CHAPTER 3. CAPTURE AND MARKING

A. Overview

Scientific studies of birds often require that birds be captured to gather morphometric data and to collect samples for pathological, genetic, and biogeochemical analysis. These data and samples can be used to understand evolutionary relationships, genetics, population structure and dynamics, comparative anatomy and physiology, adaptation, behavior, parasites and diseases, geographic distributions, migration, and the general ecology of wild populations of birds. This knowledge informs us about avian biology and natural history and is necessary to effect science-based conservation and management policies for game and non-game species, endangered species, economically important species, and bird habitat conservation (White and Garrott 1990).

Capture is generally necessary to mark birds, which allows scientists to investigate demography, migration/movement patterns, or identify specific individuals after release (Day et al. 1980). Many techniques have been developed to capture and mark birds (Nietfeld et al. 1994; Bub 1995). The assumption that marking does not affect the birds is critical because it is the basis for generalizing the data to unmarked birds (Murray and Fuller 2000).

The purpose of this section is not to describe capture and marking techniques, but instead to discuss the effects that different capture and marking techniques have on a bird's short- and long-term physiological well-being and survival. The more commonly used methods are covered and described briefly, but the focus is on the potential impacts of the method. Thus, even if a particular method is not covered, the researcher is alerted to concerns that may arise and questions to be considered in refining methods so as to reduce impacts. Representative literature citations are provided to illustrate each point, but this document is not intended to be an exhaustive critical literature review. The North American Banding Council publishes peer-reviewed, taxon-specific manuals describing capture and marking methods in detail and offers training programs and certification. The standard references for bird capture and marking by Bub (1995) and McClure (1984) are comprehensive.

Training is the key to avoiding avian injury and mortality. Despite the availability of excellent reference materials such as the publications of the North American Banding Council, no one should attempt to capture birds or remove birds from nets or other traps without training. Supervision by the trainer or other experienced researcher may be discontinued once proficiency has been demonstrated. Under U.S. law, "A banding or marking permit is required before any person may capture migratory birds for banding or marking purposes or use official bands issued by the Service for banding or marking any migratory bird." (50 CFR 21.22). Permit applications must be accompanied by references from licensed banders attesting to the proficiency of the applicant. However, 50 CFR 13.25(d) allows permitted banders to teach and supervise others who do not yet have permits: "Except as otherwise stated on the face of the permit, any person who is under the direct control of the permittee, or who is employed by or under contract to the permittee for purposes authorized by the permit, may carry out the activity authorized by the permit."

The North American Banding Council's Bander's Study Guide (North American Banding Council 2001) provides an exhaustive list of the causes of injury and mortality and methods to assure that these are infrequent occurrences. Even experienced banders can benefit from reviewing this material periodically, and those just learning to band or who have little experience should study this manual diligently. Some of the basic good practices are discussed here.

B. General considerations

The chosen method of live trapping birds must minimize the possibility of injury or death to captive individuals and minimize stress. Investigators need to consider the time of day, time of year (moult or breeding status of the birds), weather, number of birds to be captured, number and training of staff required, and the possibility of predation. They must be familiar with the biology and behavior of the species they are capturing, and plan all captures and releases accordingly. For example, some species are flightless during moult and should be captured and released in a way that does not affect their survival during this vulnerable stage. Breeding birds (e.g. incubating females) must be released as soon as possible to avoid prolonged absence from the nest (less than one hour depending on the species). Diurnal birds should never be released after nightfall as they may have difficulty finding a suitable roost for the night and be vulnerable to nocturnal predation. The mesh size of a net or size of a trap should be appropriate to the species targeted so that birds are not able to escape, become entangled or injured. Traps should be have no sharp edges that might injure birds or investigators. The opening of a trap should be positioned to allow the investigator to reach all parts of it to remove birds easily. For units with trap doors or moving parts, all mechanisms should be in good working order and be safe for trapped birds and investigators. Avoid disturbance to vegetation except as needed to place the net or trap, as flattening of vegetation may affect concealment and result in increased predation.

Before trapping begins, investigators must have management plans in place for birds injured or killed during capture. The plan should include information on evaluating the condition of the bird, determining when euthanasia is appropriate, and assuring that persons who will euthanize birds are properly trained, have the appropriate materials on hand, and, when required by law, have the appropriate permits. If a licensed wildlife rehabilitator or veterinarian is nearby, consider taking the bird to that individual for assessment, treatment, or euthanasia. Attempt to donate carcasses to museums or teaching collections. See the Ornithological Council fact sheet (Appendix A) for instructions on preparing carcasses for instructions on how to save a bird for science.

As with all research methods, some injury or mortality will occur no matter how skilled or experienced the researchers and even when great care is taken to prevent harm. It is difficult, if not impossible, to know the actual rate of mortality because some birds that die between the time of capture and release, or shortly thereafter, will die from causes unrelated to the capture and handling. Further, birds are rarely seen after release, except for a short period if banded on breeding territories. Mortality resulting from capture or marking will go undetected. Attempt to determine the causes of injury and mortality and adjust practices accordingly.

Researchers and other banders should record injuries and mortalities and share this information with others, by publishing, presenting at scientific meetings, or through the North American Banding Council or other professional organizations. Problems resulting from the use of particular kinds of markers or capture methods, or in individual species are particularly important.

C. Capture methods

Mist Nets

Modern mist nets are made from nylon and vary in mesh size and length. Mist nets have three to four panels that overlap to form pockets; when a bird strikes the net, it will drop into the pocket and become entangled (Bub 1995).

Bird injuries and death sometimes occur from capture and handling, even when a highly experienced handler or bander is following all good practices, but injuries to birds and/or death resulting from mist netting seem to be infrequent. There is currently no requirement or opportunity for routine reporting of injury and mortality. The U.S. Bird Banding Lab and the Canadian Bird Banding Office do not require that injury and mortality be reported routinely although the Canadian Bird Banding Office will sometimes ask for reports on injury especially for novel capture or marking methods. However, many banding stations and individual researchers maintain records of injury and mortality. In 2009, Spotswood et al. (unpublished data) collected data from 20 banding organizations in the United States and Canada and determined that injury rates ranged between 0.06 and 2.37% while mortality rates ranged between 0.07 and 1.15%. Of the 20 organizations that provided mortality and injury rates, five also provided detailed records of individual injuries and mortalities. These data reveal that 66% of all incidents were net-related injuries and 25% were net-related mortalities. The most common causes of mortality and injury were handling, predation, net trauma, strains and cuts.

Determining mortality rates resulting from capture and marking is difficult because capture, handling, and marking may be proximate in time to the death, but not the cause of the death. A bird that died in the net or in the hand might have had a previous injury, disease, or condition such as parasites severe enough to cause death. Absent evidence of injury or predation, cause of death may not be evident without a necropsy. If practical to do so and if funding and personnel are available, consider performing necropsies under such circumstanes, necropsies will yield information that may identify practices that can be modified to reduce or eliminate the risk of injury and mortality. Conversely, mortality might be under-reported because banded birds more often than not are not seen again, particularly when banded on migration. Due to the difficulty (impossibility) of studying unmarked birds, it is difficult to assess the normal rate of mortality of wild birds and therefore, it is hard to know if mortality associated with capture and marking differs significantly from the background (natural) rate of mortality.

Recher et al. (1985) analyzed the rate and causes of mortality at a woodland banding site and at a heathland banding site in Australia from 1979 to 1981. A total of 53 out of 4184 birds died. Of these, 68% died in the net and 32% died during handling. The disparity between mortality rates at the two banding sites — at the woodland site, 2.8% of the birds died but at the heathland site, only 0.5% of birds died — was attributed this difference to the fact that at the woodland site, there were more nets open and fewer experienced banders. As a result birds were left in the mist nets too long or left open during the hottest part of the day.

