Chapter 7
Radio telemetry and bird movements

RADIO TELEMETRY

Understanding the role that wildlife play in the ecology of AI viruses requires knowledge of the detailed movements of wild birds over varying spatial scales. On the one hand, concurrence between the migratory patterns of some Palearctic breeding waterbirds and the spread of the H5N1 HPAI virus across Asia and Europe in the northern fall and winter of 2005/06 illustrates the importance of studies designed to identify specific migratory routes, stopover points and non-breeding areas that may span entire continents. On the other hand, studies documenting the local movements of wild birds between poultry farms and nearby wetlands may be invaluable to establish viable pathways of H5N1 HPAI transmission from poultry to wildlife (or vice versa).

Radio telemetry is a technique for determining bird movements over areas ranging in size from the restricted breeding territories of resident bird species to the movement patterns of international migratory species (reviewed in Fuller *et al*. 2005). Radio telemetry has important applications in the investigation of infectious diseases of migratory species, including H5N1 AI virus ecology. Specific objectives for AI-related telemetry studies have already been identified during the FAO-OIE International Scientific Conference on Avian Influenza and Wild Birds in May 2006[10]. In fact, telemetry projects tracking the local movements and migration routes of wild birds identified as potential virus hosts are already under way[11].

The basic concept of a radio telemetry study sounds simple; attach a radio transmitter to an animal and track the signal to determine the animal's movements. Because radio-marked birds can be relocated more frequently and consistently than those marked by other methods, telemetry can provide a history of detailed movements that is not possible with simpler mark-recapture or mark-resight studies. However, while it may be tempting to radio-mark a sample of animals just to "see where they go", the fact is that radio telemetry is a rather expensive proposition compared to mark-recapture/resight studies, and a successful telemetry project requires careful consideration, thorough planning, and specific objectives.

Having identified achievable objectives, several issues regarding the proposed telemetry project need to be addressed, including, but not limited to: 1) the type and size of radio transmitter; 2) the least invasive attachment technique; 3) capture and marking of the radio-transmittered sample; 4) the optimal tracking technique(s); and 5) data analysis

[10] www.fao.org/avianflu/en/conferences_archive.html

[11] www.fao.org/avianflu/en/wildbirds_home.html

options. Entire books have been dedicated to the subject of planning and conducting radio telemetry studies, so a thorough discussion of all the relevant issues is obviously beyond the scope of this Manual. The reader is instead directed to excellent reviews by Kenward (2001) and Fuller *et al.* (2005) for more detailed discussion of radio telemetry techniques.

The capture, handling and marking of wild birds are activities strictly regulated in most countries. Researchers should always be aware of and comply with local and national laws regarding these activities and obtain all the required local, state, provincial and federal permits.

Radio transmitters

In the past, radio transmitters were simple very high frequency (VHF) transmitters attached externally to the bird or implanted (Figure 7.1) with an accompanying power supply, antenna and mounting material. Recent technological advances have resulted in the development of Platform Terminal Transmitter (PTT; Figure 7.2) and Global Positioning System (GPS; Figure 7.2) transmitters with capabilities far beyond those of conventional VHF radio transmitters. While modern PTT and GPS transmitters operate using the same basic principles as VHF radio transmitters (emission of an electromagnetic signal at a specified frequency which is detected by receivers tuned to the frequency), these more advanced transmitters use orbiting satellites to receive and relay transmitter signals. Thus, VHF, PTT and GPS transmitters have very different characteristics which render them suitable for very different species and studies (Table 7.1).

