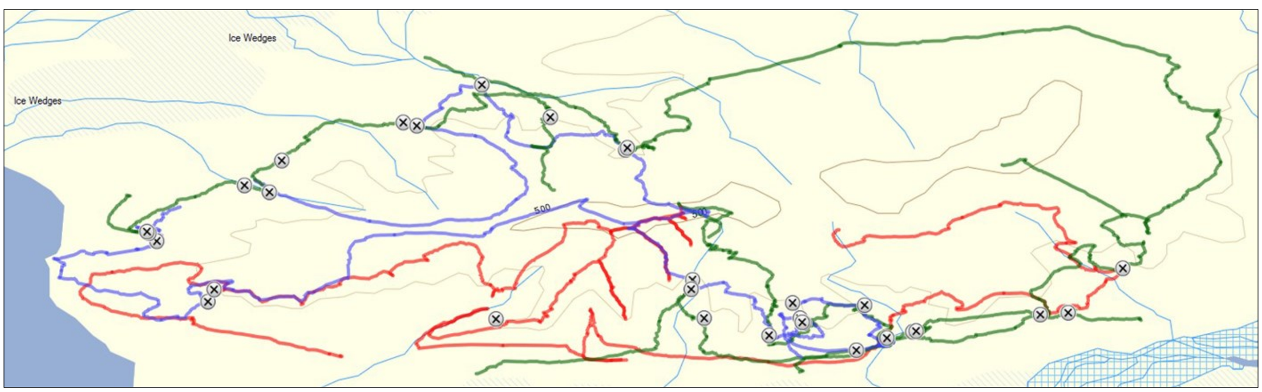

Figure 2.1. Example of raptor survey tracks recorded during a field season. Each color represents a different person and the grey circles with a black 'x' are raptor nesting sites.

2.1.4. Nest sites found opportunistically

Raptor nests may sometimes be found outside the systematic searches described above. Indeed, nests or birds showing signs of territorial defense can be found opportunistically, e.g. during other activities in the field or by colleagues studying other species. This information, including the GPS coordinates and the species, should still be recorded and entered in your database but you should note that it was found accidentally rather than during a systematic search.

2.2. Time period

The best time to conduct raptor surveys is during the nesting period when pairs occupy and defend territories. Their nesting habitats are usually snow free early in the spring because most sites are windswept and receive little snow during the winter. Most raptors arrive on their territory and start their breeding activity before snowmelt in spring because their breeding cycle is fairly long compared to the short Arctic summer.

It is important to know the breeding phenology of species that can be found in your study area to time your surveys accordingly. Furthermore, some species are sensitive to human disturbance during the breeding season, so visits to the nest structure should be planned at a time that minimizes disturbance. For instance, several species are more likely to abandon their nests if a nest visit occurs during egg-laying or early incubation than later on. Nest visits should thus take place halfway through the breeding season, preferably late incubation or early brood rearing, but not too late not to miss failed breeders or abandoned nests.

Table 2.1 presents the breeding phenology of several species to help you plan your surveys. Be aware that these dates may vary depending on annual variation in weather conditions, elevation and latitude of your field site.

Table 2.1. Approximate range of arrival, laying and hatching dates for the most common raptors found in the Arctic and raven (from Richards & Gaston 2018 and Birds of North America online [birdsna.org]).

Species	Arrival date	Laying date	Hatching date
Gyrfalcon	late January to mid-March [€]	early April to mid-May	May to June
Golden eagle	April	mid- to late April	late May to mid-June
Snowy owl	late April to early June	early May to early June	early June to early July
Rough-legged hawk	early to mid-May	late May to early June	mid-June to early July
Peregrine falcon	mid- to end of May	early to late June	early to mid-July
Short-eared owl	May	June	July
Common raven	*resident, present year-round*	early March to mid-April	early April to mid-May

[€] Gyrfalcons can be resident in some regions

For new monitoring programs, a high number of nesting sites will probably be discovered during the first year that you encounter a high abundance of small mammals (especially lemmings and voles) because more individuals will breed when this food source is abundant. However, this will be variable among species as generalist species, such as the peregrine falcon, will usually be present at the same density regardless of small mammal abundance whereas specialist species, such as the snowy owl, are generally totally absent when small mammals are low. However, during those years, specialists can sometimes be seen early in the season when they presumably sample food abundance but they will quickly leave their territory if they cannot find enough food to sustain a breeding effort. Hence, it might take a few years to get a complete list of all potential nesting sites in your study area. Nonetheless, new sites can still be discovered afterwards when new individuals recruit into the breeding population or old nesting sites are destroyed and replaced.

2.3. Material required

- GPS receiver
- 1:50 000 topographic map of study area
- field book
- binoculars and/or spotting scope
- camera
- photo registry of nesting sites of your study area (optional; see Section 2.4.1)
- hard hat (optional)

2.4. Data management

The key to a successful long term monitoring program is to keep good data records. Therefore, it is important to enter all field data in predefined datasheets or computer files as soon as possible when you are back to camp after a day in the field. Here are two elements that will facilitate the monitoring of raptor nesting sites.

2.4.1. Photographic registry of nesting sites

Since raptor nests can be hard to locate in the field and some might not be easily accessible, a photo registry of raptor nesting sites in your study area should be created. Each nesting site should be photographed from a distance to get an idea of the surrounding area and the exact location of the nest (see Figure 2.2 for an example) and a close-up photo of the nest itself should also be taken. Pictures are then downloaded on a computer and classified and named according to nesting sites. Each picture should also be accompanied with a short description of where the photo was taken, including geographical coordinates and direction (N, S, E, W) towards which the photo was taken and notes on how to easily reach the nesting site. It is recommended to print a hard copy booklet of the registry and to hand out the document to each members of your research team, or to download it to an iPad if they carry them in the field, as this will help them to locate the nesting sites faster during field surveys. This is especially useful if the personnel carrying out field survey is not the same every year.

2.4.2. Permanent nesting site ID for long term monitoring

Since most raptor species presented here can occupy nesting structures for more than one year, we recommend that you identify each nesting site with a permanent ID based on the species that uses the nest. We suggest a notation using the 4-letter bird

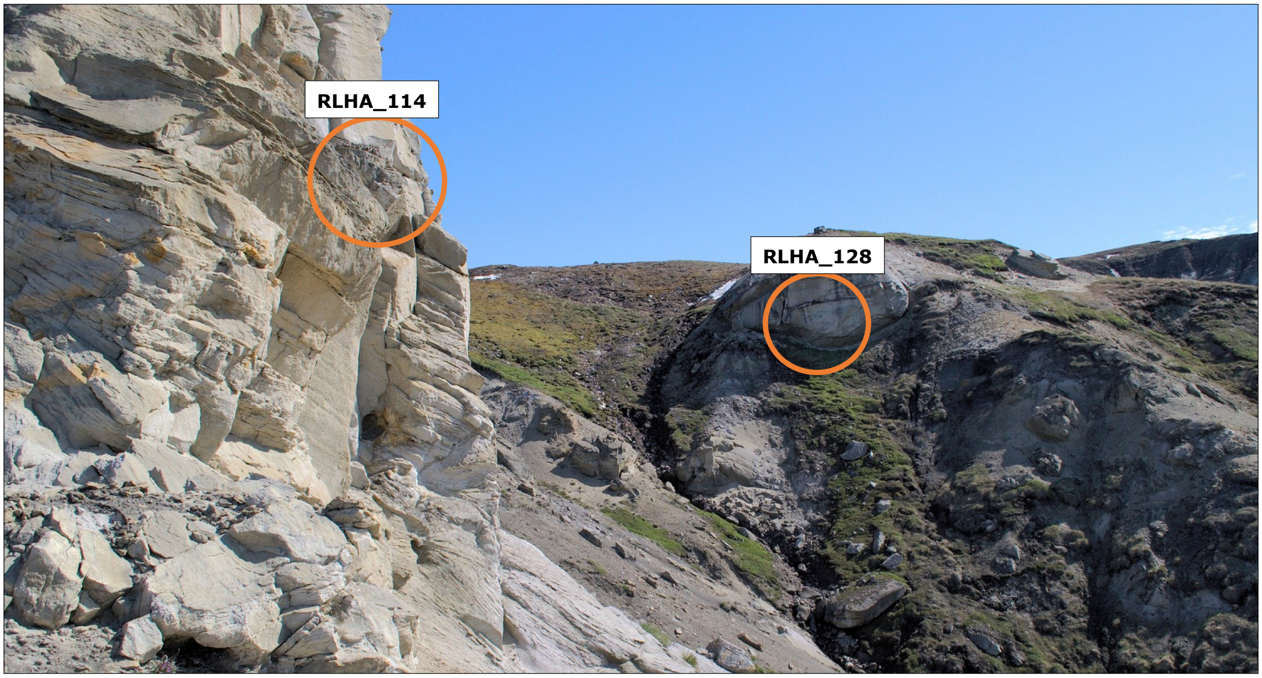

Figure 2.2. Example of a picture included in the Bylot Island raptor nest registry showing the location of two known raptor nesting sites.

species codes used by the US Bird Banding Laboratory to identify species, followed by sequential numbers. We provide below the codes for the most common Arctic raptors (Table 2.2) but a complete list of the species codes can be found at the Institute for Bird Populations website (www.birdpop.org/pages/birdSpeciesCodes.php).

If a nesting site is used by more than one species over the years, we suggest using multiple site ID (i.e. one for each species; e.g. RLHA_025 and PEFA_010 for the same site) and adding notes when the switch in occupancy between two species occurred. If a nesting site cannot be associated to a particular species, it can be simply tagged as 'unknown' with the year it was discovered (ex: UNK_2018_01) and a specific ID can be given the next time the species occupying the site is identified.

Table 2.2. Standard 4-letter codes used to identify common Arctic-nesting raptor species.