Simple, basic measures can prevent most injury and mortality with the use of mist nets. Nets set for diurnal species should be closed or taken down at dusk to avoid accidental capture of nocturnal species and vice versa. When nets are closed, clothespins or other fastener will keep them from unwinding in the wind; loose sections can trap bats and nocturnal birds or birds active in the early morning. When mist nets are set near the ground, it is important to clear away plants and debris so that birds are not accidentally overlooked when nets are checked. It is also more difficult to remove a bird from a net that is entangled in vegetation.

Mist nets must be checked frequently; the number of nets set up should reflect the skilled manpower available to check them (Recher et al. 1985). Birds are susceptible to heat, cold, thirst, or hunger and so should not be left in nets longer than necessary (Recher et al. 1985). If the substrate below a net becomes heated by insolation, temperatures lethal to small birds may be reached quickly. Similarly, extreme cold poses special problems, especially for small species. Nets should be shaded or positioned to avoid full exposure to the sun. Trapping or netting should be avoided if the ambient temperature is below 0^0C or above 35^0C, or in windy or rainy weather. Nets and traps should be watched or checked at least every 20 minutes during the nesting season, during migration, or if it is hotter from direct sun or cooler due to microclimate of the area, and about every 30 minutes (at least once per hour) during the rest of the year.

Put anti-predation measures in place. If predators in the area seem to be observing the nets, the nets should be closed. If a bird is taken by a predator, check nets more frequently or close the nets. Ground-dwelling predators – even frogs – can take birds from the lowest tier of the net so raising the net may be adequate to prevent this problem. Killing predators is not an acceptable option, and killing avian predators is a federal offense under the Migratory Bird Treaty Act (16 U.S.C. 703 et seq.). Before releasing birds, scan for predators in the area and check the condition of the bird. Released birds may be disoriented, slower, or in a weakened state, making it harder to evade predators. Fire ants and other insects can be problematic. Clearing vegetation and raising the nets to avoid contact with vegetation or the ground is necessary in these cases. In addition, it is good to know the possible large mammal species that may be in the area, such as moose, elk and deer that have been known to cause problems with mistnets.

Removal of birds from mist net requires training and skill gained from experience. A small crochet hook can be used to help remove more entangled birds from the net. Small scissors or knife can be used to cut the net for the most difficult birds. Infrequently, a bird will get its tongue entangled in the net and great care must be taken to gently remove the net.

Injuries sometimes occur in-transit between the net and the banding station. Banders employ various methods for transporting birds including nylon bags, cloth or mesh bags, and small buckets. Birds can be safely transported from the net to the banding station in nylon, cloth or mesh bags. Small modified buckets may be useful to transport species such as towhees or other long-legged perching birds that may be prone to leg joint dislocations. Carrying them in a bucket that allows them to stand can help alleviate this risk (Cox, pers. comm.).

Cannon/Rocket Nets

Cannon and rocket nets are fired over a predetermined area, usually to catch shorebirds, waterfowl, or waterbirds. Cannon and rocket nets are dispersed quickly using explosive charges. Phutt nets are fired using compressed air and do not have the range or netting area that cannon or rocket netting can achieve. Cannon/rocket netting can be effective in catching adult waterbirds away from the nest. Birds are lured to the site with bait or decoys (Parrish et al. 1994; Heath and Frederick 2003). Because cannon/rocket netting involves the use of explosive charges, special training and permits are required and an experienced team is needed to coordinate the set and firing and to remove and process birds quickly and efficiently. If nets and explosives are not set up and detonated correctly, birds and or humans can be injured or killed (Bub 1995).

As reported in the few papers published on this subject, injuries and mortalities seem to be rare occurrences. King et al.(1998) reported one avian mortality and a broken wing when rocket netting 142 American White Pelicans (*Pelecanus erythrorhynchos*) due to strikes by the rocket and leading edge of the rocket net. Cox and Afton (1994) reported a 1% mortality rate for 18 firings that captured 1,116 waterfowl. Eleven of the 12 mortalities resulted from drowning when they became trapped between the platforms from which the nets were fired and the stakes holding the nets. Over several years of rocket netting shorebirds, mortality ranged from 0 to 2.1% except for the first net attempt, when a lack of a sufficient number of banders and adequate holding facilities resulted in mortality of 10.7% of the birds caught (Jurek 1974). The longer Ring-billed Gulls spent under the net, the less likely they were to be resighted and it was assumed that they had deserted the colony. Of those that remained, however, time under the net did not affect resumption of breeding. This particular study reported no adult or chick mortality but three nests were damaged by the net (Southern and Southern 1983).

Funnel Traps

Funnel traps consist of a funnel leading into a trap. Birds walk through the funnel into the trap, often lured by bait, where they are most often unable to exit. These traps are used most commonly to trap birds that walk or feed on the ground (Bub 1995). Buck and Craft (1995) reported minor injuries (minor scrapes) associated with capturing Great-horned Owls (*Bubo virginianus*) and Red-tailed Hawks (*Buteo jamaicensis*) in funnel traps, but none were serious or life- threatening. Kearns et al. (1998) reported 48 trap mortalities (1.6% of total captures) using a modified cloverleaf funnel trap; of these, 22 (46%) were due to predatory mammals, 16 (33%) resulted from drownings due to changing tides, 10 (21%) were due to unknown causes.

Trapping at Nest Sites

Trapping at nest sites is a common practice when the investigator hopes to mark nestlings and it is also useful because adult birds are reliably found at nest sites. The method is often employed for long-legged wading birds such as storks or ibis. However, trapping on the nest and repeated visits to wading bird colonies may have adverse effects on nesting success (Jewell and Bancroft 1991) and may bias reproductive and population studies. Additionally, nest-trapping techniques limit researchers to capturing only incubating or brooding birds. As with all species, a variety of capture techniques may be needed, particularly if large sample sizes are needed. King et al. (1998) used padded, modified leghold traps submerged in flooded fields. Of the 52 birds caught, none suffered injury other than a mild abrasion to the leg of one bird. Fuertes et al. (2002) used a modified fish trap called a “single strip Dutch sleeve” to capture rails, crakes, and moorhens. One mortality was reported due to a mammalian predator and four birds exhibited skin abrasions at the base of the bill. Mehl et al. (2003) used leg-hold noose mats to capture Killdeer (*Charadrius vociferus*), Dunlin (*Calidris alpina*) and Piping Plovers (*Charadrius melodus*) in Texas and California. Mehl et al. (2003) reported three leg injuries and one mortality due to an avian predator out of 2410 birds captured. Finally, Herring et al. (2008) used modified flip traps and net guns to capture Great Egrets (*Ardea alba*) and White

Ibis (*Eudocimus albus*). The flip trap caused two birds to receive minor abrasions and a mild hematoma but no mortalities. Four mortalities occurred using the net gun (3 Great Egrets and 1 White Ibis) when weights on the net struck the birds. Anti-predator measures are particularly important when trapping at nest sites, both for the trapped birds and the young at the nest.

Raptors

Raptor banding requires special permission from the U.S. Bird Banding Laboratory of the U.S. Geological Survey and in Canada, from the Bird Banding Office as well as provincial or territorial permits. A comprehensive review of raptor research and management techniques has recently been updated (Bird and Bildstein 2008).

It might seem a matter of common sense to wear heavy gloves to protect against puncture wounds from the talons and beaks of raptors. However, the North American Banding Council cautions against the use of gloves in most raptor handling situations. Gloves can make it difficult to be sure that the bird is not held too tightly, harming the bird, or too loosely, allowing the wings or feet or even the entire bird to slip free (Hull and Bloom 2001). Some banders give the bird an empty glove to bite and grasp while handling the bird with the other (bare) hand. This method is useful in removing raptor nestlings from the nest. In addition, a hood can be used to quiet the bird.