The size of the transmitter in relation to the bird can be a limiting factor when considering PTT and GPS transmitters. The general rule of thumb is that a radio transmitter should not exceed 2-3 % of the bird weight, although this may increase to 3-4 % for smaller birds (<50 g). Using this measure, VHF radio transmitters are available for all but the smallest bird species, with the smallest transmitters weighing slightly less than 1 g. In contrast, the

FIGURE 7.1
Implanted VHF radio transmitter

FIGURE 7.2
Platform terminal transmitters (PTT; three on the left); Global Positioning System (GPS) transmitter (one on the right)

CREDIT: SCOTT NEWMAN

TABLE 7.1
Characteristics of radio transmitters used in avian telemetry studies

	Radio transmitter type		
	VHF	**Satellite (PTT)**	**Satellite (GPS)**
Transmitter wt.	< 1 g to 12	12-18 g	30-60 g
Species	> 20 g	> 500 g	> 1 kg
Minimum cost	US$ 100/ea	US$ 3,200/ea	US $3,800/ea
Attachment	Anchor, feather, implant	Collar, backpack, implant	Collar, backpack, implant
Power source	Battery	Battery or solar	Battery or solar
Duration	Days to months*	Months to years	Months to years
Range	0.1 to 100+ km*	Unlimited	Unlimited
Tracking	Manual	Satellite	Satellite
Tracking interval	Continuous*	4 hours	Continuous
Accuracy	± 5 m to 1 km*	±100 to 200 m	±10 to 20 m
Frequency	VHF	UHF	UHF

* Depends on the size of the transmitter and the tracking method employed.

smallest PTTs weigh 12-18 g, limiting their use to species weighing 500 g (e.g. small ducks and gulls) or more. GPS transmitters weigh 30-60 g, thus can only be used with large species weighing 1 kg or more (e.g. geese and swans).

PTT location accuracy is generally good (within 100–200 m) for most uses, although the larger and more expensive GPS transmitters greatly increase location accuracy (10-20 m). Location accuracy for VHF transmitters will depend mostly on the tracking method used and the effort expended. If radio-marked birds are tracked and visually sighted, locations can be pinpointed to within 5 m, but in many cases visual sightings are not possible and locations are estimated with varying degrees of accuracy using techniques specific to the tracking method (see *VHF Telemetry Tracking*).

A variety of useful options can be incorporated into VHF and satellite-based radio transmitters, although these options invariably increase the weight, power consumption and cost of the transmitter. Activity, temperature, pressure, and mortality sensors convey data by changing the transmitter pulse rate. Timers programmed to switch the radio transmitter on and off at specified times are a particularly useful energy-saving option. Timers can switch transmitters on to coincide with pre-scheduled tracking periods or times when predictable orbiting satellites are scheduled to pass overhead.

There are considerable differences in cost between satellite-based and VHF transmitters (Table 7.1) that may prevent the use of the PTT and GPS transmitters in projects with limited funds. However, PTT and GPS transmitters eliminate the need for expensive tracking equipment and personnel.

PTT and GPS transmitters

Despite their size and cost, if PTT or GPS transmitters are suitable for the species to be radio-marked, the logistic advantages compared to conventional VHF telemetry are considerable. PTT and GPS tracking is automated and conducted by satellite systems. Because PTT and GPS signals are received by orbiting polar satellites, there are no spatial tracking biases because the signals can be received from anywhere in the world, including remote or inaccessible areas where marked birds may be otherwise undetectable.

Fortunately, PTTs are suitable for radio-marking waterbirds and several other large species (>500 g) vulnerable to the H5N1 HPAI virus, thus satellite telemetry has broad applications in AI-related wildlife studies. Satellite telemetry provides opportunities to follow the movements and migratory routes of waterbirds that are not possible with any other technique. PTT transmitters provide a nearly continuous history of a bird's movements, revealing detailed information concerning the migration route, rate of travel and stopover duration during flights that may cross entire continents.

The longevity of solar-powered satellite-based transmitters allows long-term studies that can determine annual fidelity to specific migration routes and stopover points, data which may help identify high-risk disease outbreak zones. The accuracy of PTT and GPS transmitter locations also permits analysis of spatial and temporal habitat use, including possible overlap with poultry production and disease outbreak sites.

Strategies in which a few individuals are marked with PTTs and larger samples with conventional VHF radio transmitter or other marks (see *Mark-Recapture (Resight) Studies*) can increase sample sizes and mitigate the high costs of PTT transmitters.

VHF radio transmitter

Many smaller species susceptible to the H5N1 HPAI virus, including shorebirds, cormorants, rails, coots, grebes, corvids and sparrows, as well as the smaller ducks, gulls, raptors, herons and egrets, are not suitable candidates for satellite telemetry studies, either because they are diving birds or are too small (<500 g) to accommodate PTTs. The current limitations of satellite-based telemetry technology leave VHF transmitters the main option for these species.