Species	4-letter code
Common raven	CORA
Golden eagle	GOEA
Gyrfalcon	GYRF
Peregrine falcon	PEFA
Rough-legged hawk	RLHA
Short-eared owl	SEOW
Snowy owl	SNOW

Your nesting site ID log should be updated on a yearly basis to make sure that your field crew has the most recent information of known sites in your study area. It should contain the following information:

- Nesting site unique ID
- GPS coordinates of the nest
- Comments on the coordinates (e.g. exact nest location, estimated location based on nearest vantage point, site where territorial behavior was observed)
- Date that the site was last visited
- Nest status at last visit * (intact, destroyed or unknown)
- Nest occupancy at last visit (occupied, vacant or unknown)
- Nest environment (cliff, hoodoo, small mound, ridge, etc.)
- GPS coordinates of best viewpoint to observe nest content and its direction (compass bearing) compared to the nesting site (useful to minimize disturbance at the nest or if the nest cannot be reached on foot)

*** CLASSIFYING RAPTOR NEST STATUS ***

Since raptors breed in habitats vulnerable to geomorphological hazards, nest status should be recorded at each visit. Here are a few tips to help you categorized the nests.

Intact: the nest is occupied by a bird or the nest is vacant but unaltered since the last visit

Destroyed: the nest has fallen or has been dislodged due to the collapse of material supporting it, or the nest has been fully or partially (>50%) buried by falling material or the nest has totally disappeared

(from Beardsell et al 2017)

To minimize risk of errors, the same site ID should never be reused to identify a different nesting site. For example, if a nesting site is found destroyed, its ID should not be reused for a newly discovered site. The only exception to that should be if a new nest is found very close to a previously destroyed nest but the ID should take that fact into account. For example, if RLHA_214 was destroyed in 2017 but the birds rebuilt another nest structure on the same ledge a few meters away in 2018, then this new nest can be identified as RLHA_214a.

Keeping a log of nest ID up to date will be useful when planning a route to survey raptor nest in the field (see Section 2.1.2).

3. Monitoring tundra-nesting seabird and crane abundance

As for raptors, the abundance of predatory seabirds and cranes nesting on the tundra can be influenced by food resources and nesting sites availability. Similarly, competition among individuals of the same species ('intra-specific competition') or with other species ('inter-specific competition') present at your field site can also affect their abundance and nesting distribution.

3.1. Field methods

All tundra-nesting seabirds and cranes present in the Arctic are migrants, hence the best period to determine their annual abundance is during the summer breeding season by counting the number of occupied nests found over pre-defined areas.

3.1.1. Defining areas to survey

Species included in this chapter generally favour lowlands or gentle slopes. Even if they are seabirds, they can breed quite far inland. As with raptors (see Section 2), you need to define suitable habitats for nesting seabirds and cranes in your study area on 1:50 000 topographic maps to define the areas that will need to be searched. It is recommended to measure the size of the search area on maps if you wish to convert nest counts into density later on. The size of the area to survey will depend of the nesting density of these species in your study area but will typically range from 20 to 100 km2. The relatively even and flat topography of the habitat used by these species will allow more systematic nest searches (e.g. by following parallel transects) than in the case of raptors. Here, we present the general description of preferred nesting habitat of the most common jaegers, gulls and cranes found in the Arctic.

Typical lowlands where seabirds and cranes nest on Bylot Island, NU.

Long-tailed jaeger

This jaeger found in both wetlands and moist upland habitats at low elevation. In wet habitat such as polygon tundra, they will nest on a small mount or dry ridges around low-center polygon but in drier habitats (more common) their nests can be found anywhere on level ground. Their nest bowl is a very shallow depression directly on the ground or in moss and lichen without any nest material.

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Parasitic jaeger

They are found in both wetlands and moist upland habitats at low elevation, sometimes near rivers. Similar to long-tailed jaegers, in wet habitat such as polygon tundra they will nest on a mount or dry ridges around low-center polygon but in drier habitats (more common) their nests can be found on level ground. Their nest consists of an unlined shallow depression in the tundra without nest material. They tend to be more coastal than long-tailed jaegers and will often be more abundant close to a goose or seabird colony.

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Pomarine jaeger

This species prefers wet graminoid tundra in lowlands and avoids upland habitats. Their nest is usually located on a small ridge such as a polygon rim and the nest bowl is a simple, unlined shallow depression in the tundra.

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Glaucous gulls

The gull species uses a wide variety of nesting habitats, from coastal cliffs where they tend to nest colonially to inland tundra where they nest in a more dispersed fashion. Gull nesting in lowland tundra are always found near water, often on small islands or the edge of freshwater ponds and lakes. Nests can also be found on isolated boulders in rivers or deltas. Nests are easy to find as gulls typically build a mound made of mud, mosses and other vegetation, sometimes 30 cm high or more. These structures are often reused in subsequent years and grow in size as nest material is added each year.

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Herring gulls

This species can use a wide variety of nesting habitats similar to glaucous gulls. In the Arctic, nests are often found associated with water on islands in freshwater lakes or rivers. The nest bowl is made out of dead vegetation usually lined with feathers. This species does not reuse the same nest more than one breeding season but the same pair can build another nest nearby in the same territory in subsequent years.

Sabine's gull

This gull species nests in lowlands in association with water, typically wet mossy tundra near freshwater ponds or near the coast, often on small islands. The nest bowl is simply a shallow depression scraped in vegetation, sometime lined with feathers or vegetation such as grasses or sedges. Breeding pairs do not usually reuse the same nest bowl in subsequent years. They nest solitary or in small, loose colonies. Sabine's gulls can also be found nesting in association with other birds such as arctic terns and herring gulls.

Sandhill crane

Although not a seabird, cranes breed in the same type of habitats and use some of the same food resources as tundra-nesting seabirds. In the Arctic, they are mainly found close to or in wetland areas in lowlands. Their nests can be found directly on the ground on dry habitat, including sand dunes. In wetter habitats, cranes built their nest on mounds drier than its surroundings. Vegetation such as grasses and sedges are usually used to line the nest and branches are often added to delimit the nest periphery.


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3.1.2. Systematic search of areas to survey

Nests of tundra-nesting predatory birds will be found by conducting systematic searches in the survey area that you will have previously defined (see Section 3.1.1). However, depending on the resources available to you, priority should be given to areas that can be search both easily and repeatedly over the years. Indeed, it is important to be able to survey the exact same area each year to ensure a good monitoring program that will allow detection of annual variation in abundance or temporal trends. Since gulls are found in slightly different habitats than other species, nest searches for these species will be treated separately below.

3.1.2.1. Jaegers and cranes

Nest searches of these species should be conducted along parallel linear transects spaced out by at least 200 m and no more than 400 m (shorter distance between transects will increase detection rate). These transects should be predefined on maps in order to cover the whole area to be surveyed. Observers should scan regularly the surrounding while walking along the transects. Because individuals tend to reuse the same territory year after year, observers should pay special attention to previously occupied territories.

Sandhill crane on its nest.

Sometimes, incubating birds, which have a typical crouched posture easily recognized by an experienced observer, can be spotted in the distance. However, more commonly territorial defense behaviour of an individual in flight will be the first indication of an occupied breeding territory. All species will give alarm calls when people are at 100 m or more from their nest. Jaegers will circle around the observer (the louder the birds are, the closer the nest is) whereas cranes will feign the broken wing and try to lure the observer away from their nest (jaegers may also feign broken wing when close to their nest). Extensive searches of the area for a nest should be conducted when defence behaviour is observed. All nests found should be positioned with a GPS receiver, the species noted, and, if necessary, their content checked (see Section 4 for more details on checking nest content). If you fail to find the nest of individual exhibiting strong nest defence behaviour, their position should be noted with a GPS receiver and they should be counted as a breeding pair. You should record the type of territorial defense behaviour encountered (e.g. alarm call in flight or on the ground, attacks by the bird, presence of one or two members of the pair) by all birds, even for birds that you found the nest. Similarly, if a nest is found without any bird observed nearby, this should be noted. However, observations of individual showing no sign of territorial defense along the transect should not to be recorded.

*** TIP FOR FINDING NESTS ***

Jaegers and crane nests may be hard to find due to the lack of nest material and egg color that blends well with the surrounding. A trick to find nests is to walk 50 to 100 m away from the site where an individual gives alarm calls and to seat quietly at a good vantage point. After a few minutes, birds should return to their nest and take an incubating position. Once you have spotted the exact location of the incubating bird, start walking toward the bird. Do not remove your eyes from the site even if the bird takes off. This will allow you to concentrate your nest search over a very small area once you reach the site.

These species have precocial young which mean that chicks leave the nest with their parents 1 or 2 days after hatch and sometimes even if the other egg is just starting to hatch. Hence, nests found will be mostly at the egg stage. Young chicks sometimes stay near the nest (especially jaegers) so it may sometimes be possible to find a newly-hatched

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Young parasitic jaeger .

brood. These observations should be noted and the position of such broods recorded with a GPS receiver. Attacks by the parents, or parents feeding the brood can help to locate them.

Transects will need to be walked only once but should be timed during a period when most birds are nesting (see Section 3.2). However, if nest defence behaviour were observed but no nest was found, the site could be revisited a few days later and searched again to confirm presence of a nest, especially if the same behaviours are observed.

3.1.2.2. Gulls

Since gull nesting inlands are closely associated with freshwater ponds and lakes, searches for these species should be concentrated in those habitats. Nest searches should be conducted in these areas by walking along the shores of lakes or through areas dotted with ponds. Gull nests are typically located in small islands in ponds/lakes or along the shore, often on peninsula advancing in the water. Thus, all islands should be thoroughly scanned with binoculars for the presence of nests.

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Lake on Bylot Island, NU showing three islands with a glaucous gull nest.