Most raptor banding involves the use of a live lure animal. The animal is harnessed in a protective jacket and tethered and can be placed behind a net, within the bownet, or inside a trap. When a raptor approaches, the tether line is pulled to cause the lure animal to move. The North American Banding Council manual of raptor banding techniques details the appropriate care of the lure animal, stating that, “it is of utmost importance to treat any living animals within your care in a thoughtful, humane manner at all times.” Specifics include providing adequate shelter, clean enclosures, and a diet appropriate in food types and quantity. In the field, lure animals should be given food and water, and sheltered from heat, cold, and rain. The protective jacket must be large enough to allow the bird to breath and flap freely and should have no rough or sharp edges. Use only healthy animals, and use no individual for more than 1-2 hours in good weather. Lure animals should be rotated out of use for one or more days to allow them to recover from the stress. Each bird should be checked for injury when returned to its enclosure, and injuries should be treated immediately (Hull and Bloom 2001). Bal-chatri traps used along roadsides are usually in place for no more than an hour, so lure animals can be given food and water when retrieved from the traps. The lure animals should have some kind of refuge to escape the raptor's talons and beak.

In some limited instances, non-living lures may be used to capture some species of raptors. Eagles and vultures are attracted to carion. Taxidermied owls, alone or in combination with taped vocalizations, may lure some owl species into mist nets. Nero (1980) had success casting a fishing line to drag a stuffed mouse across the ground. This method has been used for both Great Gray Owls (*Stix nebulosa*) and Spotted Owls (*Strix occidentalis*). Generally, though, trapping diurnal raptors requires the use of live lures. The Golden Gate Raptor Observatory devoted 15 years of effort and more than $150,000 trying to develop an effective mechanical lure. Although a professional robotocist succeeded in creating a lure with a reliable power supply and remote control systems as well as realistic appearance and movement, it was difficult to use and proved unreliable in capturing the majority of raptors to which the mechanical lures were presented (Hull, pers.comm. 2010). Others have used mechanical lures entailing a motorized head inside a stuffed owl toy or taxidermied owl with a motorized head with limited success (Jacobs and Proudfoot 2002; Jacobs 1996), but mechanical lures can fail at critical moments. An extensive and detailed review of raptor capture methods by leading raptor biologists each with many decades of experience suggests the possible use of non-living lures in only two methods (Bloom et al. *in* Bird and Bildstein 2008).

Capture myopathy

Most research that requires capture of a wild animal presumes that the individual will be returned to the wild in as close to its original condition as possible. Capture myopathy, also known as cramp or exertional rhabdomyosis, which can result from handling and capture, delays release or may preclude release altogether and may even result in morality. Capture myopathy is a state of muscle tissue degradation that can render a bird incapable of standing, walking, or flying (Purchase and Minton 1982; Rogers et al. 2004). The condition is most common in long-legged birds waterbirds but may frequently occur but not be recognized in other species such as Mallards, Wild Turkeys (*Meleagris gallopavo*), and Northern Bobwhites (*Colinus virginianus*) (Minton 1993). Susceptibility to capture myopathy varies from species to species and from bird to bird because normal levels of creatine kinase and aspartate transaminase vary with nutrition, physical condition, reproductive status, and season (Dabbert and Powell 1993; Hulland 1993; Mueller 1999; Viña et al. 2000). As a cause of mortality, it frequently impedes captive breeding programs (Bailey et al. 1996a; Bailey et al. 1996b) and biases the results of field experiments (Abbott et al. 2005; West et al. 2007).

The underlying effect of capture myopathy is muscle necrosis caused by the inability of the vascular system to remove waste products and re-oxygenate the tissue after contraction (Wight et al. 1979). In critical cases, a bird may suffer dyspnea, hyperthermia, weakness, muscle rigidity, and collapse but less obvious symptoms may last longer, increasing susceptibility to predation or contributing to death weeks or months after capture.

To avoid causing capture myopathy, the method of capture needs to be well-planned so as to trap, process, and release birds quickly. This entails have enough people with enough experience and preparation to reduce handling time. Do not chase birds and minimize pursuit time when using funnel traps. As struggling is thought to be a cause of capture myopathy, reduce struggling by covering the bird's eyes or placing it into a darkened box or holding cage. Investigators should avoid catching birds in high temperatures. When high temperatures cannot be avoided, ensure that the bird's temperature is controlled with good ventilation. It may also be necessary to shade birds in the net both before and while they are being extracted. Holding cages should be placed on damp sand or ground, as heat from dry sand considerably increases the temperature in the cages. If only dry sand is available, the hot top layer should bescraped away before the keeping cages are erected. Damp cloths located out of reach of the bird may provide shade and cooling (Clark and Clark 1992).

Some capture methods may be more likely to cause capture myopathy than others. For the capture of Little Bustards (*Tetrax tetrax*), cannon nets (as compared to leg nooses or funnel traps), along with longer handling and restraint times, explained 41% of the variance in the probability of the occurrence of mobility disorders following release (Ponjoan et al. 2008). However, Minton (1993) found that for large wading birds, mist nets resulted in more cases of capture myopathy than did cannon nets. Certain procedures were found effective in reducing the incidence of this condition, including removing susceptible species from nets first and moving them to holding cage, allowing the legs to dangle when carrying birds, and processing susceptible species first.

When planning capture of birds known to be susceptible to capture myopathy, learn to recognize the symptoms. Some of these symptoms, such as shallow panting or open-mouth breathing, can also be signs of the ordinary stress associated with capture. Elevated body temperature, weakness or tremors in a limb, inability to stand or walk, ataxia (lack of muscle coordination), depression, and shock.

Observe birds if capture myopathy is suspected. It may be possible to treat incipient cramp by bathing the birds' legs in water. Banders have observed that Red Knots, released after a catch with signs of slight cramp, went immediately to stand in the water. After a short time they moved away, having apparently lost their symptoms or shown great improvement. Following these observations, banders immediately took birds with incipient cramp to the tide edge and their legs were bathed before release. This treatment seemed to be effective, with all birds on which it was tried recovering, probably because it rapidly reduced the bird's temperature. This technique was only tried on birds in the very early stages of cramp and may not be effective if the condition is allowed to develop (Clark and Clark 1922). Muscle relaxants have been shown to alleviate cramp. Diazepam given to Red Knots and Eurasian Oystercatchers (*Haematopus ostralegus*) completely abated the clinical symptoms (Piersma et al. 1991). Of course, consult with a veterinarian before treating birds with any form of medication to assure proper dosage. Birds treated with diazepam or similar substances must be kept in safe, quiet, dark places while they recover.

If planning to capture species known to be susceptible, obtain veterinary advice or arrange to have a veterinarian onsite if possible; determine options for veterinary and rehabilitative care in advance of the planned capture. If veterinary and rehabilitative care are not available, and field treatments such as those described above fail, arrange for a humane method of euthanasia to be administered by someone skilled (and if required by law, holding a valid permit to do so). Releasing a disabled bird is not humane.

The course of treatment for capture myopathy potentially involves drugs, nutritional and mineral supplements (vitamin E and selenium), as well as physical therapy and massage. Three Sandhill Cranes were treated 2-8 times/day for 8-12 days until they could stand on their own (Businga et al. 2007); a group of knots (*Calidris spp.*) required 2 weeks of rehabilitation (Rogers et al. 2004); and a Rhea (*Rhea americana*) regained the ability to walk only after 4 weeks of "persistent, aggressive physical therapy, muscle relaxants, and anxiolytics…" (Smith et al. 2005).

With appropriate treatment, survival and release may be possible. In the Sandhill Cranes mentioned above, all three birds survived; both adults were observed with chicks in the subsequent 3-7 years. The juvenile was observed flying with a flock for two days after release (Businga 2007). The knots suffering the effects of capture myopathy were kept in slings and given rehabilitative exercise. Of these birds, 80% survived. When able to walk steadily and flap effectively, the birds were released. Half the released birds were resighted the following year; this compared favorably to the resighting rate of 52% of birds that did not suffer myopathy (Rogers et al. 2003).