Studies examining the long-range migratory movements of these species with VHF telemetry have been conducted, but are logistically difficult because they require the mobilisation of telemetry tracking teams across vast areas, many of which may be inaccessible to observers on the ground. Therefore, practical applications of VHF telemetry to AI-related studies are more likely to address issues such as the local movement of birds to assess their utilisation of areas where risks of exposure to AI viruses may be increased, such as on farms.

VHF telemetry studies require considerably more logistical planning than satellite-based studies, mainly due to the manual tracking efforts that are required. The need for manual tracking makes VHF radio transmitter features such as transmitting power (range) and operating life important considerations. Radio transmitter batteries are finite power sources, thus there is a direct trade-off between the range and operating life; increasing range decreases life and vice versa. The optimal compromise between the two depends on study objectives.

The transmitting range of the radio transmitter greatly affects the search effort required to locate the signal, thus range should be increased (at the expense of transmitter life) if the species is expected to move over a large area. Conversely, if the species is expected to remain in a relatively confined area, search effort is reduced and the range can be decreased, extending the transmitter life. Because the range and operating life are directly related to the size of the radio transmitter, the geographic scope and duration of telemetry studies on smaller species are limited compared to larger species.

VHF radio transmitters are available from a number of reputable vendors. The best advice we can offer is to read the telemetry literature and speak to knowledgeable and experienced researchers to determine which type is preferred for the species of interest. It should be noted that radio transmitter features (e.g. frequency, pulse rate, power and duration) are specified when the transmitters are ordered and are difficult if not impossible to modify once the transmitter is constructed.

CAPTURE AND RADIO-MARKING

It is generally assumed that radio-marking will have some effects on the animal, but efforts can be made to minimise marking effects so that they do not disrupt the normal movements and behaviour of the marked individual. This is good for the marked animal, and it is also good for the study. Detrimental effects of radio-marking can be reduced by: 1) minimising capture and handling time; 2) using the smallest possible radio transmitter suitable for the objectives of the study; and 3) using the most inconspicuous and best fitting attachment method available.

Capture techniques have already been discussed (*see Chapter 3*) and it is assumed that a reliable technique has been identified and preferably field-tested before actual radio-marking is conducted. Well-planned efforts will help minimise the time in captivity and the stress associated with capture and radio-marking. Having said this, a brief observation period in a quiet secluded holding area is advisable after radio-marking to allow the bird to recover from the procedure (especially if anaesthetics are used) and to detect any problems before release.

To minimise time in captivity, marking procedures should be conducted at or as near as possible to the capture site. If possible, schedule captures to avoid periods when birds may already be physiologically stressed, such as breeding or migration. If bird movements during these sensitive periods are of interest, attempt to capture and mark individuals a few weeks before the event, when handling is less likely to disrupt breeding or migratory behaviour. This also gives the bird time to recover from capture stress and become accustomed to the transmitter before nesting or migration begins.

The long-term effects of radio-marking on an animal depend largely on the radio transmitter itself and method used to attach it. Intuitively, larger and more cumbersome transmitter/attachment packages are more likely to have greater negative effects. There is always a tendency to use the largest radio transmitter suitable for the species of interest, regardless of the study objectives; however, the use of smaller transmitters is strongly advised if they meet the objectives of the study, because they are less disruptive and less costly.

External transmitters undoubtedly increase aerodynamic drag during flight (and hydrodynamic drag for diving species) and several studies have documented decreased survival, reduced reproductive success, lower chick feeding rates and other detrimental effects. Ideally, the transmitter would remain attached for the duration of study, then fall off soon

FIGURE 7.3
Telemetry transmitter attachment using a neck collar

CREDIT: USGS WESTERN ECOLOGICAL RESEARCH CENTER afterwards, but this is seldom the case. Transmitter retention for the duration of the study is never guaranteed, regardless of the method used.