As for other avian predators, gulls will start to fly and make alarm call around observers approaching their nest (100 m or more from the nest). Gulls may sometimes begin flying over you when you are quite far from their nest and become more aggressive as you get closer. Extensive searches of the area should be conducted when such nest defence behaviour is observed. For some species (e.g. glaucous gull), nests are easy to find at a distance as they form a mound protruding above the surrounding landscape. When parents have started incubation, they can be easily spotted on their nest mound from a long distance, before they leave it to attack the approaching observer. Presence of fresh feathers from prey remains or fresh regurgitation pellets around the nest, new nest material or scraping in the nest are also indications of an occupied gull nest. All nests found should be positioned with a GPS receiver, the species noted and, if necessary, their content checked (see Section 4 for more details on checking nest content). Presence of individuals, their number and their behaviour when the observer is near the nest (e.g. alarm call in flight or on the ground, attacks by the bird) should be noted. If a nest cannot be reached because it is located on an island, record the closest position possible and try to assess the content of the nest from the behaviour of the parents or with the use of binoculars or a spotting scope. You should also record the presence of individuals showing signs of territorial behaviour and the GPS coordinate of the observation even if a nest is not found.

Gull nesting habitat should be visited during a period when most birds are nesting (see Section 3.2). However, if nest defence behaviour were observed but no nest was found, the site could be revisited a week or two later and searched again to confirm presence of a nest, especially if the same behaviours are observed.

3.1.2.3. Other tundra-nesting bird species

During systematic searches for jaegers, gulls and cranes, nests of other tundra birds such as passerines, ducks or geese will likely be found. The identity of the species, the location of their nests and their content can also be recorded if you wish to keep biodiversity records at your field site. Be careful to avoid disturbing these nesting birds to minimize the risk of having nests destroyed by predators when the incubating bird is absent. If a duck or goose is flushed from its nest, the eggs should be covered with down from the nest.

3.1.3. Recording GPS tracks

It is important to have a log of all transects or sectors of your study area that have been searched for nests every year. Nowadays, all research personnel carry GPS receivers with them while working in the field; hence, the best way is to record the tracks of their daily route by programming the GPS to record automatically and continuously during the searches. If the GPS memory does not allow such daily recordings, then you should ask your staff to record points periodically during the day. These tracks should be saved and downloaded daily into a computer for safe keeping (see Figure 3.1 for an example). This will allow you to adjust your search area if some transects could not be visited in some years.

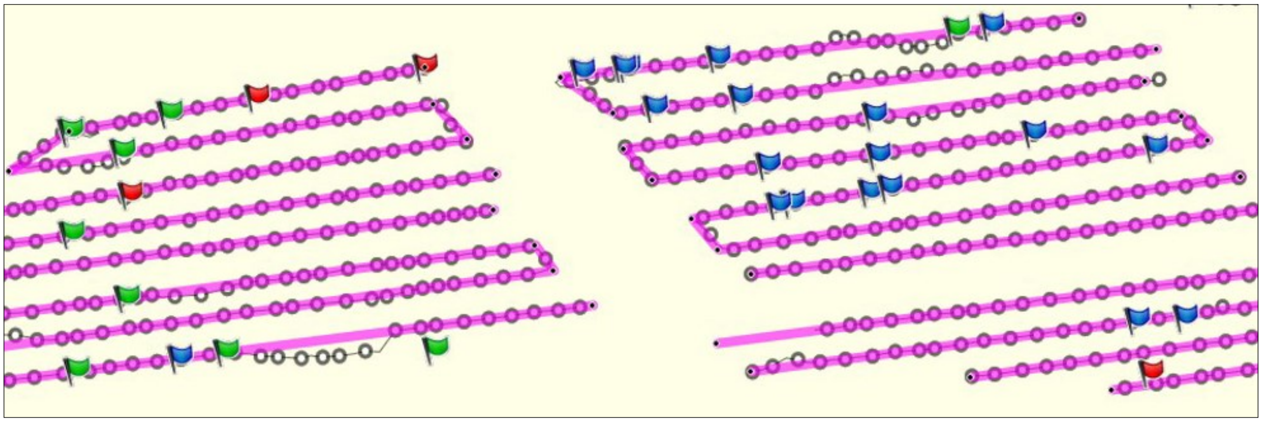


Figure 3.1. Example of seabird survey tracks recorded during a field season. The pink lines represent the theoretical location of each transect while the dotted line shows the tracks recorded by the GPS. Each flag represents a seabird observation (different color for different species).

3.1.4. Nests found opportunistically

Seabird or crane nests may sometimes be found outside the area where systematic searches are conducted. For instance, nests can be found opportunistically during other activities in the field or by colleagues studying other species. These nests should also be positioned with a GPS receiver and the species identified. These records should be added to your database but with the mention that they were found accidentally rather than during a systematic search. Over the years, if opportunistic nests are found repeatedly within the same area, you could extend your annual search area to include this new sector, if possible.

3.2. Time period

The best time to conduct tundra seabird and crane surveys is during the nesting period when pairs occupy and defend territories. These species will start breeding only when nesting sites become snow free and thus phenology of nesting will be influenced by the timing of snow disappearance in lowlands, which often become snow-free later than slopes. However, for those species nesting on mounds or ridges around polygons, these sites may become snow-free earlier than the surrounding landscape.

It is important to know the breeding phenology of the species that can be found in your study area to plan your surveys accordingly. Since these species are not known to abandon their nest after a simple nest visit, surveys can be scheduled between the end of laying and late incubation. If surveys are done during brood-rearing, jaeger and crane nests may be hard to locate because young leave the nest soon after hatch.

Table 3.1 presents the breeding phenology of several species to help you plan your surveys. Be aware that these dates may vary depending on annual variation in weather conditions, elevation and latitude of your field site.

Table 3.1. Approximate range of arrival, laying and hatching dates for the most common tundra-nesting seabirds and cranes found in the Arctic (from Richards & Gaston 2018 and Birds of North America online [birdsna.org]).

Species	Arrival date	Laying date	Hatching date
Long-tailed jaeger	late May to early June	early to late June	late June to late July
Parasitic jaeger	mid-May to early June	late May to mid-June	late June to mid-July
Pomarine jaeger	late May to early June	early to late June	early to late July
Glaucous gull	late April to early May	late May to late June	late June to early August
Herring gull	late April to late May	early to late June	early to late July
Sabine's gull	late May to mid-June	early to late June	late June to mid-July
Sandhill crane	late May to early June	early to late June	late June to mid-July

Higher numbers of nests of some species will probably be discovered during years of high small mammal abundance (especially lemmings) because more pairs will breed in those years. This applies to specialist species, such as the pomarine and long-tailed jaegers, which may not nest at all when small mammal abundance is very low, contrary to more generalist species like gulls, parasitic jaegers and cranes that will generally breed every year regardless of small mammal abundance. However, during years of low small mammal abundance, specialists can sometimes be seen early in the season when they return to their breeding territory but they will quickly leave their territory and move elsewhere if they cannot find enough food to sustain a breeding effort.

3.3. Material required

- GPS receiver
- 1:50 000 topographic map of study area
- field book
- binoculars and/or spotting scope
- list of permanent glaucous gull nesting sites of your study area (optional; see Section 3.4.1)

Long-tailed jaeger on its nest.

3.4. Data management

The key to a successful long term monitoring program is to keep good data records. Therefore, it is important to enter all field data in predefined datasheets or computer files as soon as possible when you are back to camp after a day in the field. Here are one elements that will facilitate the monitoring of nesting sites of some species.

3.4.1. Permanent nests ID for long term monitoring

Some species like the glaucous gull built nest structures that can be occupied for more than one breeding season. Hence, we recommend that you identify each nesting site of those species with a permanent ID. We suggest a notation using the 4-letter bird species codes used by the US Bird Banding Laboratory to identify species, followed by sequential numbers (ex. GLGU_024).

Your nesting site ID log should be updated on a yearly basis to make sure that your field crew has the most recent information of known sites in your study area. It should contain the following information:

- Nesting site unique ID
- GPS coordinates of the nest
- Comments on the coordinates (e.g. exact nest location, estimated location based on nearest accessible point, site where territorial behavior was observed)
- Date that the site was last visited
- Nest status at last visit (intact, destroyed or unknown)
- Nest occupancy at last visit (occupied, vacant or unknown)
- Nest environment (island, edge of pond/lake, etc.)
- Nest accessibility (by foot, with waders, by boat, not accessible)

To minimize risk of errors, the same site ID should never be reused to identify a different nesting site. For example, if a nesting site is found destroyed, its ID should not be reused for a newly discovered site. The only exception to that should be if a new nest is found very close by to a previously destroyed nest but the ID should take that fact into account. For example, if GLGU_045 was destroyed in 2017 but birds rebuilt another nest structure a few meters away in 2018 then this new nest can be identified as GLGU_045a. Keep in mind that a destroyed nest can always be rebuild in the future, even if there is new a nest close by.

4. MONITORING AVIAN PREDATOR REPRODUCTIVE SUCCESS

Annual reproductive success is a key determinant of population growth. The process starts with the production of eggs and ends (from a northern perspective) with the fledging of young and their southward movement during migration. The reproductive success of a bird depends on a multitude of factors including weather, habitat, food resources, competition and predation. In many areas, predation is a leading cause of nesting failure, and thus nesting success is strongly influenced by predator-prey interactions. When monitoring reproductive success of avian predators, the following parameters are of interest:

- Laying date: date that the first egg is laid in a nest
- Hatching date: date at which the first egg hatched in a nest
- Fledging date: date at which the first chick fledged
- Clutch size: total number of eggs laid in a nest during a single laying bout
- Nesting success: proportion of nests where at least one chick hatched
- Hatching success: proportion of eggs that produced chicks at hatch in nest where at least one egg hatched
- Fledging success: proportion of hatched chicks that produced fledglings * (sometimes defined as proportion of eggs that produced fledglings)

Note: these are the most common definitions used for the previous reproductive parameters; however, definition may vary in some studies.