Necropsy by a veterinarian is the only way to confirm that capture myopathy was the primary cause of death. If capture myopathy is confirmed, capture and restraint techniques and protocols should be reviewed and modified.

D. Marking

General considerations

Studies that use marking techniques operate under the assumption that the marking technique does not affect the individual or that the negative impacts from the mark are negligible. It is essential to the welfare of the birds and to the integrity of the research that the marking procedures not adversely affect the behavior, physiology, or survival of individuals. Because of the difficulty in providing appropriate controls for the marking method and the difficulty of observing and measuring impacts in the field, where individuals may be seen only once, systematic studies of possible adverse effects of marking procedures are still few and often suffer from small sample sizes that lead to weak statistical inference (Murray and Fuller 2000). However, the number of published studies reporting the effects of marking techniques on survival, reproduction, and behavior of captive and wild populations is increasing and reported here for consideration in the design and implementation of marking studies on birds. Investigators should not assume that marking procedures will have no adverse effects on their subjects and should make efforts to evaluate and report any such influences.

For a marking procedure to be effective, it should meet as many of the following criteria as possible (Marion and Shamis 1977).

- **a**. The bird should experience no immediate or long-term hindrance or irritation.
- **b**. The marking should be quick and easy to apply.

c. The marking code (digits or colors) should be readily visible and distinguishable.

d. The markings should persist on the bird until research objectives have been fulfilled.

e. The bird should suffer no adverse effects on its behavior, longevity, or social life.

f. Careful records should be made of all aspects of the marking procedure.

Despite the effects marking techniques can have on birds, marking is a necessary research technique. In selecting a marking method, attempt to meet as many of these criteria as possible, giving special consideration to the adverse effects attributed to the marking technique you choose, the effects it may have for the species you are studying, the effect it may have on the data that will be generated, and its acceptability for the proposed study.

The North American Banding Council's Bander's Code of Ethics outlines the basic standards that constitute ethical banding and marking practices. A particular problem arises with regard to the accuracy of data. Birds vary in appearance among individuals, between sexes, between life stages, and across seasons. Identifying the species and ageing and sexing the bird, along with collecting other morphometric measurements, can be time-consuming. This time can be reduced using tabular format that summarizes the diagnostic criteria (Sakai and Ralph 2002). Covering a wide range of taxa, including raptors, passerines, hummingbirds, and woodpeckers, the publication can be ordered from the Klamath Bird Observatory.

All types of markers require permits from the U.S. Bird Banding Laboratory or the Bird Banding Office of the Canadian Wildlife Service. Special permission must be obtained to place "auxiliary" markers – essentially, anything other than the government-issued, numbered metal bands – on a bird.

In special cases it may be possible to identify individuals of some species on the basis of unique markings or vocalizations (see Pennycuick, 1978; Gilbert, et al. 1994) without the necessity of handling or attaching markers to them and where feasible, these methods should be considered as an alternative to physical marking by the researcher.

Metal Bands

Prior to the use of banding (ringing), most bird life histories were a complete mystery (Bairlein 2001). By the early 20th century, bird banding became organized and banders submitted their data to the American Bird Banding Association, which compiled and stored the information. The U.S. Bird Banding Lab has handled these functions since 1920. Because of the advances banding has contributed to our understanding of birds, banding has been called the greatest advance in the study of birds in the 20th century. Researchers have been successfully using bands to study birds for many decades (Coulson 1993).

In North America, numbered metal (usually aluminum, but various alloys for special purposes) bands are issued by the Bird Banding Laboratory of the U.S. Geological Survey or by the Bird Banding Office of the Canadian Wildlife Service to approved banders and are applied to a variety of bird species. Birds banded with metal bands almost always need to be recaptured in order for the band numbers to be read and for data to be generated. The large bands placed on larger birds such as raptors and some waterbirds are considered field-readable because they can often be read with the use of binoculars or a spotting scope.

It is imperative that bands of the correct size be used. Applying bands that are too small for the species in question, that do not account for growth in juvenile birds, that fail to consider size dimorphism when choosing band size which could result in a large band slipping over the foot, or incorrectly determining how many bands can be safely fitted on one leg may cause serious injury to or even loss of the banded leg (Calvo and Furness 1992; Reed and Oring 1993; Gratto-Trevor 1994; Sedgwick and Klus 1997; Amat 1999). Recommended band sizes for all species of North American birds can be found in the North American Bird Banding Manual (Gustafson et al. 1997) and in the Identification Guide to North American Birds (Pyle 1997, 2008).

When appropriate band sizes are used, the occurrence and rate of adverse effects on the subjects is ordinarily very low. In their 19-year study of Spotted Sandpipers (*Actitis macularia*), Reed and Oring (1993) documented toe or leg loss in eight of 267 birds banded and seen again after banding. During that same time, the researchers observed three unbanded birds missing feet and one missing a toe. Gratto-Trevor (1994) reported similar results: in an eight-year study of Semipalmated Sandpipers (*Calidris pusilla)* no leg injuries were observed in the 278 banded birds seen in subsequent years. In some cases, however, much higher injury rates have been reported. Amat (1999) reported an injury rate of 1.9% in a seven-year study of Snowy Plovers (*Charadrius alexandrinus*). Both Reed and Oring (1993) and Amat (1999) reported that the injuries did not affect reproduction. An unusually high incidence of leg injuries in Willow Flycatchers (*Empidonax traillii*) was reported by Sedgwick and Klus (1997). The overall injury rate of 9.6% of banded birds that returned in subsequent years ranged from relatively minor (irritation) to leg loss in 33.9% of the cases. Survival of these birds was significantly lower than the population at large. The problems seemed largely attributable to the use of two color bands or one aluminum band and one color band on one leg. Two or more aluminum bands should not be applied to the same leg as the edges may flange over and injure the leg (Berggren and Low 2004).

A literature review compiled by Marion and Shamis (1977) covers a wide range of species-specific reports, including report of adverse impacts or band loss. Band injuries include simple irritation or discomfort, entanglement of a toe in the band (Berggren and Low 2004), accumulated mud, ice, or fecal matter between the band and leg (MacDonald 1961; Amat 1999), and loss of the foot (Calvo and Furness 1992; Reed and Oring 1993; Gratto-Trevor 1994; Amat 1999; Pierce et al. 2007). Observations of banded chicks becoming entangled in vegetation led Bart et al. (2001) to study the impact of color bands on Semipalmated Sandpipers banded at hatch; in fact, there was no difference in mass or survivorship of the banded chicks, even when two or three bands were placed on a chick. The birds wearing three bands were actually re-sighted more often that the birds with no bands or one or two bands. Causes of injury often seem to be species-specific. Henckel (1976) reported leg lesions on banded Turkey Vultures (*Cathartes aura*), apparently resulting from the accumulation of fecal matter under the bands; these birds defecate on their legs to take advantage of evaporative cooling. Long-legged birds trying to remove bands or preen legs may catch their bills in the bands; banding above the tarsal joint prevents this problem (Salzert and Schelshorn 1979).

Colored Leg Bands

Color banding (ringing) has proved to be a useful technique in recognizing individual birds without the need for recapture. The ability to track individual birds has increased our understanding of bird movements and behavior (Hole et al. 2002). One or two colored leg bands are often applied to one or both legs of a bird. They are being used increasingly in studies of behavior and ecology, often involving large numbers of individuals (Cresswell et al. 2007; Pierce et al. 2007). The use of color bands requires special permission from the U.S. Bird Banding Lab or the Canadian Bird Banding Office.