External attachment techniques have been developed that indirectly attach transmitters to birds via a neck collar (Figure 7.3), backpack harness (Figure 7.4) or leg band (Figure 7.5). Neck collars and backpacks generally have excellent transmitter retention (often for the life of the bird) and are currently the only attachment methods available for PTT and GPS transmitters. Various harness designs are available that provide better fits to particular species because poorly fitting harnesses may cause abrasions or impede wing movement. VHF transmitters attached with leg bands also have excellent retention, but problems with transmission range have been noted, possibly due to the shorter antennae and proximity to the ground.

Other external radio-marking techniques use adhesives (e.g. glue, tape, epoxy, resins, etc.), sutures and stainless steel prongs (Figure 7.6), either alone or in combination, to attach VHF radio transmitters directly to the bird. Transmitter retention is generally good for a few weeks to a few months (rarely longer); although a certain amount of early transmitter loss should be expected when using these techniques. Care should be exercised when applying adhesives because some are known tissue irritants. The use of sutures and prongs requires relatively simple medical procedures, but they are still invasive techniques and the assistance of qualified veterinarians is highly recommended until the researcher gains some experience with these methods.

External radio marks may disrupt behaviour for short periods as the bird adjusts to the transmitter, and some species will not tolerate the transmitter at all. For species intolerant of external radio transmitters, abdominal or subcutaneous implants are an option. Radio

FIGURE 7.4
Telemetry transmitter attachment using a backpack harness

CREDIT: NICOLAS GAIDET

FIGURE 7.5
Telemetry transmitter attachment using a leg band

CREDIT: USGS WESTERN ECOLOGICAL RESEARCH CENTER

FIGURE 7.6
Telemetry transmitter attachment using a subcutaneous prong and suture

CREDIT: SCOTT NEWMAN

transmitter implants involve highly invasive surgical procedures and are best left to qualified veterinarians or wildlife biologists specifically trained for the technique.

Again, the best advice is to read the telemetry literature and speak to knowledgeable and experienced researchers to determine which attachment technique has proven most effective for the species of interest. Field trials marking small numbers of birds are always helpful to identify detrimental radio-marking effects and potential transmitter retention problems before costly projects begin.

VHF TELEMETRY TRACKING

It is sometimes assumed that the difficult part of a telemetry project is finished once the radio-marked animals are roaming freely, waiting to be located. While this may be true for satellite telemetry studies, VHF telemetry studies require considerable search effort devoted to finding and determining location coordinates for the transmitter-marked samples. All the expense and effort that goes into radio-marking a sample of birds is wasted if effective telemetry tracking techniques are not employed.

Telemetry tracking employs a VHF receiver (Figure 7.7) connected by coaxial cables to a receiving antenna(e) to search for signals emitted by the radio transmitters. The most practical receivers allow the user to programme the desired frequencies into the unit, scan for signals at pre-set intervals, and stop the scan when a signal is detected. Adjustable volume and gain (power to receive the signal) controls are also useful. Some models have jacks to attach headsets, a particularly important option to block extraneous noise when conducting aerial surveys. Advice from experienced researchers is invaluable when considering the different receiver models available.

The most important features to consider with telemetry antennae are portability and directional capability. Directional capability is a result of the reception pattern of the antenna in which noticeable peak and null signals are heard depending on the orientation of the antenna in respect to the signal source. The most common antennae used in avian telemetry studies are the Adcock H and Yagi antennae (Figures 7.8, 7.9 and 7.10).

The H antenna has less directionality compared to the Yagi, but has only two elements, thus is smaller and easier to use when tracking on foot. The Yagi has the best directional capability of all the common telemetry antennae, but with a number of long cross ele-

FIGURE 7.7
VHF receiver and switch box used for aerial tracking in conventional telemetry studies

CREDIT: SCOTT NEWMAN

ments, is also the most cumbersome. Yagi antennae are used primarily on masts mounted onto vehicles, at fixed receiving stations, or attached to the wing struts of aircraft.

