

ABSTRACT

Title of Document: THE DEVELOPMENT AND TESTING OF
THREE TECHNIQUES FOR ATTACHING
SOLAR-POWERED GSM SATELLITE
TRANSMITTERS ON SURF SCOTERS

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Sciences

Implanted satellite transmitters are used in seabirds to track migration routes, breeding, and wintering grounds. However, high mortality rates, handling stress, and inadequate small-scale location data necessitates the use of external transmitters. Three external transmitter attachment techniques were tested on 12 surf scoters (*Melanitta perspicillata*) including a Teflon tape harness, sutures to anchor the transmitter through the dorsal vertebral processes, or a 3D individually customized silicon harness. Body weight, serum and hematology chemistry, behavioral time budgets, and dive performance provided measures of impacts for each transmitter. Global System for Mobile Communications (GSM) transmitter performance was evaluated for accuracy, precision, and battery

performance for use in seabirds. All methods had transient effects on weight, serum chemistry, immune response (sutured transmitters), and increased bottom and total dive times. Teflon harnesses impacted behavior. Silicon harnesses induced the least deleterious effects compared to other treatments. We recommend use of silicon harnesses for deploying external transmitters in wild seabirds.

THE DEVELOPMENT AND TESTING OF THREE TECHNIQUES
FOR ATTACHING SOLAR-POWERED GSM SATELLITE
TRANSMITTERS ON SURF SCOTERS

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List of Abbreviations

PTT – Platform terminal transmitter

PWRC- Patuxent Wildlife Research Center

GPS – Global positioning system

GSM – Global system for mobile communications

Literature Review

Introduction:

Biotelemetry has undoubtedly become the primary resource for studying movement and habitat use in wildlife populations. Beginning in the 1960's with simple "build-it-yourself" radio-transmitters, the technology has progressed to extremely advanced satellite transmitters with profound abilities (Dywer 1972, <http://www.microwavetelemetry.com/bird/GSM.cfm> 2014). These advances have opened new study possibilities. Almost any species: from fish, to birds, to small terrestrial mammals, and more are now studied with remarkable resolution. As an economically and ecologically important species, a great deal of research has been performed on waterfowl. A large body of work follows the history and evolution of tracking these animals. As technology advanced, researchers have adapted new techniques and methods for attaching and retaining the new transmitters on many species of waterfowl. A primary focus of these studies has been the investigation of the effects imparted by these techniques. Recently, with changing research needs and more advanced devices, new methods are desired to harness this technology.

Sea ducks species are one such group of waterfowl that are common subjects of telemetry studies. There are 15 species considered sea ducks. Most species are common along the Atlantic coast, where they winter in the coastal bays and just offshore in the Atlantic Ocean. One of the more common species in the Chesapeake Bay is the surf scoter (*Melanitta perspicillata*), where they can be found in the highest densities of all their wintering sites. They are also common in the Delaware Bay, and off of the Atlantic

Coast between the mouths of these two bays (Silverman et al. 2013). Despite being listed as a species of least concern, there is mounting evidence of declines in the species (Berlin 2006, Silverman et al. 2013). This has prompted a number of surveys and satellite telemetry studies. As there is little known about these species, the initial goal of the telemetry studies was to delineate migration routes, wintering, molting, and breeding areas, for the purpose of informing survey design. With recent offshore wind farm development plans, the focus of telemetry studies has switched from long-range migration and general use areas to fine scale habitat utilization throughout their coastal range. These current research goals are unobtainable with the current use of battery powered implantable satellite transmitters. Past studies have noted deleterious effects of external transmitters on sea ducks, leading to the use of implantable transmitters in surf scoters. However, new technology, in the way of solar-powered GPS transmitters, has the potential to answer the current research questions. Our objectives in this study are to 1) examine the performance of solar-powered GSM-GPS satellite transmitters; 2) develop and test methods for externally attaching these transmitters; and 3) determine the effects of each method on weight, hematology and serum chemistry, behavioral activity budgets, and diving performance.