When used in combination with aluminum bands, plastic bands must be of the same size or upper bands can slip inside the lower bands, resulting in leg injury or loss (Berggren and Low 2004). Most injuries appear to occur more frequently when metal bands or combinations of metal and colored bands are applied to the same leg (Sedgwick and Klus 1997). Berggren and Low (2004) found that 2.5% of banded North Island Robins (*Petroica longipes*) exhibited adverse effects from colored bands. The most common injury sustained was trapping of the back toe between the band and the tarsus. This particular injury was believed to be caused by the bird perching sideways on upright vegetation. Accumulation of leg scales between the band and the leg resulted in constriction that caused the loss of toe function and swelling above and below the band in Bell Miners (*Malurus cyaneus*) (Splittgerber and Clarke 2006). Armstrong et al.1999 found that 54% of banded Hihi, or Stitchbird (*Notiomystis cincta*) suffered injuries due to split color bands and experienced partial loss of foot function. Foot function and survival increased when split bands were replaced with wrap-a-round plastic bands. Pierce et al. (2007) observed plastic (celluloid or PVC) color band injuries in 13.2 – 35.3% of recaptured flycatcher species that included accumulation of scales, swelling above and below band, and loss of a foot. No further injuries were observed when the plastic bands were replaced with color bands made of anodized aluminum. The authors recommended the use of a single color band of anodized aluminum, which reduces the number of available color combinations. However, Koronkiewicz et al. (2005) developed a method to make striped color bands of anodized aluminum. Alternatively, if only one plastic color band is used, it could be placed above the numbered metal band. The authors also noted that the behavior or morphology of the flycatchers Muscicapidae and closely related Monarchidae families, and possibly Tyrannidae flycatchers of the Americas, might explain why these species seem to suffer injuries from plastic color bands that are not seen in other species.

Particular care must be taken when banding nestlings before they are old enough to be banded with permanent bands. A technique for color banding nestling passerines is given by Harper and Neill (1990). This technique involves the use of bands made from colored plastic straws; removing these temporary markers requires that the birds be recaptured before fledging. When nestlings are banded close to the fledging stage, they may fledge prematurely and may be difficult to recapture. It is therefore important to estimate the age of the nestlings from size, appearance, and behavior if the hatch date is unknown, and to know the duration of the nestling period (from species accounts or prior experience).

Color bands can also affect behavior. Studies have shown that certain band colors, especially those that are similar to plumage or soft part colors involved in social signals, may affect mating attractiveness, dominance status, or aggression in some species. Early investigations focused on the use of bands that matched the color of natural ornamentation, such as throat patches, wing patches (or epaulets), eye ring, or bill color. Not unexpectedly, results were mixed. Mating preference among captive Zebra Finches (*Taeniopygia guttata*) was observed in several experiments (Burley 1981; Burley et al. 1982; Burley 1985, 1986a, b). Beletsky and Orians (1991) found that red color bands had no impact on male mortality or reproductive success of Red-winged Blackbirds (*Agelaius phoeniceus*). Weatherhead et al. (1991) placed red plastic bands or red anodized aluminum bands on Red-winged Blackbirds and found little effect, positive or negative, for either band type, in terms of territory loss or harem size. Mating success was not determined, and it was suggested that genetic analysis is needed to determine the extent of extra-pair paternity before determining reproductive success in polygamous or polyandrous species. Holder and Montgomerie (1993) found that male Rock Ptarmigan (*Lagopus mutus*) banded with red or orange bands did not have greater mating success, in contrast to a study of the same population in earlier years. However, they did observe a higher rate of territorial intrusion. Hannon and Eason (1995) found no evidence that red or orange color bands affected mate choice, reproductive success, or survival in Willow Ptarmigans (*Lagopus lagopus*). Johnsen et al. (1997) found that color bands matching natural ornamentation did not affect pairing success, but males with matching bands spent less time guarding mates and more time displaying and intruding into neighbors' territories. Johnson et al. (1993) found the same result in American Goldfinches (*Carduelis tristis*). Hansen et al. (1999) used color bands to create artificial asymmetry on female Bluethroats (*Luscinia svecica*) to determine if males preferred symmetrical mates; the positive result suggests that asymmetry rather than specific colors might account for observed impacts of color bands on mate choice.

Another concern of banding is that it may increase predation due to the conspicuousness of the band. In a study of Common Redshanks (*Tringa totanus*), Cresswell et al. (2007) did not observe increased predation risk due to the presence of color bands.

Depending upon the duration of the study, it may be important to consider that some colors of commercially available celluloid bands fade. After two years or so they may be unrecognizable (Hill 1992; Lindsey et al. 1995). Several suppliers offer UV-stable bands. Most colors of UV-stable plastic remain bright for several years unless covered with an obscuring substance such as dirt or algae. Blue bands fade relatively quickly.

In recent years, studies of long-distance migrants, especially shorebirds, have employed plastic flags with unique colors representing different countries and different positions being used to represent points of origin. This system is coordinated by the International Shorebird Banding Project. The flags are larger and more conspicuous than bands, so can be seen over longer distances. To avoid interference with the many ongoing shorebird studies, always consult with the International Shorebird Banding Project before affixing flags to shorebirds.

Loss of color leg bands can also affect estimates of mortality and population size and this should be considered when choosing band types (Nelson et al. 1980). An inexpensive alternative to commercial color bands is described by (Hill 1992).

Dyes and Ultraviolet Markers

Dyes applied to the plumage are used extensively on birds, especially colonial waterbirds and waders. It can be hard to see bands on these birds because their legs are often underwater. Water-proof, felt-tip markers are useful for short-term markers, as are tattoo inks, wax cattle-marking sticks, and non-lead paint. Picric acid, Rhodamine B and Malachite Green are among many frequently used dyes. Picric acid (picronitric acid; trinitrophenol; nitroxanthic acid: carbazotic acid; phenoltrinitrate) can pose a significant explosion hazard. During extended storage, it may lose water and become unstable. Never open nor touch a bottle of dry or contaminated picric acid; an explosion could result from the friction produced. Crystallized picric acid is a severe explosion risk, is especially reactive with metals or metallic salts, and is also toxic by skin absorption and inhalation. For all these reasons, the use of picric acid is strongly discouraged**.** Methods of dye use are discussed in (Kennard 1961; Taber 1969; and Day et al. 1980). Recommendations for fixatives to improve retention of the dyes on feathers can be found in (Belant and Seamans 1993). Caution must be exercised in applying the dye, especially when contour feathers are extensively colored. The alcohol or detergent base may remove oil from the bird's feathers, and wetting can lead to heat loss. Care should be taken to ensure that dyed birds are thoroughly dry prior to release. A method for color-marking incubating birds by applying dye to their eggs (Paton and Pank 1986; Cavanagh et al. 1992) can result in high rates of egg mortality and should be used only with appropriate cautions (Belant and Seamans 1993). Dyed birds are sometimes treated differently by conspecifics, and may be subject to greater risk from predators (Frankel and Baskett 1963). Fingernail polish can be used on nestling toenails to mark individuals prior to being old enough to band. Investigators should make systematic attempts to evaluate such possible effects because they may influence not only the welfare of the subjects but the research results as well. Paint of any kind should be used only sparingly on feathers because of its impact on feather structure and function.

Aerial and ground spraying techniques, developed to mass-mark birds in roosting or nesting colonies, employ various colors of fluorescent particles (suspended in a liquid adhesive) that are sprayed from agricultural spray systems (Jaeger et al. 1986; Otis et al. 1986). The marker is visible under long-wave UV light when a bird is examined in hand and is retained for several months or until molt. No adverse effects have been noted, and behavioral changes are not likely because the marker is not visible in daylight. As with any spray application, the nature of the habitat and the composition of the spray formulation should be examined for potential environmental concerns. Fluorescent dyes are also useful for locating and tracking cryptically colored birds (Steketee and Robinson 1995).