Telemetry tracking surveys are most often conducted from ground-based or aerial platforms, but the methods for determining location coordinates differs between the two platforms. Aerial surveys are conducted with a single receiver attached to two directional antennae mounted on either side of the aircraft. The receiver is set to scan frequencies

FIGURE 7.8
Four-element Yagi antenna mounted on aircraft strut

CREDIT: SCOTT NEWMAN

FIGURE 7.9
Yagi antennae mounted on a tower at a remote tracking station attached to a data logger

CREDIT: SCOTT NEWMAN

FIGURE 7.10
Hand-held Adcock H antenna

CREDIT: SCOTT NEWMAN

through both antennae as the observer(s) listen through a headset. When a signal is detected, the observer switches back and forth between antennae with a switch box to determine on which side of the aircraft the signal is located and directs the pilot to manoeuvre the aircraft accordingly. As the signal is "boxed" in with a series of turns, the signal becomes progressively stronger until it is the same on either side of the aircraft, at which point the location coordinates are recorded.

Ground-based surveys, conducted on foot or in a vehicle, utilise a technique called "triangulation" to accurately locate signals. Scanning from a fixed location with known position coordinates, the signal is detected with a directional antenna and the bearing to the point of the strongest signal is recorded. Shortly thereafter, the procedure is repeated at another nearby location. When the bearings from the fixed listening stations are plotted, two intersecting lines are produced that indicate the approximate signal location. Some vehicle-based systems increase directional capability by using two precisely-configured Yagi antennae mounted on a mast.

A combination of aerial and ground-based (or shipboard) surveys is often the most effective and cost-efficient tracking strategy. Aerial surveys offer more extensive spatial coverage and greater signal reception range, but locations are less accurate and surveys are more expensive. By contrast, ground-based surveys provide more accurate locations, often allow observations of marked individuals and are less costly. Utilising the strengths of both techniques, aerial surveys can be used to approximately locate signals over a large area and direct ground-based surveys for more accurate locations. Although ground reception range is limited compared to aerial surveys, scanning from hills, towers and other elevated points will greatly increase the range.

Programmable data loggers are data storage devices that are attached to or incorporated into receivers and allow remote tracking from fixed receiving stations. Data loggers are most useful for recording the presence/absence of marked birds within a restricted area and could have important applications for AI-related studies, such as continuous monitoring for the presence of marked birds in poultry farms or near disease outbreak sites.

Like receivers, data loggers have an internal battery, but external power sources (e.g. solar panels or 12-V batteries) can greatly extend the time between maintenance visits. Data loggers can be programmed to conduct continuous scans or scan at pre-set intervals to save battery power. Data can be downloaded directly into laptop computers in the field.

With the availability of reliable, accurate and affordable GPS units, the days of marking telemetry locations on topographic maps are just about over. Hand-held GPS units are particularly useful for marking the location coordinates of radio transmitter-tagged animals or monitoring stations, and delineating areas covered during telemetry tracking surveys. Their ease of use, portability and compatibility with most spatial analysis software makes GPS units required equipment for any radio telemetry study.

DATA ANALYSIS

Since its inception as a wildlife tracking technique in the early 1960s, radio telemetry has been used to study local movements, dispersal and migration routes, estimate home ranges, habitat use and selection, estimate population abundance, examine intra- and inter-specific relationships and estimate survival. Analysis of animal movement and distribution has become a sophisticated science in itself, and the details of specific analysis techniques are best found in reviews by White and Garrott (1990) and Fuller *et al.* (2005).

Fortunately, from the perspective of AI ecology, the primary use of radio telemetry data is relatively straightforward; examining movement and habitat preferences of potential host species that may acquire and transmit the viruses, determining the potential overlap between wild bird and poultry habitat use, and determining if wild bird movements temporally coincide with new outbreaks in wild birds or poultry. For example, telemetry data can establish current migration routes of waterbirds to reveal possible temporal and spatial relationships between their movements and patterns of AI outbreaks in wildlife and poultry. This could be accomplished simply by plotting telemetry locations together with disease outbreak data and visually inspecting the resulting map. However, care should be taken when designing telemetry studies to make sure that the observed movements are representative of the population, because different portions of a population (sexes or age cohorts) may exhibit different movement patterns.