History of Transmitters:

Early radio-transmitters were simple electrical circuits constructed and packaged by the researchers (Dwyer 1972, Swanson et al. 1976). These radio devices performed the same as the radio-transmitters today, emitting an ultra high frequency (UHF) or very high frequency (VHF) signal that is unique to the transmitter (Walls and Kenward 2007). An antenna is used to filter out other frequencies and detect signals from the desired

transmitter. This requires an active researcher using an antenna to locate and monitor the animal (White and Garrott 1990). Due to this, the range of radio-tracking studies is extremely limited in range (White and Garrott 1990). Radio-transmitters placed on waterfowl can typically be located by ground-based antenna at ranges of 1.5-2.5 km up to around 7 km (Perry 1981, Pietz et al. 1995, Iverson et al. 2006). Antennas are often mounted on planes to increase this range upwards of 12 km (Perry 1981). Once an outfitted animal leaves the range of the antenna, it cannot be tracked until within range again. When tracking waterfowl, the marked individuals can leave the study range and no longer be found; resulting in lost data, time, and money (Perry 1981). While these transmitters still have many relevant applications in regional studies, current long range migration studies in waterfowl cannot utilize these devices.

Although satellite transmitters were available, it was not until the 1980's that technology allowed for these transmitters to be produced in packages small enough to track birds (Britten et al. 1999, Meyburg and Fuller 2007). The small satellite transmitters earned the nickname PTT, which stands for platform transmitter terminal. Researchers began attaching the smaller devices to birds of all species, reporting on their uses, benefits, and drawbacks. These early satellite transmitters operate within a network of satellites that contain the Argos system (Meyburg and Fuller 2007). The Argos system is a software platform that is installed in certain polar orbiting satellites that collects sensor and location data from compatible devices (Argos User Manual 2013). Polar satellites pass directly, or near directly, over the north and south poles on each orbit, which takes approximately 100 minutes. This results in about 14 passes over each pole per day. Because they pass through the poles on each orbit, transmitters at higher

latitudes have more opportunities to transmit locations. Sitting at an altitude of 850 km above earth, the satellite's range has a circular radius of about 2500 km from the point of earth perpendicular to their location. This transfers to less opportunity to transmit locations for transmitters at lower locations, as smaller longitudinal distances are covered towards equatorial locations. Figure 1 shows the average coverage of single satellite on two subsequent orbits through the poles. The number of satellites with the Argos system has doubled since 2006, alleviating many coverage issues (Argos User Manual 2013). However, large errors may occur due to the method of estimating transmitter location.