Neck Collars

Plastic neck bands or collars have been used extensively for marking waterfowl. (Aldrich and Steenis 1955) concluded that properly applied neck bands are effective markers with few adverse effects on geese. In general, neck collars seem to be superior to nasal discs for tagging waterfowl in terms of visibility and retention as well as the elimination of injury (Sherwood 1966), and have little impact on behavior or survival on geese but may not be acceptable for use in ducks, which can get their bills stuck in the collars (Helm 1955) and may interfere with reproductive success in female Black Brant (*Branta bernicla nigricans* (Lensink 1968). Ankney (1975) found that female Lesser Snow Geese (*Chen caerulescens*) that were neck-banded died of starvation at a rate disproportionate to that observed in the population as a whole, which was supported with additional data the following year (Ankney 1976). One unbanded adult Tundra Swan (*Cygnus columbianus*) seized the neck band of another to hold the second bird during an aggressive encounter, thus preventing the second bird from fighting back (Hawkins and Simpson 1985). MacInnes and Dunn (1988) examined the recovery and recapture rates for neck-banded Canada Geese over seven years and found that the rate of recapture was about half that for birds marked with leg bands although they could not determine if the cause was increased mortality, emigration, or both. When both members of a pair were banded, or the male was banded, nest initiation was slightly delayed but there were no significant differences in clutch size or brood size in three of four years. Greater White-Fronted Geese (*Anser albifrons* *frontalis*) spent significantly more time preening on foraging grounds but not at roosting sites, and seemed to compensate by spending less time in alert postures, but otherwise seemed unaffected (Ely 1990). In a rigorous study to address potential concerns of necks collars on Emperor Geese (*Chen canagica*), Schmutz and Morse (2000) found that adult females marked with tarsal bands had a 17% higher mean annual survival rate than those marked with neck collars and they speculated that the negative effects of neck collars principally arise from a chronically increased energetic demand.

Icing is a particular concern. Ballou and Martin (1964) applied neck bands to 1,564 Canada Geese *(Branta canadensis*) over a four-year period. They observed two deaths resulting from severe icing. In another study, all 68 Canada Geese wearing collars experienced some icing; 12 accumulated a half kilogram of ice while the others acquired a thin layer of icing. All birds were able to fly and the ice fell off spontaneously as temperatures warmed. In a second incident, 10 birds experienced heavy icing of nearly 1 kg; 1 died and four were unable to fly. Ice on the collar of the dead bird was 1 cm thick inside the collar and apparently constricted the neck (Greenwood and Bair 1974). Two icing incidents occurred among 164 neck-banded Pink-footed Geese *(Anser branchyrhynchus*). During the first incident, light icing formed on the collars of about 25 birds and heavy icing (5 – 10 cm) on the collars of about 25 birds. In the second incident, five birds (of 123) experienced light icing and 13 experienced heavy icing. In all cases, the birds were observed feeding and there was no significant difference in the abdominal profile indices of the iced birds compared to birds without icing. There was no observed mortality and no statistically significant difference in resighting rates (Madsen et al. 2001). In unpublished research, Hestbeck (pers. comm.) found that cone-shaped rubber collars collected ice but sat lower on the neck such that the body, rather than the neck, carried the weight of the collar and the ice. Aluminum neck collars seem less susceptible to icing than plastic collars (MacInnes et al. 1969) but some species will catch their bills in the bands if the ends are not overlapped to eliminate a gap.

As with all marking techniques, responses differ among species, and investigators should systematically evaluate any possible influences of the marker. Because neck collars affected survival, Schmutz and Morse (2000) suggested that collars are useful for providing information on distribution, but may be undesirable when estimates of demographic parameters are required.

Nasal Discs and Saddles

These numbered and/or colored plastic discs or plates are applied to each side of the bird's bill and fastened together through the nasal opening by various methods (Bartonek and Dane 1964; Sugden and Poston 1968; Doty and Greenwood 1974). They have been applied primarily to waterfowl. Various undesirable results have been reported, including high rates of marker loss, often with injury to the nares (Sherwood 1966), higher mortality rates attributed to entanglement with submerged vegetation (Sugden and Poston 1968), mortality due to ice accumulation (Byers 1987), and reduced success in obtaining mates (Koob 1981; Regehr and Rodway 2003). Due to the potential for entanglement with vegetation or submerged fishing nets, nasal discs are better suited for species of birds that do not dive and should not be used to study pairing success of the birds (Alison 1975).

Pelayo and Clark (2000) found no evidence that nasal markers had an adverse influence on nesting patterns of pre-laying and laying female Ruddy Ducks (*Oxyura jamaicensis*). Although bill scratching was more frequent, nasal markers did not appear to influence overall reproductive behavior during nesting and or brood rearing. Regehr and Rodway (2003) also found no impact of nasal discs on Harlequin Ducks (*Histrionicus histrionicus*) on behavior, timing of pairing, or female pairing success. However, they did find that males with nasal discs had lower pairing success, and females with nasal discs were less likely to reunite with previous mates. A comprehensive study on the effects of nasal saddles on dabbling ducks (Anatinae) was completed by (Guillemain et al. 2007) who studied the impacts of these markers on Mallards (*Anas platyrhynchos*), Green-wingedTeal (*Anas crecca*), Northern Pintail (*Anas acuta*), and Eurasion Wigeon (*Anas penelope*) in the field and in the aviary. The found that nasal saddles had no effect on body mass, time budgets or other aspects of behavior, apart from a reduced pairing probability in the Teal and, in the Pintails, a slight reduction in the number of aggressive interactions won after marking.

Patagial (Wing) Markers and Leg Tags

Wing tags are highly visible, may be coded for individual recognition, and are retained by birds for relatively long periods of time (Marion and Shamis 1977). Like other markers used to identify individual birds, patagial markers are useful in studies of social behavior, migration, and natal and winter site fidelity. Descriptions of tag types and evaluations of their effectiveness may be found in Anderson (1963), Hester (1963), Hewitt and Austin-Smith (1966), Southern (1971), Curtis et al. (1983), Stiehl (1983), and Sweeney et al. (1985). Some reports indicate that most birds accept patagial tags readily, and adverse effects seem to be minimal (e.g., Maddock 1994). American Kestrels (*Falco sparverius*) marked with patagial tags actually had higher breeding success than did unmarked control birds (Smallwood and Natale 1998). On the other hand, (Kinkel 1989) reported that the survival and reproductive behavior and abilities of Ring-billed Gulls (*Larus delawarensis*) were adversely affected for up to four years after tagging. The effects disappeared when the tags were replaced with color bands. Howe (1979) reported significant impact on survival, as determined by interannual return rates, when none of 27 Willets (*Catoptrophorsus semipalmatus*) returned in the year after banding, compared to a return rate of 64% of birds banded but not marked with wing markers. Howe surmised that for these very long-distance migrants, the drag that might be caused by the markers, or abnormal replacement of feathers at the time of molt might have impaired flight during migration. Tags sometimes result in some wing callouses (Curtis et al. 1983; Kochert et al. 1983) and feather wear (Southern 1971) and in some species, feathers in the area of the tag may not be replaced at the time of molt (Howe 1980; Kochert et al. 1983).

A Velcro™ leg tag developed for marking gull chicks (Willsteed and Fetterolf (1986) may not be suitable for all species because of differences in growth rates that require frequent adjustment of the tag (Cavanagh and Griffin 1993).

Radio/Satellite Transmitters

Radio and satellite transmitters represent a great advance for studying birds in the 21st century. Radio transmitters emit a radio frequency that can be detected by a researcher utilizing specialized hand-held equipment. Satellite transmitters send signals to earth-orbiting satellites that transmit the data to a central computer from which researchers can download the data.

Studies utilizing radio/satellite transmitters make the assumption that data collected from tagged animals reflects the natural state of the organism being studied. This is not always the case. Researchers utilizing radio/satellite transmitters to study birds should consider the effects the transmitters may have on a bird's natural behavior and measure these affects during the study.