Over smaller scales, using telemetry data to establish the local movements and habitat preferences of wild birds might involve home range analyses to examine direct overlap with poultry farm operations, as well as indirect exposure to infectious materials such as poultry farm waste runoff into wetlands. Home range analysis uses telemetry locations to describe an animal's spatial distribution over a specified time. Home range analysis could be as simple as connecting locations to form a minimum convex polygon that theoretically encompasses the animal's total area of use. Or it may involve complicated probabilistic models reflecting differential use patterns over an area (e.g. adaptive kernel home range) that require sophisticated geographic information system (GIS) programs.

Familiarity with GIS is by now an indispensable skill for those working with animal movement and spatial data. The program Arcview GIS, among others, offers a vast array of options which allow the user to plot locations, quickly calculate distances and movement rates, and perform movement, home range, habitat use and a variety of other spatial analyses. GIS programs also have sophisticated mapping capabilities which permit visual and statistical analyses of relationships between marked birds and habitat or climatic variables.

The availability of high quality satellite imagery of the earth's surface through computer programs such as Google Earth[12] with add-on capabilities will allow the user to plot GPS locations and visualise movements of birds in relation to their environment.

MARK-RECAPTURE (RESIGHT) STUDIES

Prior to the advent of radio telemetry technology, studies of animal movements were conducted using mark-recapture or resighting techniques. Mark-recapture (or resight) studies are conceptually simple and straightforward. Basically, animals are captured, marked for later identification, and released. Subsequent recaptures or resightings, depending on the marking technique, provide information concerning the movements of the marked individuals. Mark-recapture studies are applicable to any bird species which can be safely captured and marked, and depending on the range of the species, can extend over extensive geographic areas limited only by the efforts of the research team.

The marking of wild birds is widely used to investigate the location-specific aspects of avian biology where large numbers of birds may be marked with a combination of colours and/or numbers to provide individual bird recognition. Individual marking provides a valuable tool to study movements of migratory waterbirds and has been increasingly used in conjunction with avian influenza surveillance. It is important that any planned marking project is approved through the responsible country or regional agencies to ensure that the proposed scheme will not conflict with other current or planned marking programmes.

There are well-coordinated marking schemes for different species in Eurasia through EURING[13], Africa through AFRING[14], the Asia-Pacific region[15], and a variety of schemes within the Americas.

The principal consideration when choosing a marking method is to avoid techniques that will adversely affect the health, survival, behaviour or reproductive success of the marked individual. Some techniques that are appropriate for one species may not be appropriate for another. Trial studies marking small samples may be warranted to assess

[12] Available for free download from http://www.earth.google.com.

[13] http://www.cr-birding.be/

[14] http://www.safring.net

[15] http://wetlands.tekdi.net/colorlist.php

effects before marking large numbers of birds. As for all capture and handling activities, the marking of wild birds is strictly controlled in most countries and permits should be acquired from the proper local, state, regional, provincial and federal authorities.

Table 7.2 lists a variety of marking techniques and some important characteristics to consider when planning a mark-recapture study. Does the technique allow identification of marked individuals or are birds marked as a group? Is the technique invasive? Is recapture or resighting the most efficient means of obtaining the desired data? Answers to these questions will help determine the optimal marking technique.

Numbered metal leg rings (or "bands") are the most common and widespread method of marking birds. Rings are (or should be) placed on every bird that is captured and released into the wild. Numbered metal rings allow for individual identification of marked birds, but birds must be recaptured in order to read the numbers. A combination of metal and coloured plastic rings (Figure 7.11) has been used on a variety of long-legged bird species (e.g. shorebirds). The coloured plastic rings or flags permit individual recognition without the need for recapture. Rings and ringing techniques were discussed in more detail in *Chapter 4*.

Although birds marked with metal leg rings require recapture, rings are probably the least disruptive of the marking techniques described here. The other techniques result in conspicuous external marks that may be visible from a distance, but also may cause detrimental physical and behavioral effects. In fact, patagial and web tags require an invasive procedure in which the skin is punctured to attach the tag. Birds marked with patagial or web tags can be identified from a distance, but may need to be recaptured if the tag numbers are too small to read.