*** FLEDGED YOUNG ***

A chick is considered to have fledged if…

1) It has left the nest;
2) It is fully feathered;
3) It is capable of flight.

Note that a fledged young may still be dependent on its parents for food.

(from Hardey et al 2013)

Fledged young long-tailed jaeger (dark morph).

We provide below the field and analytical methods that should be used when monitoring reproductive success of avian predators.

4.1. Field methods

4.1.1. First time a nest is found

Whenever an active nest (i.e. with eggs or chicks) is found during your survey (see Sections 2 and 3), the following steps should be taken:

1) Record the nest position with a GPS receiver and give it a unique number. This could be the permanent ID of the nesting site (see Sections 2.4.2 and 3.4.1) or, for species that do not reuse the same nesting site in subsequent years, use the 4-letter bird species codes used by the US Bird Banding Laboratory to identify species, followed by sequential numbers (see Table 2.2). A complete list of the species codes can be found at the Institute for Bird Populations website (www.birdpop.org/pages/birdSpeciesCodes.php). The year should always be associated with the nest number to distinguish nests with the same number (e.g. at the same nesting site) in different years.

2) With the precision of GPS nowadays, it should not be necessary to add a marker in the field to find nests during subsequent visits. However, use of marker may sometimes be useful for nests of species that are very secretive such as jaegers. If needed, an inconspicuous marker (e.g. bird feather or small wooden stake) could be put 3 to 5 meters from the nest in a specific cardinal direction (north, south, east or west), preferably the same for all nests to minimize confusion during revisits. The marker should be put on an elevated place, with its larger side towards the direction you would normally came from. However, be aware that there is a risk that markers may increase the chance of detecting the nest by some predators like foxes.

3) If the nest is found at the egg stage, write a different number (1, 2, 3, …) on both tips of each egg with a permanent marker. Number the eggs from the dirtiest one (#1) to the cleanest one, if possible. The assumption is that the dirtiest one will have been laid first. If several nests are close to each other, mark the nest number on the large tip of each egg as well to minimize confusion during future visits.

Glaucous gull eggs from a monitored nest.

4) If a nest is found at the egg stage but after the end of egg-laying, its laying date can be inferred by floating eggs to determine its incubation stage (see Section 4.1.3 for details of this method).

5) If the nest already contains chicks at the first visit, take notes on their development stage (e.g. size, locomotor ability, eyes opened or not, amount of down/feather and color, etc.) in order to be able to determine the approximate age of the young (also see Section 4.1.4). If young differ in stage of development, record information for the least and the most advanced chicks. Take photos whenever possible as a photo is worth a thousand words!

6) In a field book, the following information should be recorded:

- Number of eggs or young present in the nest
- Nest stage *
- Signs of predation *; if some eggs are broken (inside or outside the nest) or some young are dead, this should be noted
- Egg stage if the eggs are floated
- Development stage of chicks if they are present
- All other relevant information, like the presence of an egg of a different color, presence of a bird on the nest (or nearby), behavior of parents during the nest visit, and chicks found outside the nest (how far?) should also be recorded.

During visits, minimize time spent and disturbance at the nest because it could result in nest destruction by predators or abandonment by parents.

Recently hatched young peregrine falcon with hatching eggs.

*** USING DATA CODES DURING NEST VISITS ***

To reduce the amount of time spent at a nest recording notes during a visit, we recommend that you develop standard codes for information that will be regularly taken by field workers. Codes are also useful to speed up data entry into a database and for subsequent data analyses. Here is an example of nest stage and predation codes that could be used in the field:

Nest stage codes

0 – Unknown

1 – Nest active without eggs (new nest material, prey remains, scratching)

2 – Nest active with warm eggs (incubation has begun)

3 – At least one egg starting to hatch (strong knocks or small crack on at least one egg)

4 – At least one egg at the end of hatching (hole-piped on at least one egg)

5 – At least one young in the nest (may still contain eggs) or nearby (for precocial young)

6 – At least one young has fledged (seen near the nest) but live young still present in the nest

7 – Empty nest, young fledged with success (some eggs or dead chicks may remain)

8 – Nest completely destroyed (predation, natural hazard like landslide) or abandoned (cold eggs found after the beginning of incubation, all young dead without evidence of any fledging)

9 – Other (provide details)

Nest predation codes

0 – No sign of predation since last visit

1 – Some missing or broken eggs, or missing and dead chicks (without evidence of any fledging) since the last visit

2 – Complete predation: all eggs broken or missing or all young missing or dead (without evidence of any fledging) since last visit

4.1.2 Nest revisits

Ideally, nests should be revisited periodically (e.g. during the laying period, beginning of incubation, hatching period, mid chick rearing period and near fledging) to check their content. Every time a nest is revisited, **repeat step #6 mentioned in the previous section** (Section 4.1.1). However, pay special attention to the following points:

- If eggs are still present, count separately the number of eggs already marked with a number (i.e. present at a previous visit) and those without a number (i.e. new eggs laid since the last visit). Carefully note the number written on each egg present in the nest as this will allow you to identify those that could have gone missing since the last visit (e.g. due to predation). Write a number on the new eggs, continuing the sequence of numbers for that nest. This information will help determine the total clutch size of the nest.

- Carefully note all signs of predation, including eggs or young missing since the last visit (without evidence of young fledging) in addition to broken eggs or dead young at the nest.
- Be careful to distinguish a nest where all eggs or chicks have been predated from one where chicks hatched successfully and have left the nest. When a nest at the egg stage is found empty during a revisit and you are unsure if this is due to predation or an early fledging, try to look for the remains of predated eggs in or around the nest. Large fragment of hard shell with simply a hole in them are indicative of predation because those are not found in nests where young hatched successfully (chicks trample the hard shells into fine pieces or shells are removed by the parents after hatch).
- Parental behavior during the nest visit should be noted (e.g. nest defense behavior like alarm calls or attacks and their intensity), especially if a previously-active nest is found empty (this may help to determine fledging success, see below).

Since females of most avian predators lay their eggs at intervals of about 2 days (occasionally longer) and start to incubate immediately after the first one is laid, eggs do not hatch all at the same time (see Table 4.1). Also, in some species, the hatching interval between eggs can be less than the laying interval because eggs laid later in the clutch can benefit from a more constant nest temperature right from the start of their incubation. Thus, it is possible that the hatching date of the first egg (which defines the hatch date of the nest) will be missed. This is why it is important, whenever nests contain both eggs and chicks during a visit, to note the developmental stage of each chick to be able to approximate the hatching date (see Section 4.4).

Snowy owl nest showing hatched young ranging from 1 to 9 days old and one unhatched egg.

Table 4.1. Typical clutch size, egg laying interval and incubation timing and length for the most common avian predators found in the Arctic (from Richards & Gaston 2018 and Birds of North America online [birdsna.org]).

Species	Clutch size	Laying interval (days)	Onset of incubation	Incubation period (days)
Common raven	3 to 7	2 d between 1st and 2nd; 1 d afterwards	begins with 1st or 2nd egg	20 to 25
Golden eagle	1 to 3	3 to 5	begins with 1st egg	41 to 45
Gyrfalcon	3 to 4	2 to 3	begins with last egg	34 to 36
Peregrine falcon	3 to 4	2	begins with 1st or 2nd egg	33 to 36
Rough-legged hawk	3 to 5	2 to 3	begins with 1st egg	31 to 33
Short-eared owl	1 to 13	1 to 2	begins with 1st egg	26 to 37
Snowy owl	4 to 9	2	begins with 1st egg	32 to 33
Glaucous gull	1 to 3	2	begins with 1st egg	27 to 28
Herring gull	3	2	begins with 1st egg	28 to 30
Sabine's gull	2 to 3	1	begins with 1st egg	20 to 26
Long-tailed jaeger	1 to 2	2	begins with 1st egg	23 to 26
Parasitic jaeger	1 to 2	2	begins with 1st egg	25 to 27
Pomarine jaeger	1 to 2	2	begins with 1st egg	25 to 27
Sandhill crane	1 to 3	2	begins with 1st egg	29 to 32

It is especially difficult to ascertain fledging success in species where chicks leave the nest relatively early after hatching and hide in the vegetation, sometimes up to a few hundred meters from the nest. Depending on the species, this can happen soon after hatch or later during growth (Table 4.2). For example, young owls gradually leave the nest starting with the oldest one around 2-3 weeks of age. When a nest that had previously young is empty (or some young are missing, especially in owls), search around the nest for hiding chicks. Intense defense behavior of parents (e.g. alarm call, attacks) around an empty nest is a sign that the young fledged successfully but are hiding somewhere. However, be careful because parents may still exhibit defense behavior around a nest recently predated, although at a lower intensity. Even if you fail to find the young,

Eleven-day old young long-tailed jaeger hidden away from its nest.

you can record a nest as successfully fledge based on intense defense behavior by the parents but add remarks.

Note that in broods of some raptors like short-eared and snowy owls, cannibalism among siblings is possible, especially if food is scarce. Hence, small owlets that hatched last can disappear from the nest early during the brood-rearing period due to this behavior.

Table 4.2. Age at which chicks leave the nest after hatch and fledge for the most common raptor and tundra nesting seabird species found in the Arctic (from Richards & Gaston 2018, Birds of North America online [birdsna.org] and Hardey et al. 2013).