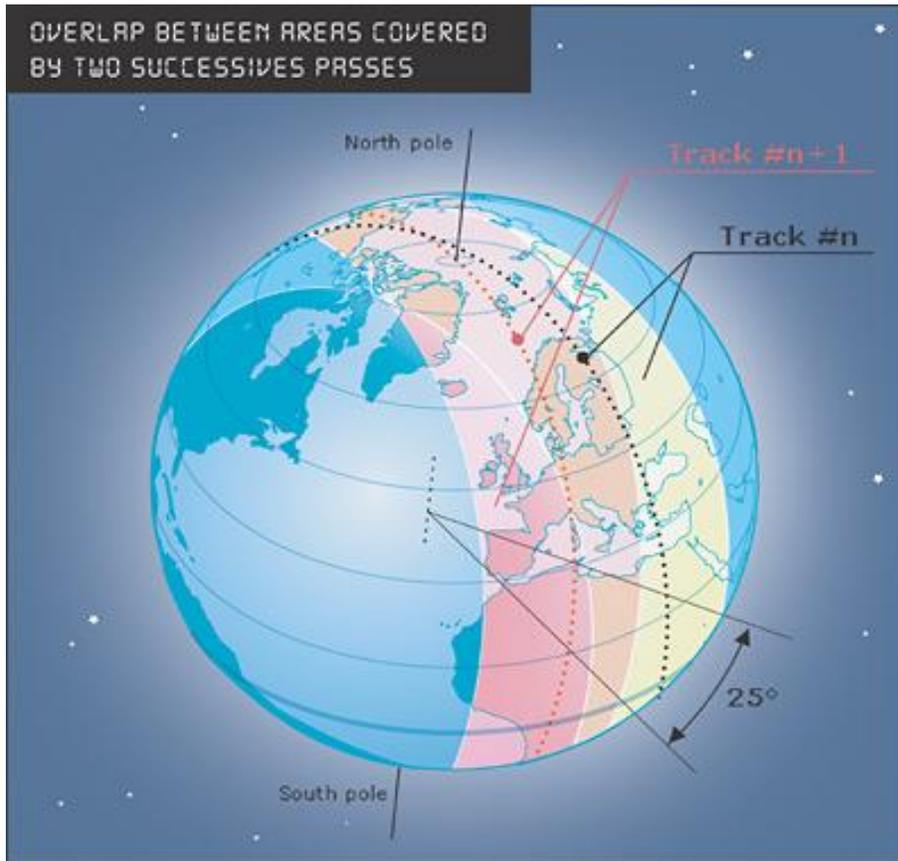


Figure 1: A depiction of a single Argos satellite and its coverage on two orbits. The amount of overlap is much greater at the poles, allowing for more location fixes (Argos User Manual 2013).

The Argos system uses the doppler effect to estimate transmitter location (Meyburg and Fuller 2007, Argos User Manual 2013). Each transmitter emits a specific frequency between 401.620 MHz and 401.680 MHz at a given rate, usually 1 transmission per minute (Argos User Manual). As a satellite approaches within range of a transmitter, it analyzes the frequency transmissions received from a transmitter. According to the doppler effect phenomenon, as the satellite is moving towards the transmitter, the frequency received by the satellite will be higher than the frequency transmitted by the device. Likewise, the frequency will be lower as the satellite is moving away. Using these measurements, the Argos software can estimate the inflection point at which the frequency transmitted equals the frequency received and determine when that satellite passed over the transmitter (Argos User Manual 2013). These locations are then filtered by Argos software and categorized into classes by their estimated errors. Location classes 3, 2, 1, and 0 correspond to decreasing accuracy estimates. Location class 3 is associated with an error of 250 m or less. Location class 2 is between 250 m and 500 m. Location class 1 has an error of greater than 500 m but less than 1500m. Lastly, class 0 locations have an estimated error greater than 1500 m (Argos User Manual 2013). Additionally, location classes A, B, and Z are given when no estimates of error are available, or when no location is estimated at all (Britten et al. 1999). The most accurate estimates, locations 2 and 3, only occur 10-15% of the time (Meyburg and Fuller 2007). In other words, researchers can expect, at best, 15% of the time their study animal will be within 500 m of a given location. Coupled with the constraints of battery life, most Argos transmitters become quite limited in their application.

As radio transmitters are capable of monitoring animals in local habitats, most satellite transmitters have been implemented for long distance and duration studies (Meyburg and Fuller 2007). However, in order to get the yearlong migration and breeding data, the transmitters cannot remain turned on as the battery will die far in advance. A standard waterfowl-sized PTT manufactured by Microwave Telemetry Inc. has a battery life of up to 1000 hours (http://www.microwavetelemetry.com/bird/batteryPTT_45g.cfm 2014). If left on, this translates to only 41 days of transmitter life. To remedy this problem, transmitters are programmed to turn on and off at a set interval. This is known as the duty cycle. Traditional duty cycles can range from 4 hours on and 72 hours off to 13 hours on and 24 hours off, depending on the question under study (Britten et al. 1999). More conservative duty cycles can see battery life extend beyond two years (http://www.microwavetelemetry.com/bird/batteryPTT_45g.cfm, 2014). These transmitters have proven themselves to be quite useful in delineating waterfowl migration routes and breeding areas (Douglas et al. 2012). However, as the focus of studies switches to small scale movement and habitat use, these PTT's are quickly losing their effectiveness. The newest technology addresses these issues first hand.