Neck collars (Figure 7.12), nasal discs (Figure 7.13), nasal saddles, and coloured leg bands or flags provide conspicuous marks that permit identification of marked individuals over long distances with the aid of binoculars or a spotting scope. With highly visible external marks, these techniques are especially valuable for local studies examining habitat

TABLE 7.2
Wildlife marking techniques commonly used in avian studies*

Marking Technique	ID	Invasive	Codes	Recapture -Resight	Duration
Leg Rings					
Metal	Ind	Non	Number	Recap	Life
Plastic, Darvic	Ind	Non	Colour	Resight	Months/Life
Neck collars	Ind	Non	Colour+number	Resight	Life
Nasal discs	Ind	Inv	Colour+shape	Resight	Life
Nasal saddles	Ind	Inv	Colour+number	Resight	Life
Streamers	Group	Non	Colour	Resight	Weeks
Flags	Ind	Non	Colour+number	Resight	Life
Plumage dyes	Group	Non	Colour	Resight	Weeks
Patagial tags	Both	Inv	Colour+number	Both	Life
Web tags	Both	Inv	Colour+number	Both	Life

* Characteristics for each technique include whether the mark permits identification of birds as individuals (Ind) or a group; invasiveness of the technique (invasive [Inv] or non-invasive [Non]); whether number, colour or shape codes are used to identify marked birds; whether data are acquired through recaptures or resightings; and duration of the mark.

FIGURE 7.11
Coloured leg rings used as a marker in mark-recapture or resight studies

CREDIT: ROB ROBINSON

overlap between domestic and wild waterbirds near open farm systems. In fact, many of these techniques are commonly used in waterbird studies. However, care should be exercised when attaching nasal discs or saddles because poorly fitting marks can easily become entangled in vegetation and their use is not recommended for diving species.

Plumage colouring agents provide conspicuous external marks that are often visible over very long distances but do not permit individual identification. Dye, paint or bleaches applied to feathers are generally most conspicuous on evenly coloured species; dark dyes for lighter birds and light dyes or bleaches for darker birds. Birds marked with dye, paint or bleaches should be visible until feathers are shed during the next body moult, thus timing of the marking relative to moult patterns is critical. Care should be exercised when applying colouring agents because they may irritate sensitive tissues.

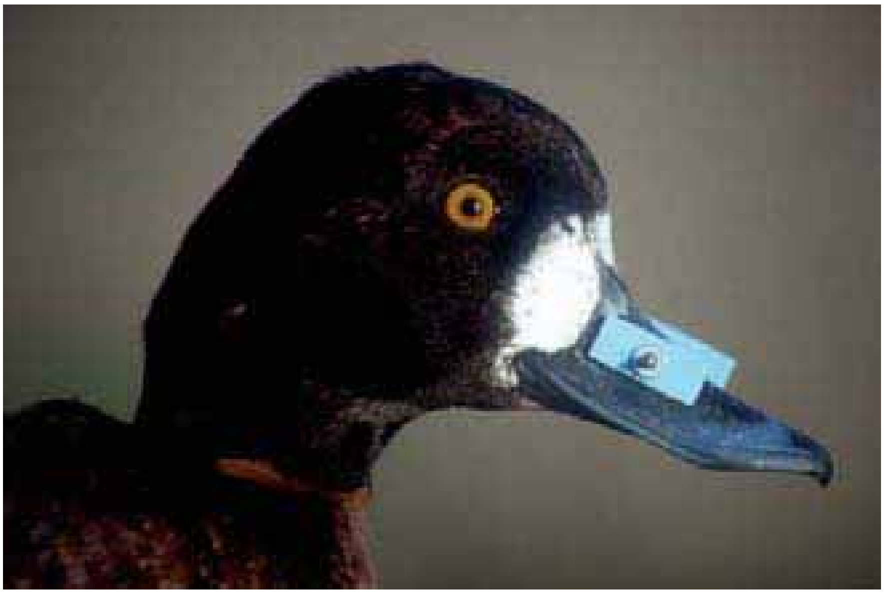
Coloured plastic streamers offer another conspicuous external mark that is visible over long distances, but does not permit individual identification. Plastic streamers and plasticised PVC tape attached to leg bands, neck collars or tail feathers provide a short-term mark that should degrade and fall off over time (weeks to months). Streamers should be cut to a length that is visible from a distance, but short enough to avoid entanglement in vegetation.