Species	Age of chicks when leaving nest (days)	Age at fledging (days)
Common raven	*Stay in nest until fledging*	28 to 50
Golden eagle	*Stay in nest until fledging*	45 to 81
Gyrfalcon	*Stay in nest until fledging*	45 to 50
Peregrine falcon	*Stay in nest until fledging*	35 to 42
Rough-legged hawk	*Stay in nest until fledging*	35 to 40
Short-eared owl	12 to 18; move away until fledging	27 to 35
Snowy owl	14 to 28; move away until fledging	45 to 50
Glaucous gull	*Stay at the nest or close to it until fledging*	42 to 50
Herring gull	2-3; stay close to nest until fledging	35 to 50
Sabine's gull	1 to 2; stay close to nest for 4-6 days then move away until fledging	~ 20
Long-tailed jaeger	1 to 2; move away from nest until fledging	25 to 34
Parasitic jaeger	1 to 2 move away from the nest until fledging	26 to 38
Pomarine jaeger	2 to 4; move away from the nest until fledging	~32
Sandhill crane	1; stay close to nest for 10-14 days then move away until fledging	49 to 70

* MONITORING NESTS USING AUTOMATED CAMERA *

Automated camera installed at a rough-legged hawk nest.

Depending on resources available, automated cameras can be used to monitor activities at nests using a time-lapse option. This can be especially useful at raptors nests difficult to reach. The camera can be installed above the nest to get a better view of its content when the adults are away. Hatching date as well as the growth of nestlings (see Section 4.1.4) can then be monitored through photos or videos taken during the nesting period. This will also minimize the disturbance made by regular nest visits.

4.1.3. Determining nest incubation stage with the egg flotation method

4.1.3.1 Description of the egg flotation method

In wild birds, it is impossible to always time our first visit to a nest during the laying period when it is easy to estimate laying date based on the number of eggs already present in the nest and egg-laying interval (see Table 4.1). When nests are found after the end of egg-laying, we need to know the stage of incubation in order to estimate laying date. Researchers have developed a variety of methods to determine the incubation stage, the most common one being the flotation method (or egg immersion technique). By floating each egg in water, we can approximate the incubation stage of the nest based on egg position and angle in the water. Freshly laid eggs will sink to the bottom and lay flat but as embryos developed during incubation, air will accumulate inside the air chamber located at the blunt end of the egg and make them buoyant. Eggs will first take a vertical position in water and eventually move up in the water column until they breach the surface as they get closer to the hatching date, as shown in Figure 4.1.

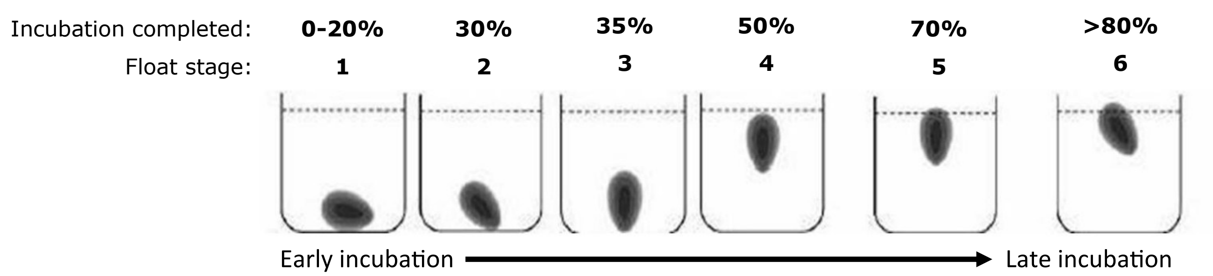


Figure 4.1. Change in the flotation pattern of a typical egg in relation to its incubation stage (adapted from Liebezeit et al. 2007).

The number of days an egg will spent at a certain float stage will vary among species, and thus the conversion of proportion of incubation complete into actual days of incubation need to be calibrated for each species *. However, even without the appropriate conversion chart for a given species, the general flotation pattern of Figure 4.1 can be useful in determining the incubation stage of nests and help you plan future nest visits. You have to keep in mind the limited precision of the method, as the error associated with the estimation of incubation stage may be the order of ± 3-4 days.

4.1.3.1 Using the egg flotation method in the field

Here is a step-by-step description of how to float eggs in the field:

1) Gently place 1 egg in a lukewarm water-filled transparent plastic container (you should carry a thermos with warm water in the field; cold water should be avoided, especially for smaller eggs). If you don't have a transparent plastic container available, a clean plastic bag (Ziploc) can be used. Float all eggs when clutch size is

≤3 eggs and at least 3 eggs when the clutch is bigger. Whenever the egg color allows it, the cleanest and dirtiest eggs should be floated as we assume that these were laid first and last, respectively.

- Eggs should not be floated for more than a few seconds, especially if lukewarm water is not available, to avoid decreasing the internal temperature of the egg.
- Inspect each egg before putting them in water. DO NOT FLOAT eggs with pips or cracks to prevent water from infiltrating the shell. If an egg is at that stage, the chick will hatched fairly soon and thus flotation is not required to determine incubation stage.

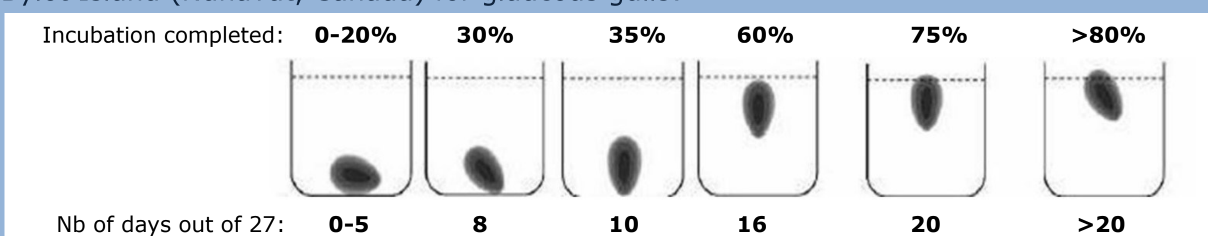
2) Match the positioning of each egg with one of the float stage (1 to 6) on the chart (see Figure 4.1). If the egg stage falls between two categories, a midway category can be recorded (ex: stages 2.5 or 4.5).

3) Dry the eggs and replace them in nest in the same position you found them.

*** DEVELOPING A SPECIES-SPECIFIC FLOTATION CHART ***

In order to convert the incubation stage estimated by egg flotation (see Figure 4.1) into the actual number of days elapsed since the beginning of incubation, a certain number of nests must be monitored intensively. These nests must have been found during egg-laying in order to determine when incubation started (see Table 4.1) and the eggs need to be floated several times throughout the incubation at regular intervals. This task is beyond the scope of this manual but numerous papers have been published on the subject and can help you if you need to develop a float chart for a given species. We recommend consulting the following papers: Westerskov (1950), Van Paassen et al. (1984), Walter & Rusch (1997), Liebezeit et al. (2007) and Rizzolo & Schmutz (2007).

Here is an example of flotation chart that we developed and use at our study area on Bylot Island (Nunavut, Canada) for glaucous gulls:



4.1.4. Determining the age of chicks

When a nest is found after all eggs have hatched or you missed the hatching period during your nest monitoring, the only way to estimate the laying and hatching dates is to determine the approximate age of nestlings present in the nest. The age of the oldest one is then used to back-calculate the hatching date, and then the laying date.

For some species, researchers have developed charts relating age of chicks to their body mass or other body measurements such as the length of a flight or tail feather. However, these techniques require handling birds and can only be done by trained fieldworkers. The simplest method to age chicks for most people is to compare the external appearance of young (plumage development, eyes opened or not, etc.) in monitored nests with a published photographic guide. Nonetheless, it is important to remember that description of plumage development can be subjective and that growth rate of young can vary in relation to food availability, competition among chicks of the same brood, sex of the bird, weather conditions and geographic location.

Photographic guides* to age nestlings have been developed for several raptor species. Although most of them were made for species that are not found in the Arctic, using the guide of species closely related to arctic ones can still be useful to determine the approximate age of young when visiting a nest during the brood-rearing period. Your description of the external appearance of young (or even better, your photos) should be compared to those photographic guides to determine approximate age of nestlings.

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Rough-legged hawk brood about 22 days old.

*** PHOTOGRAPHIC GUIDES TO AGING RAPTOR CHICKS ***

Here are a few photographic guides available that can be used to determine the approximate age of raptor chicks. Most of these guides can be easily found on the web. Each picture is accompanied by a physical description of the bird that points to important change in their external appearance at each stage of their development.

Raptors found nesting in the Arctic: see Hoechlin (1976), Anderson et al. (2017) and The Canadian Peregrine Foundation (2019). The online resource Birds of North America [birdsna.org] developed by The Cornell Lab of Ornithology also has development data in each specific species account. Though not available to all without a subscription, it can usually be accessed from a university or college library.

Raptors found nesting elsewhere: see Moritsch (1983a, 1983b, 1985), Boal (1994), Gossett & Makela (2005) and Madden et al. (2018).

4.2. Precautions to be taken when visiting avian predator nesting sites

4.2.1. Seabird nests on islands

Visiting seabird nests located on islands entails some risks and the following points should be considered before attempting to visit these nests.

- A small inflatable boat may be necessary to access nests located on island. Always bring a long pole with you when you paddle to an island nest. Drive the pole in the ground when reaching the island and attach your boat to it. This will prevent it of being blown away, and of you being stranded!
- If you wade to an island nest through shallow water, also bring a long pole with you. The bottom of ponds can be muddy and the water often becomes murky when walking, so make sure to test the water depth in front of you with a pole when progressing toward these nests.
- When an incubating bird leaves an island nest, inspection of its content from the shoreline with binoculars or a spotting scope is sometimes enough.
- Birds often lay their eggs before the ice is completely melted on ponds. At this period of the year, some nests may be hard or even impossible to access safely. Avoid taking any undue risk (e.g. walking on thin ice) since you may have other opportunities to visit these nests later.