New solar-powered GPS PTT's are able to obtain precise location estimates as often as every minute (<http://www.microwavetelemetry.com/bird/GSM.cfm> 2014). Traditional GPS antennas are added to these transmitters, negating the need for a satellite to be outfitted with the Argos software (<http://www.microwavetelemetry.com/bird/GSM.cfm> 2014). In suburban testing of GPS transmitters, Adams et al. (2013) found the average location error to be 30 m.

Additionally, because the battery can be recharged via the solar panel, transmitters in sunny areas can actually be left on at all times. GPS units have the added benefit of data logging. Traditional Argos transmitters can only transmit data through an encoded radio-wave emission (Argos User Manual, CLS Group, 2014). This greatly limits the amount of data that can be transferred by a PTT. New GPS units only use satellites to determine location. These locations are then shared through cellular networks. Cellular networks have the capability of transferring large amounts of data in short time periods. As such, large data loggers are placed in the GPS transmitters so that locations can be stored when transmitters are outside of cellular network range. Once within range, cell towers can then download the logged data. The loggers have the ability to store up to 258,000 GPS locations (<http://www.microwavetelemetry.com/bird/GSM.cfm> 2014). That equates to one year of GPS fixes recorded every two minutes. The solar powered transmitters also deliver much longer life spans. Microwave Telemetry lists transmitter life as 3 years, but have had transmitters last as long as 9 years (<http://www.microwavetelemetry.com/bird/GSMspecifications.cfm> 2014). While the new technology is certainly very promising, it is important to completely understand the performance that can be expected from these devices.

While the effectiveness of the GPS devices is documented, little has been done to understand the charging capabilities of the solar panel under different light conditions and temperatures. This is particularly important because the PTT's are programmed to decrease GPS fixes and data transmission as the battery voltage decreases (<http://www.microwavetelemetry.com/bird/GSMspecifications.cfm> 2014). In fact, after the battery reaches a certain low voltage threshold, a transmitter will turn off until the

solar panel is able to fully charge it again. There is also evidence that extreme cold may inhibit the batteries ability to operate. Because of these sensibilities, our goal is to investigate temperature and voltage trends while attached to the ducks to estimate performance. Additionally, we would like to understand how feather coverage will affect the battery performance, as waterfowl have a tendency to preen feathers over backpack harnesses (Davenport et al. 2012). Although the capabilities of the solar power PTT's far exceed those of traditional Argos PTT's, these transmitters are limited to external mounting only.

Transmitter attachment:

One of the most heavily studied questions regarding telemetry in waterfowl species is how to attach transmitters and how these attachment methods affect bird behavior. Over time, many different methods have been employed to attach transmitters to birds, and many studies have found varying effects in different waterfowl species. Through these studies, two main methods have become the recommended techniques for long-term transmitter attachment. The first is through the use of Teflon ribbon (Bally Ribbon Mills, PA, USA) to create a backpack style harness, with the transmitter mounted dorsally. Although the research indicates behavioral and health impacts on outfitted waterfowl, it is the primary method used in dabbling ducks for satellite telemetry today. There has also been a small amount of research done on diving ducks and seaducks using the harness method. These studies have noted large impacts on outfitted birds. Because of this, a technique of implanting satellite transmitters was developed. While this method has also been found to have effects on the birds, it is the current method used for implementing transmitters in diving waterfowl. There are a few primary drawbacks to

these transmitters. First, mortality associated with surgery and implantation is considered too high, ranging anywhere from 10% to 50% depending on species. Also, the transmitters are limited to the Argos system and, therefore, do not have the advantages of the solar-GPS transmitters. With the focus of studies changing from delineating migration routes and important breeding and wintering areas to fine-scale habitat use, further investigation into back-pack harnesses is warranted, as traditional implanted transmitters do not meet these study needs.