Impacts generally

Many studies have examined the impacts of external and implanted radio transmitters on survival, reproductive success, various aspects of behavior, and physiological indicators of stress on a wide variety of species in captivity and in the wild. A small sampling of the extensive literature demonstrates the importance of searching the literature for information specific to the species to be studied and for reports of particular problems and solutions, such as transmitter design and methods for attaching the transmitters. For any particular species, some papers report no effect, some describe behavioral changes of short duration, but others report reduced reproductive success or reduced survival. Casper (2009) devised guidelines for the instrumentation of wild birds and mammals. After reviewing the literature, she concluded that there is a lack of evidence with which to justify the broad application of hard and fast rules for instrumentation across the wide range of avian species, which differ in size and lifestyle. Further, the causes of adverse impacts, when they occur, are multifactorial and are related not only to the mass, size, and shape of the device, but also, capture method, the handling time, the attachment method, food availability and the length of deployment.

A recent meta-analysis by Barron et al. (2010) of 84 papers reporting the use of transmitters found that overall, birds are significantly negatively affected by devices in each of 12 measures except flying ability. For two of these 12, energetic expenditure and nesting propensity were substantial, while the impact on offspring quality, body condition, device-induced behaviors, nest success, and foraging behaviors were less so.

Studies of impacts on passeriformes, an order that includes many small birds and many that migrate between the Northern and Southern hemispheres each year, are relatively few in number, probably because transmitters small and light enough to be used on these species necessitate the use of very small, short-lived batteries. Data can be collected for only a brief period. As transmitter and battery size and weight continue to shrink, however, it is likely that more studies of passerines will involve the use of radio or satellite telemetry. Negative reactions by parents to back-pack transmitters on juvenile Louisiana Waterthrush (*Seiurus motacilla*) may have contributed to the mortality of the marked birds or removal of the devices; success in tracking fledglings marked only with color bands was much greater and less time-consuming than the time needed to find and recover transmitters that had become detached (Mattsson et al. 2006). Two studies found no difference in following-year return rates in Wood Thrushes (*Hylocichla mustelina*) or Swainson's Warbler (*Limnothlypis swainsonii*) (Powell et al. 1998;

Anich et al. 2009). Overwintering Hermit Thrushes (*Catharus guttatus*) carried backpack transmitters for one month. Assessments of hematological indicators of stress (heterophil-lymphocyte [H/L] ratios) did not change and did not differ from birds that did not carry transmitters (Davis et al. 2008). Sykes et al. (1990) compared three attachment methods (harness, velcro, and adhesive) and observed a weight loss in both male and female Common Yellowthroats (*Geothlypis trichas*) though the weight loss was significant as compared to control birds only in the birds wearing harnesses.

A similar device known as a geolocator collects information that is retrieved when the bird is recaptured. Because geolocators do not transmit signals, they are smaller and lighter than transmitters and can be used on smaller birds. However, the ability to collect the data depends on recapturing the bird.

Though some behavioral changes, such as increased preening and/or reducing feeding, can impact survival, reported behavioral changes tend to be of short duration.

Gilmer et al. (1974) observed numerous behavioral changes, particularly as to increased comfort behaviors such as preening, by Mallards and Wood Ducks (*Aix sponsa*) fitted with external transmitters, though the changes abated over time. (Hill and Talent 1990) reported that neither Least Terns (*Sterna antillarum athalassos*) and Western Snowy Plovers (*Charadrius alexandrinus nivosus*) showed behavioral changes related to the radio transmitters and they detected no difference between birds with transmitters and controls in terms of daily nest and egg survival, nest depredation, or nest desertion.

Greenwood and Sargeant (1973) observed significantly greater weight loss in captive Mallards and Blue-winged Teal fitted with transmitters than in the control birds (the extent of the loss was directly related to the weight of the transmitter for the Teal but not for the Mallards. When harnesses were fitted to account for age (based on wing length), sex-based difference in size, and body mass data, as well as general body shape, so as to assure a good fit, survival of Saker Falcons (*Falco cherrug*) as measured by return rates, was not affected (Kenward et al. 2001).

Reports on survival and reproductive success have also been mixed and often contradictory, even within a single study. Sooty Shearwaters (*Puffinus griseus*) fitted with imitation satellite transmitters to test for effects before embarking on an expensive telemetry study experienced significant weight loss compared to birds without transmitters during the pre-breeding period but not during the mid-breeding period. There was no difference in colony attendance during the breeding period, but a significant difference during the mid-breeding period, when birds were also handled; colony attendance also dropped for birds that were handled but not wearing transmitters. However, in contrast to other studies, the transmitters seemed to have no effect on chick-raising. The chicks of birds with transmitters emerged from the burrows at the same time as other chicks and showed no reduction in growth rate (Söhle 2003). Paton et al. (1991) documented significantly lower survival among female Spotted Owls fitted with backpack-mounted transmitters (*Strix occidentalis caurina*) as well as reduced nesting and fledging rates. In contrast, Foster et al. (1992) found no differences in survival or body mass in Spotted Owls carrying transmitters but these birds produced significantly fewer young. Two birds died from entanglement in the harnesses and another died from subcutaneous abrasions caused by the harness. Sixteen birds retrapped to remove or replace harnesses had abrasions; in three cases, these were considered life-threatening. These problems appeared to be caused by poor harness fit. Pietz et al. (1993) found that radio-marked female Mallards preened and rested more and fed less than did birds without transmitters which seemed to result in delayed nest initiation, smaller clutches, and reduce egg volume. Houston and Greenwood (1993), however, found no differences in number of clutches, egg mass, or time between nestings in a study of captive female mallards fitted with transmitters of weights ranging from 4 g to 18 g, whether attached with surgical glue or a harness. Results obtained by Rotella et al. (1993) were similar to those reported by Pietz et al. (1993) in that wild female Mallards fitted with harness backpacks nested fewer times and spent less time incubating than did birds without transmitters or birds whose transmitters were sutured or implanted; further more than half the sutured backpacks became detached within two months.

Increased predation on tagged birds is also a concern. All 38 radio-collared Sharp-tailed Grouse (*Tympanuchus phasianellus columbianus*) died over the course of a year (Marks and Marks 1987). Based on the return rate of unmarked birds, 17 marked birds should have returned the following year. Examination of remains of 22 of 23 recovered carcasses showed that mortality was due to predation. The researchers suggested the tagged birds were more conspicuous or perhaps reluctant to fly due to the slapping of the antenna (Marks and Marks 1987). However, Wheeler (1991) reported that predation of Blue-winged Teal (*Ana discors*) hens marked with transmitters did not seem abnormally high, though there was no control group comparison.

Transmitters can also affect nestlings and fledglings. Adults carrying transmitters may feed at reduced rates and outright nest abandonment has been reported, although these impacts may be reduced if transmitters are fitted when the chicks are older. Three of four female American Woodcocks (*Scolopax minor*) fitted with transmitters when their chicks were one-two days old abandoned their broods, but four other females radiomarked when their broods were four or more days old did not abandon the broods; none of the 22 females banded when their chicks were one or two days old abandoned the broods (Horton and Causey 1984). Transmitters negatively affected survival of Dusky Canada Goose goslings (*Branta canadensis occidentalis*) during the first 28 days of life, but not thereafter, and the affect was greatly reduced for goslings that survived the first two or three days after hatching (Fondell et al. 2008). Reduced growth rate and fledging success of chicks raised by parents carrying transmitters has been reported in Cassin's Auklet (*Ptychoramphus aleuticus*) (Ackerman et al. 2004) and Tufted Puffins (*Fratercula cirrhata*) (Whidden et al. 2007).