Most mark-recapture studies require the capture of sizable samples of birds, and several capture techniques were discussed in *Chapter 3*. However, creative remote marking techniques have been developed that avoid the stress that invariably accompanies capture and handling. Remote marking techniques for birds usually involve the application of non-toxic dyes or paints that colour the plumage when birds visit nest sites or water sources where the agent has been applied. These methods generally do not allow for individual identification of marked animals, but should be considered if group marking fits the objectives of the study. For example, dyes introduced into water sources in open poultry farms can be used

FIGURE 7.12
Neck collar used as a marker in mark-recapture or resight studies

CREDIT: NYAMBAYAR BATBAYAR

FIGURE 7.13
Nasal disc used as a marker in mark-recapture or resight studies



CREDIT: DARRELL WHITWORTH

to temporarily mark wild birds and determine if movements between farms and natural wetlands are occurring.

Mark-recapture studies require considerable post-release recapture or search effort, often over large geographic areas, to obtain the desired movement data. Marking should only be conducted if adequate resources are available to conduct follow-up surveys. Communication and coordination with other researchers and wildlife managers (always a good thing) to make them aware of the presence of marked individuals will maximise the recapture and resighting returns.

STABLE ISOTOPE ANALYSIS

The recent emergence of stable isotope analyses (SIA) has added a powerful tool to the study of broad avian migration patterns. The utility of stable isotopes (e.g. hydrogen, carbon, nitrogen) as indicators of avian migration patterns is based on the strong correlation between the concentration of some isotopes in the environment and the concentration of these same isotopes as they are assimilated in avian tissues, most notably feathers. Since some isotopes in the environment tend to demonstrate predictable patterns over continental scales, the concentration of isotopes in feathers can reflect the general location of the bird when moult and feather growth occurred. SIA requires sophisticated laboratory techniques that are beyond the scope of this Manual, but Hobson (1999) provides an excellent review.

The spatial resolution of SIA is probably in the order of many hundreds of kilometres on latitudinal scales and even greater longitudinally. Although SIA cannot be used to examine detailed movements or identify specific breeding sites, it can reveal broad migration patterns that do have applications in AI-related studies; for example, determining the general breeding areas of waterbirds captured on staging or non-breeding grounds, or collected at disease outbreak sites.

Despite its limitations, the SIA technique does have advantages. Birds only have to be captured once and need not be marked in any way to determine their broad scale movements. The SIA sampling procedure, removing a small number of feathers, is very simple and can be performed on any species regardless of size. SIA does not suffer the geographic biases associated with mark-recapture or VHF radio telemetry studies in which remote areas are rarely sampled. Although satellite telemetry does not suffer from similar geographic biases, it is very expensive compared to SIA.

REFERENCES AND INFORMATION SOURCES

Fuller, M.R., Millspaugh, J.J., Church, K.E. & Kenward, R.E. 2005. Wildlife radiotelemetry. *In* Braun, C.E., ed. *Techniques for wildlife investigations and management*, pp. 377-417. The Wildlife Society, Bethesda, USA.

Hobson, K.A. 1999. Tracing origins and migration of wildlife using stable isotopes: a review. *Oecologia*, 120: 314-326.

Jessop, R., Collins, P. & Brown, M. 1998. The manufacture of leg flags in the light of experience. *Stilt,* 32: 50-52.

Kenward, R.E. 2001. *A manual of wildlife radio tagging*. Academic Press, London.

Silvy, N.A., Lopez, R.R. & Peterson, M.J. 2005. Wildlife marking techniques. *In* Braun, C.E., ed. *Techniques for wildlife investigations and management*, pp. 339-376. The Wildlife Society, Bethesda, USA.

White, G.C. & Garrott, R.A. 1990. *Analysis of wildlife radio-tracking data.* Academic Press, San Diego, California, USA.