Early attempts at attaching transmitters to waterfowl were fairly crude. Researchers tried methods from nasal saddles to leg-mounted and tail-feather mounted transmitters (Perry 1981, Robert et al. 2006). In the early 1970's, Dywer (1972) created the harness design that has been adopted as the primary method for attaching transmitters to puddle ducks. Although he used different materials to construct the harness, the general fitting idea has remained the same. The need for long-term retention was not an issue with radio-transmitters, and so materials did not need to be as long lived. Dywer (1972) used a flexible PVC tubing to attach the transmitters. Most modern studies however, use corrosion resistant Teflon ribbon (Cappelle et al. 2011, Cumming and Ndlovu 2011). This harness style is known as the two-loop harness. Two loops, one anterior and one posterior, are attached to the transmitter. The anterior loop sits forwards of the wings, but far enough back so as not to interfere with breathing or swallowing in the ducks. The posterior loop sits behind the wings, but forward of the legs. Figure 2 shows a diagram of the two-loop harness. Since this time, the only modification that has been made to the design of the harnesses is the addition of a small strip of material to connect the two loops along the ventral side of the bird (Cappelle 2011, Cumming and

Ndlovu 2011). All harness methods discussed in this paper will be either the original Dwyer method or the modified method with the ventral strip attached. Materials used will vary between the flexible tubing and Teflon ribbon as well.

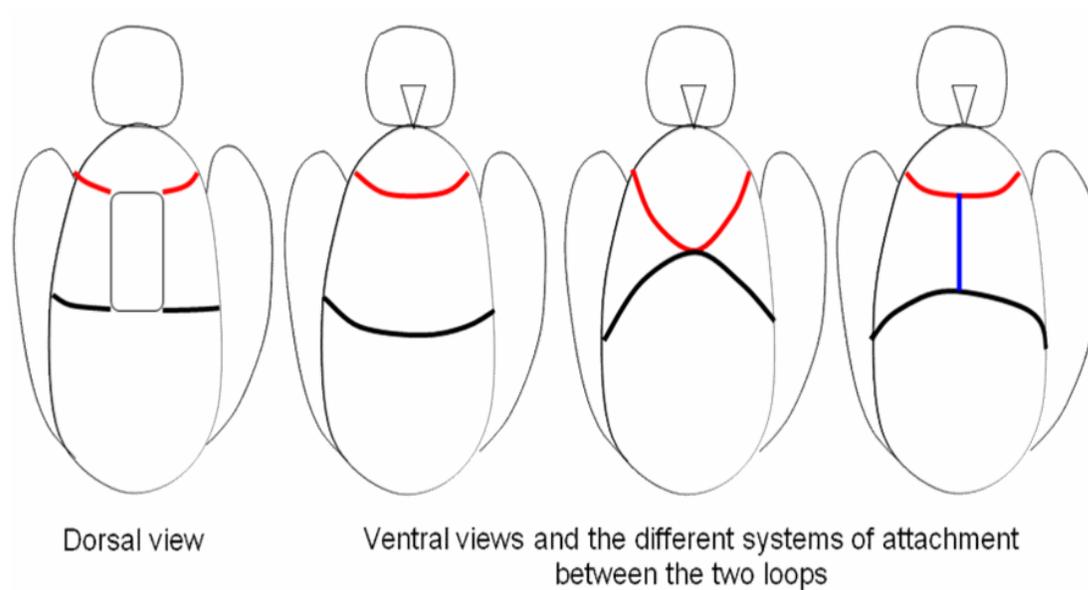


Figure 2: The Dwyer two-loop harness is the first ventral view (second from the left). The second and third ventral configurations are later improvements. Picture adopted from Vandenabeele et al. (2013).