Impacts of attachment methods

Impacts can sometimes be attributed to attachment methods. Both radio and satellite transmitters can be attached in a variety of configurations each with its own set of limitations for durability and duration of use (Mong and Sandercock 2007). These include backpack harnesses (Kenward et al. 2001; Taylor et al. 2001; Gervais et al. 2006), necklace transmitters (Haug and Oliphant 1990; Leupin and Low 2001; Sissons et al. 2001; Gervais et al. 2003; Rosier et al. 2006), gluing to skin and/or feathers (Farmer and Parent 1997), tail mounts (Giroux et al. 1990; Irvine et al. 2007), and subcutaneous or abdominal implants (Korschgen et al. 1984; Mauser and Jarvis 1991; Wheeler 1991; Pietz et al. 1995; Korschgen et al. 1996; Hupp et al. 2006; Fondell et al. 2008).

Depending on the type of transmitter implanted, nesting behavior can be negatively affected by the implants such as was found in two species of breeding Murres (Meyers et al.1998). However, transmitters that use internal coiled antennas (Korschgen et al. 1984; Olsen et al. 1992) implanted in the coelom of Mallards (*Anas platyrhynchos*) were found to not affect reproduction (Rotella et al. 1993). Transmitters that are completely implanted suffer transmission path loss, which reduces signal strength and limits detection range. A fabric-covered tube that forms a collar at the base of the antenna may help stabilize the antenna and minimize coelomic contamination, but did not control bacteria migrating along the antenna passage through the body wall. No significant health problems were found up to a year after implantation (Mulcahy et al. 2007). Mulcahy et al. (1999) caution that investigators using implanted radios with percutaneous antennas should be aware of the potential for radio extrusion and should minimize the problem by using transmitters that have no sharp edges and that are wide, rather than narrow.

Concerned about earlier reports of aberrant behavior in terns bearing radio transmitters, (Hill and Talent 1990) avoided placing the transmitters on the interscapular region, which flexes in flight, and instead glued them lower on the birds' backs, which also maintained the birds' center of gravity. Racing pigeons (*Columba liva*) suffered little effect when fitted with tail-mounted transmitters, but birds with sacral-mounted transmitters suffered lesions, flew slower, and lost weight and body condition compared to control birds (Irvine et al. 2007). Reynolds et al. (2004) found that tailmounted transmitters on male Northern Goshawks (*Accipiter gentilis*) significantly reduced apparent annual survival from 0.75 (without transmitters) to 0.29 (with transmitters). However, backpacks that weighed more than tailmounts had no sigificant effect on survival of adults.

Demers et al. (2003) tested neck collars as an alternative to harnesses on Snow Geese and found that behavior indicating discomfort eventually ceased, but that all reproductive parameters were negatively affected, including laying date and clutch size. Females with radio collars separated from their mates at a rate eight times that of females with ordinary neck collars. Gervais et al. (2006) on Burrowing Owls (*Athene cunicularia*) found that harnesses for radio transmitters had a much greater survival effect than the necklaces (another term for collars), which were not very different in mass.

Implantation averts impacts on flight but involves surgery, which can have other consequences. As Barron et al. (2010) found in a meta-analysis of 84 papers reporting the use of transmitters, anchoring or implantation, which both require anesthesia, had the highest reported transmitter-induced mortality rates. However, abdominal implantation of transmitters with percutaneous antennae can avert negative impacts such as diminished survival, increased predation, reduced physiological condition, and reduced fecundity; in a study of female Canada Geese, the implanted transmitters had no impact on migration dates and at most, a small effect on nesting propensity, but no effect on other measures of reproductive success and no impact on survival over one year in this particular species. Data on survival rates from years two to four were slightly lower, but not statistically significant, among birds carrying larger transmitters (Hupp et al. 2006). Subcutaneous implantation in female Wood Ducks did not affect reproduction, incubation, or survival as measured by interannual return rates over two years (Hepp et al.

2002). Interannual return rates of female Harlequin Ducks over two years with abdominal implants did not differ from that of birds without implants, despite a short-term reduction in mass (Esler et al. 2000). Captive Florida Sandhill Cranes (*Grus canadensis pratensis*) implanted with biotelemetry devices to measure heart rate and temperature showed no behavioral changes attributable to the transmitters or the surgery compared to control birds that had not undergone surgery or implantation (Klugman and Fuller 1990). Internally placed transmitters (i.e. in the abdominal cavity) appear to have fewer effects on reproduction (Rotella et al. 1993; Garrettson and Rohwer 1998), survival (Dzus and Clark 1996; Paquette et al. 1997), and behavior (Garrettson et al. 2000) than do external transmitters. A drawback to this technique is that the antenna is also contained in the body cavity, reducing reception range. Recent work by (Hupp et al. 2006) demonstrates that if an implanted transmitter is used with an antenna that exits the body, transmitting range increases.

Transmitter weight

Researchers should think carefully about how long data needs to be collected in determining the size of the transmitter needed. Briefly, transmitters need larger batteries to enable a longer period of data collection.

A typical guideline for the use of radio/satellite transmitters is that the transmitter not be more than 5% of a bird's mass (Cochran 1980). Caccamise and Hedin (1985) suggested that percentage of body mass is not the best determinant of the upper limit. Instead, they proposed a formula based on power requirements for flight to estimate the added cost of transportation due to the transmitter. In doing so, they illustrated that small birds can carry much larger loads relative to body mass than can large birds**.** Caccamise and Hedin (1985) also provided a general method based solely on body mass, with a process to refine that estimate for individual species by taking simple measurements of wing morphology and wing beat frequencies**.** Naefdaenzer (1993) tested the effects of radio transmitters on a various small passerine species in the 1990s. He concluded that even the smallest tits could carry up to 5% of their weight without impacts on behavior or survival. Wikelski et al. (2007) noted that the smallest commercially available satellite transmitters available in 2006 (9.5 g) were too large for ~81% of all bird species for which body weights are available following the 5% of body mass guideline. Warner and Etter (1983) found that both reproductive success and survival of female Ring-necked Pheasant (*Phasianus colchicus)* were inversely related to transmitter weight (including harness, battery, and antenna) with transmitters of between 1.98% and 3.22% of body mass. In contrast, Hines and Zwickel (1985) failed to find an effect of transmitters on survival of Ring-necked Pheasants with transmitter weights (including harnesses, antennae, and solar-power devices) ranging from 1.46% to 2.58% of body mass. Casper (2009) concluded that the 5% guideline is essentially arbitary and that the less-commonly cited guideline of 3% appears to have been extrapolated from a review of albatross and petrel studies correlating device loads with foraging trip durations and nest desertions.

In an meta-analysis of 84 papers assessing the impacts of radio transmitters Barron et al. (2010) found no relationship between proportional device mass and the magnitude of the effect when all studies were included in a regression. This suggests that relatively small devices had a similar effect as larger devices. Few studies used transmitters exceeding 5% of body mass and the meta-analysis did not compare the magnitude of effects between studies using devices above and below 5%. That there is little evidence that proportionally larger devices have greater effects suggests that increased attention to design, attachment method, and attachment site is warranted.

Weight may be less important than transmitter design. In a study of harness types, Steenhof et al. (2006) found that female Prairie Falcons (*Falco mexicanus*) that shed their harnesses and transmitters were far more likely to survive than birds that retained the equipment. The authors noted that the transmitters seemed to have no impact during the year the birds were marked; mortality apparently occurred after the birds left the breeding range, suggesting that the transmitters and harnesses may have hampered long-distance migration. The combined weight of the equipment was less than 5% of mass, leading the authors to suggest that a streamlined transmitter design that reduces drag may be more important than weight and that wing morphology and flight characteristics may be more important than body mass. Obrecht et al. (1988) suggested much the same based on the results of a wind tunnel study of the drag caused by dummy transmitters of various shapes and sizes. They found that the drag was sufficient to reduce flight range, which is an important factor in successful migration, and that drag was reduced if the transmitter was elongated with faired endings.

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