4.2.2. Raptor nests

Inspection of raptor nests should be done with caution because raptors often attack people visiting their nests and their claws can cause severe injuries. Whenever possible, we recommend inspecting raptor nests in teams of two where one person can stand alert of bird attacks while the other person can manipulate the nest content. For aggressive raptors like snowy owls or eagles, it is recommended to wear a hard hat and to bring a long pole. Drive the pole in the ground close to the nest. This will prevent the bird from hitting you if it dives on you when you are bent over the nest. Nests that require the use of climbing gear to access them should be checked by experienced and properly equipped climbers only.


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Young peregrine falcons about 19 days old.

The following points should also be considered when visiting raptor nests (based on Call 1978, Bird & Bildstein 2007 and Hardey et al. 2013):

- Raptor nests should only be approached as closely as necessary to obtain the required information during a visit. If a vantage point allows a good visual check of the nest content with binoculars or a spotting scope, then there is no need to get closer.
- If a visit directly to the nest is necessary, minimise disturbance of vegetation around the nesting site to avoid helping predators discover the nest. Care should also be taken not to destroy any feature around the nest that offers protection against harsh weather. Be careful when walking above a nest to avoid dislodging material that could fall on the nest and break eggs or injure young birds.
- Adult birds should not be flushed from the nest during rain or snow storms and under cold and windy conditions. If the adults do not return after a few minutes, it may cause the death of the embryos in the eggs or young chicks due to exposure.
- Make sure the adults (and young, if present) are aware of your presence when you approach the nest by being visible and making sound (snapping small twigs, coughing, muffled talking). Do not startle incubating or brooding adults as they may knock young birds/eggs from the nest, trample young or puncture eggs due to their sudden exit.
- Be careful in approaching nests where young birds are getting near fledging age. If they fledge prematurely, they may incur injuries, or become lost and/or abandoned by their parents.

4.3. Material required

- GPS receiver
- field book
- small permanent marker
- binoculars or spotting scope
- camera
- protection equipment for raptor nests (hard hat, long pole)
- inflatable boat with a paddle and life vest, or waders, and a long pole for island nests

For flotation method (optional)

- 1-L thermos with lukewarm water
- 1-L clear plastic container ~20 cm high and ~10 cm in diameter

4.4. Estimating laying and hatching dates by back-calculating

When the first egg is laid in a nest (egg-laying date) and when the first chick hatch (hatching date) are important reproductive parameters that can be derived from nest visit data. These data are useful to study the breeding phenology of various species or to plan future nest visits to assess the nesting, hatching or fledging success. Laying and hatching dates can be calculated in various ways, depending of the field data available. We present various calculation methods below, from the most to the least precise method.

Finding a nest during the laying period provides the most accurate method to derive egg-laying date and is the preferred method (we can confirm that a nest was still in the laying period when found if the number of eggs has increased at the next visit). When a nest is found during the laying period, it is possible to back-calculate when the first egg was laid based on the number of eggs in the nest when found and the interval between laying of successive eggs (see Table 4.1), which is fairly constant for a given species. When the laying date is known, the hatching date can be estimated by adding the mean incubation length to the laying date, which shows little variation within species (see Table 4.1). However, if incubation does not start with laying of the first egg, then the interval between laying of the first egg and beginning of incubation must be added to estimate hatching date. Here are some examples for nests **found during laying**:

Snowy owl

Laying date = visit date – ([number of eggs found in the nest during the visit × 2] – 1)

Hatching date = laying date + 32 days of incubation

Long-tailed jaeger

Laying date = visit date – 1

Hatching date = laying date + 24 days of incubation

Glaucous gull

Laying date = visit date – ([number of eggs found in the nest during the visit × 2] – 1)

Hatching date = laying date + 27 days of incubation

Note: in the previous calculations, we assume that the nest was found mid-way between the laying of two consecutive eggs; considering that eggs are laid every other day, the error in estimating laying date is thus ±1 day.

Glaucous gull pair at their nest.

One-day old long-tailed jaeger with unhatched egg.

If a nest is **found after laying has ended** but is subsequently visited during the hatching period (i.e. it contains both young and unhatched eggs), then its hatching date can be estimated by applying the same reasoning than for the laying date above (and with roughly the same level of precision). Similarly, laying date can be obtained by subtracting the mean incubation length to the hatching date. Here are some examples:

Snowy owl

Hatching date = visit date – [number of young in the nest during the visit × 2] – 1)

Laying date = hatching date – 32 days of incubation

Long-tailed jaeger

Hatching date = visit date – 1

Laying date = hatching date – 24 days of incubation

Glaucous gull (for this species the first and second-laid eggs often hatch the same day)

Hatching date = visit date – (number of young in the nest during the visit – 1)

Laying date = hatching date – 27 days of incubation

If a nest was **not visited during either egg-laying or hatching** but its eggs were floated and an incubation chart is available (see Section 4.1.3), then the number of days of incubation completed can be estimated. Laying and hatching dates can then be calculated as follows for species where incubation starts with the first egg laid:

Laying date = visit date – number of incubation days completed

Hatching date = laying date + incubation length in days

Note: in this case, the error on estimated laying and hatching dates may be around ± 3-4 days.

Finally, if a nest does not meet any of the criteria for the previous methods (i.e. not visited during laying or hatching and eggs were not floated), its phenology could still be estimated **if chicks were aged** at the first visit with young in the nest (see Section 4.1.4). Using estimated age of the oldest chick in a nest, laying and hatching dates can be estimated as follow:

Hatching date = visit date – age of oldest chick in days

Laying date = hatching date – incubation length in days

Note: error on these dates is unknown but probably at least as large as with the flotation method.

The hazard of monitoring long-tailed jaeger nest.

5. Monitoring avian predator food habits

Determining the diet of animals is often important in ecological studies. For instance, quantifying annual or seasonal variations of prey items in the diet can help to better understand predator-prey interactions or interaction among predatory species (e.g. inter-specific competition). In this section, we present in details the most common method used to determine the diet of avian predators (regurgitated pellets and prey remains) and a brief overview of other methods also commonly used (direct observation, automated cameras and stable isotopes). These methods are most easily applied at or near the nest of breeding pairs and thus require that location of the nests be known. For a full review of existing methods, see review by Barrett et al. (2007) and Marti et al. (2007).

5.1. Regurgitated pellets and prey remains

This method is based on the collection of regurgitated pellets and prey remains found either at the nest of predators or at perching or resting sites regularly used in their territory. Avian predators are known to swallow most of their prey whole, except very large ones. The prey parts that cannot be digested (or partly digested) are compacted into a small ball, called pellet, that is then regurgitated by the bird on a daily basis. These pellets can contain bones, hairs, feathers, teeth, claws, beaks, shell fragments, fish scales and otoliths or parts of invertebrate exoskeletons, among other things. Based on these prey remains, the bird diet can be reconstructed. However, these pellets do not include prey items that are highly digestible or leave few remains, such as many invertebrates. Furthermore, pellet analysis is not as reliable for all species. For instance, falcons are known to digest bones to a greater extent compared to other raptors and they often dismember their prey instead of swallowing them whole. Hence, some prey parts may rarely be present in their pellets or in a more advanced state of degradation, which could render the identification of prey remains more difficult. In many species, large prey that cannot be swallowed whole are often brought to the nest or perching sites to be dismembered. Thus, large and intact prey remains found at these sites may also provide information on the diet. Nonetheless, depending on the goal of your study, a more complete picture of the diet of avian predators may be obtained by combining pellet analysis with alternative methods (see Section 5.2).

Among avian predators nesting in the Arctic, all raptors, ravens and tundra seabirds produce pellets but not cranes.

5.1.1. Methods to collect samples in the field

The collection of regurgitated pellets and prey remains should occur during nest visits to monitor reproductive success (see Section 4) in order to minimize disturbance. Nests can be visited several times during a season at regular intervals (e.g. every 7 to 14 days) but nests located in remote areas may be visited less frequently. Nest visits can also be

Snowy owl nest surrounded by regurgitated pellets and dead lemmings.

planned strategically to coincide with particular events like the hatching period to examine any switch in their diet that often occur between different phases of the nesting cycle such as between incubation and chick feeding. Because individual pairs on a nesting territory are the sampling unit here (and not individual pellets), it is recommended to monitor as many territory as possible to obtain adequate sample size.

Pellets and prey remains are normally collected over a 5 to 10-m radius around the nest. You should systematically collect all pellets and prey remains found at each visit in order to associate each sample to a specific time period. For raptor nests located on inaccessible cliffs, searching an area under the nest, below the cliff where pellets may fall, can be useful. Raptors and jaegers use specific perching sites to rest or scan the horizon for prey in their territory where they often regurgitate pellets. If you identify such sites, it is fine to collect pellets there. Although these sites may be at some distance from the nest (e.g. 100 m or more), you should ensure that you are still in the territory of the nesting pair. This is important to be sure that pellets collected at such perching sites can be associated with a specific nesting pair. You should not collect pellets at perching sites that you cannot associate to a specific breeding pair or bird species of interest.

Some gull nests may be located on islands in the middle of ponds too deep to wade through. When available, use a small inflatable boat to reach those islands. If this is not possible, or if nesting islands of gulls are too small (i.e. limited to the size of the nest), you should search the shoreline of the pond closest to the nest. Such sites are frequently used by gulls to regurgitate pellets or abandon prey remains.

Only fresh pellets should be collected (i.e. those produced since your last visit of the site). To ensure that, at your first visit to a nesting (or perching) site, thoroughly search the surrounding area for old pellets and prey remains and removed them (i.e. collect and discard them far away). This will allow you to associate the pellets and prey remains collected during subsequent visit to specific phases of the nesting cycle. An exception to that may be if you intensively follow some nests from beginning of laying until ate chick-rearing. If such nests are again occupied and monitored the following year, you can collect the old pellets and prey remains at your first visit early in the season rather than discarding them. This will allow you to determine the diet after your last visit the previous year.