Even in this preliminary work, Dwyer (1972) recognized the importance of a few key assumptions about outfitting waterfowl with transmitters. The first and most important is that the instruments must not cause any behavioral or health effects that may lead to bias in the data collected (Pietz 1995, Barron 2010). As such, many studies focused on the behavioral impact imparted by transmitters. In this first investigation, Dwyer (1972) reported that there was a temporary period of several hours in which duck behavior was augmented. Furthermore, he noted no alteration in flight, nesting, or

brooding. As telemetry work became more pervasive, studies began to focus primarily on the effects imparted by the devices. Although there are numerous studies, only two focused on diving ducks, and one of those directly concerned seaducks (Perry 1981, Robert et al. 2006). Nevertheless, studies involving dabbling ducks are equally important to understanding concerns that need to be addressed with the application of external transmitters.

Greenwood and Sargeant (1973) published the first review of Dwyer's harness method. With groups of captive mallards (*Anas platyrhynchos*) and blue-winged teal (*Anas discors*), they were able to closely monitor instrumented birds to observe any effects. The harnesses were constructed of elastic tubing, similar to the PVC tubing used in Dwyer's original method. Results showed that ducks with the transmitters exhibited weight-loss, feather wear, skin abrasion, and spent less time on the water (Greenwood and Sargeant 1973). Through the years, similar studies have been performed on captive and wild birds. Cox et al. (1998) outfitted northern pintails (*Anas acuti*) with similar backpacks. Garretson et al. (2000) repeated Greenwood and Sargeant's (1973) study on blue-wing teal and mallards. Both studies reported deleterious effects imparted by harnesses on study ducks. Notably, Garretson et al. (2000) did not see any acclimation in their study birds over the course of the study. Despite these conclusions, backpack harnesses have continued to be deployed on waterfowl.

Throughout the early evolution of tagging methods, only one study investigating the effects of harness attached transmitters was carried out on a diving duck; the canvasback (*Aythya valisineria*) (Perry 1981). Nonetheless, the findings of this study were very influential in keeping external transmitters off of diving ducks and seaducks

(Perry 1981, Robert et al. 2006). Perry (1981) reported reduced weight in treatment versus control birds and drastically altered behavior patterns. Birds with transmitters spent up to 75% of their time on land preening at their transmitters (Perry 1981). This allocation of time certainly introduces bias into the collected data. Perry (1981) also noted that birds did not appear to adjust to the backpacks over time. It would be another 20 years before backpack transmitters were investigated again in diving ducks, and for the first time on a species of seaduck.

Diving ducks were quick to be labeled as more susceptible to the deleterious effects of backpack harnesses, despite only one study investigating the topic (Korschgen 1984, Robert et al. 2006). As all seaducks are diving ducks, this category of birds was viewed in the same way, although a formal study was never conducted. Although physiologically very similar, seaducks tend to inhabit more extreme environments than diving ducks (Robert et al 2006). Due to the lack of research, Robert et al. (2006) explored the effects of harnesses on wild Barrow's goldeneyes (*Bucephala islandica*); a small seaduck. In similar fashion, the study found that behavior was certainly altered due to the transmitters' presence. The researchers did note that the behavior returned to normal as birds acclimated to the PTT's. Through their results, the authors concluded that behavioral changes were most likely exacerbated by the extreme weather at the study area. They deemed additional investigation on additional seaduck species would be needed in more temperate areas.

While radio-telemetry was certainly still being employed in puddle ducks through these times, it was not until the early 1990's that studies began to look at new methods of transmitter attachment and their effects in a large way. Prompted by personal experience

and past studies, Wheeler (1991) attempted a new method of suturing and gluing transmitters dorsally (Green and Sargeant 1973, Perry 1981). This method attempted to place the transmitter in the same location without a harness. Using cyanoacrylate glue to attach transmitters to the feathers and unwaxed dental floss to secure transmitters by subcutaneous suturing, Wheeler (1991) was able to develop a method that showed minimal behavior impacts on mallards. Many variations on this method were attempted in the years following Wheeler's manuscript. Pietz et al. (1995) used sutures with an added steel anchor, in place of glue, which was inserted under the skin in mallards. Iverson et al. (2006) investigated this same transmitter attachment in surf scoters; a species of seaduck. Both studies resulted in similar findings as Wheeler (1991). Behavior and health in these birds was minimally impacted. However, transmitter retention times were found to be short (< 1 year) across all three studies (Wheeler 1991, Pietz et al 1995, Iverson et al. 2006). While this is a viable method for attaching radio-transmitters, retention times are not sufficient to be a viable cost-effective method for attaching satellite tags.