Example of pellets, from left to right: snowy owl, glaucous gull, rough-legged hawk and long-tailed jaeger. Average length of pellets for snowy owls is 7.3 cm (range: 4.7-11.9; n=31), for rough-legged hawks is 4.7 cm (range: 2.2-9.7; n=262) and for long-tailed jaegers is 3.4 cm (range: 1.2-8.4; n=303).

Large prey remains can be counted and identified on site at each visit rather than being collected. The state of the prey remains (i.e. whole, partially eaten or carcass) should be noted. Once counted, all prey remains are removed and discarded far away from the site to avoid counting them again during subsequent visits. One exception is when whole, fresh prey were recently delivered to the nest by the parent to be eaten by the chick or its partner. These prey should be left at the nest to avoid interfering with feeding of birds at the nest. They should be counted and identified but take note that they were left on site. If some prey remains cannot be identified, collect them in the same way than pellets.

For pellets, the goal is to collect as many as possible during each visit to the nest (ideally between 10 and 20). If there are more pellets than what you could handle, collect a random sample of all pellets present and remove and discard the remaining ones to avoid counting them again at the next visit. Pellets are collected in a plastic bag with the following information:

- Nest number or perching site
- Species
- Date of visit (including year)
- Number of pellets collected

Examples of a fresh pellet (left) vs. paler, older ones (middle and right) showing protruding bones.

When pellets are broken, try to estimate the number of pellets as accurately as possible (e.g. a pellet broken into 3 obvious pieces would count as 1 pellet). Be careful not to collect old pellets from previous years, which are paler (sun bleached) and drier than fresh pellets. Old pellets also tend to have a more irregular shape with protruding bones due to weather wear. Moss can also accumulate on old pellets. Handle the pellets carefully to minimize breakage, including in the plastic bag after their collection.

Pellets are brought back to your research facility where they should be dried fairly quickly. If drying is not possible in the field, they should be frozen (pellets kept in plastic bags at room temperature will start to rot after a few days). Pellets can be dried in a convection oven at 45-60°C until constant weight (24-48 hours). A makeshift drying box suspended over a heater can also be used. Alternatively, a conventional cooking oven can be used by wrapping the pellets in aluminum foil and drying them at 160°C (325°F) for 40 minutes. As a last resort, pellets can be air-dried in a dry and warm environment for at least 2 weeks. Dried pellets can be stored in clean plastic bags or containers to be dissected later (see Section 5.1.2). If new plastic bags or containers are used after drying, they must be clearly identified with the same information as before, i.e. nest number or perching site, species, date of visit (including year) and number of pellets collected.

5.1.1.1. Material required

- GPS receiver
- map of your study area
- field book
- plastic bags
- felt-tip marker
- drying oven (at your research facility)

5.1.2. Methods to analyze samples in the laboratory

Each pellet should be dissected and analysed individually. Depending on the objectives of your study and the time available for the analyses, several information can be recorded on each pellet and with various levels of details. This should be determined prior to starting dissections because it will govern the dissecting process. A large amount of literature exists on the subject (see below) and previous studies should be consulted prior to starting this work. Here, we simply provide an overview of laboratory procedures that will be sufficient to allow identification of the main prey consumed.

1) Because pellets are partially made of fine particles (dried feathers, fur and dust), we suggest wearing a breathing mask (or work under a fume hood) and surgical gloves when dissecting them.
2) Select a pellet and start dissecting it in a tray or shallow dish by gently breaking it apart with your fingers or a pair of tweezers. If it does not come apart easily, start with another part of the pellet to avoid breaking fragile prey items.
3) As you remove fragments from pellets, separate them into categories such as bones, fur, feathers, vegetation, invertebrates, etc. If some pieces cannot be categorized, set them aside in an unknown pile to be identified later.
4) Bones can be further separated into avian or mammalian. Certain parts such as skulls and feet should be easy to associate. For other bones, simply remember that bird bones are hollow and lightweight and mammalian bones are filled with bone marrow and heavier.
5) Whenever possible, identify prey items to the family, genus or species by comparing each fragment with reference material (from books, museum skeletons, identification keys, etc.) or by consulting with experts. If you have access to diagrams or actual skeletons of birds or mammals, you can use them to identify the part of the skeleton to which bones belong (e.g. jaw, femur, rib, etc.). Having a detailed list of all animal species (or at least known prey) present at your field site will also be useful.
6) When you have finished dissecting a pellet and identifying fragments, you should record:
    - All prey categories identified to the lowest taxonomic level.
    - The body part from which each fragment come from (e.g. jaw bone, skull, vertebra, femur, ribs, down feather, claw, beak, exoskeleton, etc.) including body side when applicable (e.g. right lower jaw bone, left femur).
    - The number of items counted in each category (e.g. 3 bird skulls, 5 mammal vertebrae).
7) Once identified and counted, all recovered prey items should be place in plastic bags (one bag per broad category if possible). Mark on bags the nest number (or perching site), the species, the date the pellet was collected (including year) and the content of the bag (ex: bird bones, brown lemming bones, feathers, unknown prey item, etc.).

Lemming bones found in one dissected snowy owl pellet. On the left side, from top to bottom: scapula, humerus, ulna, radius, pelvic girdle, femur, shinbone (some with fibula). On the right side: lower jaw and skull. At the bottom: fur.

* IDENTIFYING SMALL MAMMAL REMAINS USING THEIR TEETH *

Small mammals are a very common prey of all arctic avian predators. The easiest way to identify them is by using their lower jaw bones which are frequently found in pellets. The teeth in particular are very useful even if the jaw bones are broken up in pieces because each species has a unique dental pattern. As an example, Figure 5.1 shows the difference between the collared and brown lemmings, the two most common lemming species found in the North American arctic region.

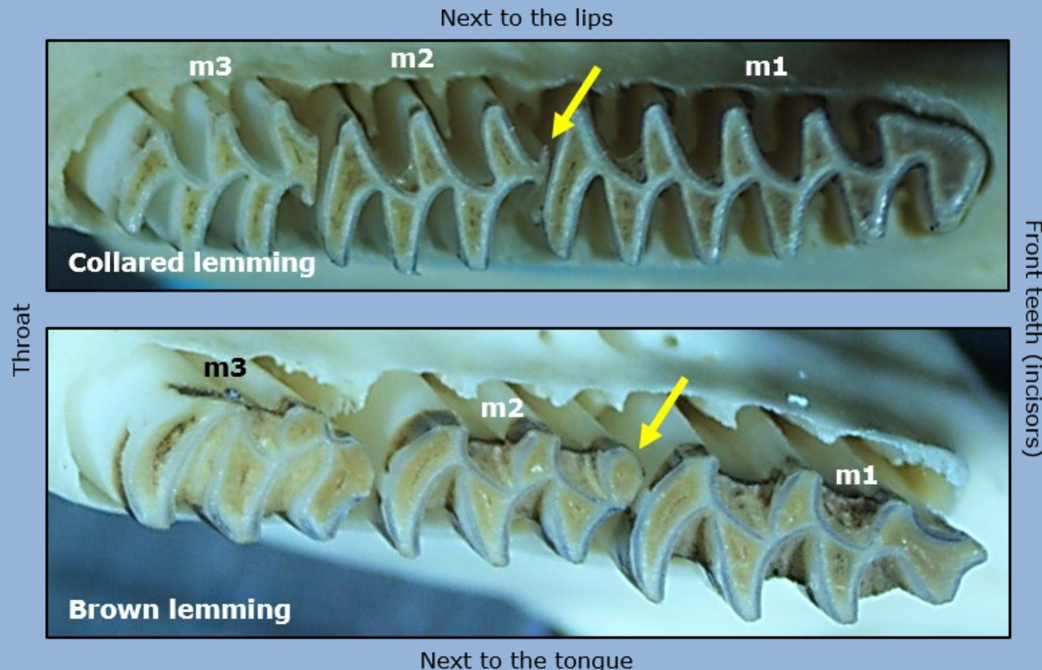

Figure 5.1. Jaw molars of a collared lemming (top) and a brown lemming (bottom) viewed under a binocular microscope (x16). Collared lemmings have a very small loop of enamel on the anterior side (front teeth) of the second molar (m2; see arrows) while brown lemmings do not. The orientation of the pictures is indicated besides the photos. © Dominique Fauteux

To identify small mammals with their teeth, we recommend consulting Driver (1949), Naughton (2012) and Fauteux et al. (2014). Measuring the size of the lower jaw bones of small mammals may also be useful to estimate the size of prey consumed. Schmidt et al. (2019) provides conversion equations to estimate the size of common small mammal species consumed by avian predators based on various jaw bone measurements.

In addition to having the list of all species consumed by the predator, you will be able to estimate the minimum number of prey consumed for some of them. For example, the number of different brown lemming jaw bones of the same side (right or left) found in a pellet will allow you to determine how many brown lemmings were consumed. Jaw bones of small mammals are especially useful for that as they are often found intact in pellets and their teeth allow an easy identification of the species and even the body size of the prey *. The same applies to some other body parts (e.g. feet of small birds, mouth parts of large insects, etc.).

To obtain further information on how to determine and analyze quantitatively the diet of avian predators based on pellets and prey remains, you should refer to the literature as numerous papers have been published on the subject. This will help you determine the most appropriate method to compile and analyze the data obtained from your pellet dissection with sound statistical techniques. We recommend consulting Errington (1930), Poole & Boag (1988), Nielsen & Cade (1990), Simmons et al. (1991), Clarke et al. (1997), Séguin et al. (1998), Redpath et al. (2001), Marti et al. (2007) and Weiser & Powell (2011).

5.1.2.1. Material required

- tray or shallow dish to dissect pellets
- tweezers
- small plastic bags
- small felt marker
- magnifying glass (x8 or x10) or binocular microscope
- breathing mask (optional)
- surgical gloves (optional)

5.2. Alternatives methods to determine the diet of avian predators

Despite its usefulness, determination of the diet of avian predators with regurgitated pellets has some limitations and biases due to the under-representation of some prey items. Alternative methods can partially overcome these biases although these methods also present some limitation and biases (see Section 5.3 for pros and cons of each method). This is why it is often recommended to combine pellet and prey remain analysis with one of these alternative methods in the same study if an accurate determination of the diet is an important objective for you. Here, we present a brief overview of some of these alternative methods.

Direct observations

Depending on the nest location, a blind can be set up at a certain distance from the nest to observe prey items brought back to the nest by parents. Most avian predators will carry the prey in their beak (sometimes in their talons) and prey can be identified with binoculars or a spotting scope when birds arrive at the nest. This method is especially well suited for species where young stay in the nest over a long period of time before fledging (e.g. raptors). However, the diet determination will be biased toward prey consumed by young at the nest compared to prey consumed by adults away from it. For further details, you can consult Poole & Boag (1988) and Rosenfield et al. (1995).

Automated cameras

Automated cameras can also be used to record prey items delivered to the nest. Depending on the type of camera, time-lapse videos or pictures can be set-up at specific intervals or cameras can be triggered by a motion sensor installed near the nest to take a series of photos or a short video whenever a movement is detected. Nowadays, rugged, high quality cameras are available for field studies and can yield images with a high resolution. Cameras can provide an almost continuous monitoring of activity at a nest but often generate an enormous amount of images that need to be processed afterward, which can be time-consuming. For further details, you can consult Booms & Fuller (2003) and Reif & Tornberg (2006).

Stable isotopes

The diet of an animal diet can be determined through the analysis of stable isotopes present in body tissues such as blood and feathers. This method requires that field workers are trained in capturing and handling birds and in techniques used to collect blood or feather samples. Hence, special training and permits are required to use this method.

Blood and feather samples collected in the field need to be properly stored (e.g. blood samples should be stored in a 70% ethanol solution and feathers in an envelope at room temperature) until processing in the laboratory. Samples are then prepared and analyzed in a specialized laboratory with a mass spectrometer to determine the ratio of stable isotopes (typically carbon and nitrogen) naturally present in organisms. However, in order to reconstruct the diet, samples of all prey types potentially consumed by the predator must also be collected in the field and analysed for their isotopic ratio*. Anybody interested in applying this technique must consult the literature to become familiar with this method. A large body of literature has been published on this subject, especially in birds.

*** BASIC PRINCIPLES OF DIET DETERMINATION USING STABLE ISOTOPES ***

In a nutshell, diet determination using stable isotopes is based on the principle that chemical elements present in body tissues of all living organisms naturally occur under various forms called isotopes. Elements like carbon or nitrogen typically have two stable isotopic forms, a common and a rare one. The ratio between these two forms, call isotopic ratio, will vary among different organisms in response to many factors such as the type of environment where they live (e.g. dry vs. wet or marine vs. terrestrial) or their trophic position in the food chain. Thus, each animal has a unique isotopic ratio in its body tissues, which acts as a natural marker. When prey are consumed by predators, the isotopic ratio of prey tissues are incorporated into the body of the predator according to their proportion in the overall diet of the predator. Thus, by comparing the isotopic ratio of predator tissue to that of its potential prey, it is possible to determine the proportion of each prey type that has been consumed, i.e. the diet. In other words, you are what you eat! The most common stable isotopes used for diet analyses are carbon (13C) and nitrogen (15N). Figure 5.2 illustrates the isotopic ratio measured in the blood of several individuals compared to the isotopic ratio of their potential prey (commonly called sources). Combining this information allows the determination of the proportion of prey consumed by each individual.

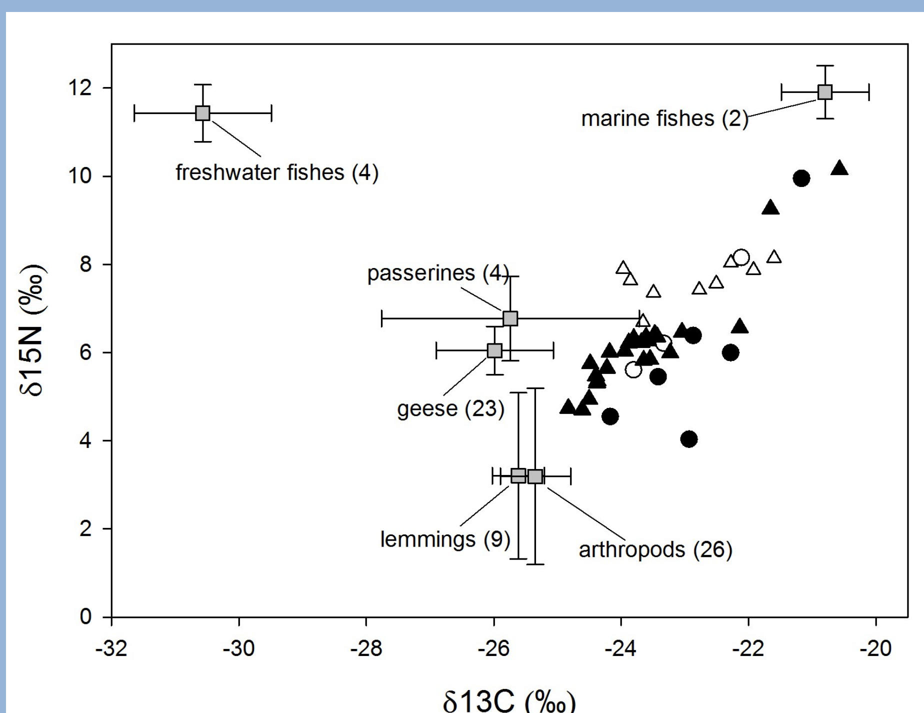

Figure 5.2. Stable carbon and nitrogen isotope values of whole blood samples from Glaucous Gull adults (circles) and chicks (triangles) captured on Bylot Island, Nunavut, Canada, in 2007 (white symbols) and 2008 (black symbols). Isotope values of various prey categories (sources) are also shown with means (grey squares) and standard deviation (horizontal and vertical lines) based on sample sizes given in parentheses. From Gauthier et al (2015).

Animal diet can change over time and thus the isotopic ratio of their tissue will change accordingly. However, because the turnover rate of elements varies among different tissues depending of their metabolic activity, sampling different tissues will provide information on the diet over different time periods. For instance, analyzing blood will provide information on prey recently consumed (past few weeks prior to sampling) whereas feathers will provide information on the diet at the time when feathers were growing, possibly several weeks/months before. Further details on this method can be found in Hobson and Clark (1992), Kelly (2000) and Hobson (2011).

5.3. Pros and cons of diet determination methods

Here are some of the pros and cons of the four methods presented above to study food habits of avian predators.

Method	Pros	Cons
Regurgitated pellets and prey remains	• Non-invasive method • Collection of samples in the field during nest visits is easy and quick • Collection requires minimal disturbance to birds • Pellets are easy to recognize in the field and can be collected by untrained workers • Seasonal and annual variations in the diet can be detected • Allow a good taxonomic resolution when identifying prey items	• Dissection of pellets is time consuming • Small prey items or those highly digestible with little or no hard parts (ex. invertebrates) are underrepresented or totally missed • Taxonomic identification of some fragment may be difficult and time consuming, and may require specialised expertise
Direct observations	• Non-invasive method in most situations • Seasonal and annual variations in the diet can be detected • Allow a reasonable taxonomic resolution when identifying prey items	• Time consuming in the field to obtain a reliable sample size • Quality of observations can be affected by weather conditions and sun position • Should be done when birds are most active to maximize data collection • Finding a good vantage point to observe birds at the nest may be difficult in rugged terrain • Some species might not tolerate the presence of a blind close to their nest or perching site

Method	Pros	Cons
Automated cameras	• Non-invasive method once the camera is installed • Require a small-time investment in the field • Provide a continuous record of the diet over a relatively long period of time • Allow a good taxonomic resolution if image quality is good	• Cameras and equipment can be expensive • Quality of the images can be affected by weather conditions and sun position • Wind or animal passing by can change the orientation of the camera away from the nest or perching site • Require large memory cards and long-lasting batteries to minimize the number of visits at the nest • Analysis of images or video can be time consuming when large numbers are taken • Some species do not eat prey at their nest or young leave the nest early during chick rearing • Cameras may attract some predators to the nest
Stable isotopes	• Consider all prey items, including those that are highly digestible • Can give dietary information over different time period depending of the body tissue sampled	• A more invasive method requiring the capture and manipulation of individuals • Require trained field workers and permits for manipulating animals • Laboratory analyses must be done in a specialised laboratory and can be expensive • All potential prey items need to be adequately sampled in the field • Does not allow a good taxonomic resolution

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6.2. Other references

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7. APPENDIX

Here is the list of all species mentioned in this manual along with their scientific name:

English common name	Scientific name
Raptors and raven	
Common raven	*Corvus corax*
Golden eagle	*Aquila chrysaetos*
Gyrfalcon	*Falco rusticolus*
Peregrine falcon	*Falco peregrinus*
Rough-legged hawk	*Buteo lagopus*
Short-eared owl	*Asio flammeus*
Snowy owl	*Bubo scandiacus*
Seabirds and crane	
Glaucous gull	*Larus hyperboreus*
Herring gull	*Larus argentatus*
Sabine's gull	*Xema sabini*
Long-tailed jaeger	*Stercorarius longicaudus*
Parasitic jaeger	*Stercorarius parasiticus*
Pomarine jaeger	*Stercorarius pomarinus*
Sandhill crane	*Antigone canadensis*
Lemmings	
Brown lemming	*Lemmus trimucronatus*
Collared lemming	*Dicrostonyx groenlandicus*

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