Seaducks and other diving ducks represented a challenge to researchers. After Perry's (1981) report on the overwhelming negative effects of harnesses, a new technique needed to be developed that was suitable for long-term deployment in this class of birds. The first attempt at implanting transmitters in waterfowl took place in the early 1980's on a variety of captive and wild ducks (Korschgen et al. 1984). Korschgen et al. (1984) implanted the radio-transmitters in the abdominal cavity of the birds. Transmitters contained external whip antennas that were contained within the cavity as well. This first study showed much promise for implanted transmitters. Birds retained their pre-surgery

weights and exhibited normal behavior. There was also evidence for normal breeding and flight patterns (Korschgen et al. 1984). With the positive results of this study, seaduck researchers saw this as a viable alternative to harness attachment (Olsen et al. 1992). In a study of canvasbacks, Olsen et al. (1992) found the outfitted birds responded very well to implanted transmitters. Behavioral impacts were again minimal. While these studies were promising, these implanted transmitters were limited in range and capability due to the lack of an external antenna (Korschgen et al. 1984, Olsen et al. 1992). Korschgen et al. (1996) remedied this by extending the whip antenna outside of the body cavity. The antenna exited the body cavity dorsally, and protrudes upwards, to increase signal strength (Korschgen et al. 1996). Figure 3 shows a surf scoter with an implanted transmitter and the visible external antenna. This technique showed similar positive results as those without external transmitters. It also allowed for satellite transmitters to be used in this fashion (Latty et al. 2010).



Figure 3: A captive surf scoter with an implanted transmitter where the external antenna is visible protruding dorsally. (Photo courtesy of R. Therrien)

With success in these early studies, researchers began implanting seabirds with these transmitters. Studies also continued on a variety of species to compare these new popular methods. In 2000, Garretson et al., compared harnesses to implanted transmitters in mallards and blue-winged teal. In a similar comparison in 2006, Iverson et al. studied four different methods of attachment in surf scoters to determine the best method. While this study investigated a seabird, it did not consider harness methods. Both of these studies supported the use of implants, while mentioning the one major drawback: mortality (Garretson et al. 2000, Iverson et al. 2006). A study was conducted on common eiders (*Somateria mollissima*) and impact that implants had on their diving ability (Latty et al. 2010). The authors found longer dive durations and decrease energy efficiency in implanted birds (Latty et al. 2010). Further expanding on the implantation versus harness argument, two recent publications have quantitatively analyzed the large pool of studies

concerned with transmitter effects (Barron et al. 2010, White et al. 2012). In the first study, Barron et al. (2010) performed a meta-analysis of all the literature on the effects of transmitters. In a survey of 84 manuscripts, the researchers came to two very important conclusions. They found that harness transmitters do in fact have larger behavioral impacts than implanted transmitters. However, mortality rates were significantly higher in those birds that had transmitters implanted (Barron et al. 2010). These same two results were found in a similar meta-analysis performed a few years after (White et al. 2012). These results on high mortality rates with implants are consistent with current studies on seabirds (A. Wells-Berlin, pers. comm.).

Although Teflon ribbon harnesses are used for outfitting dabbling ducks with backpack transmitters, it is still recognized that they do impart deleterious effects. Researchers across the world have developed and tested many alternative materials and techniques for attaching transmitters. Recently, researchers in the UK created a one-piece silicon harness that could simply be slipped over the bird's body and into place (Vandenabeele et al. 2013). The harnesses were made of Silastic® (Dow Corning Corp.), a lightweight, strong, yet soft silicon rubber that is poured into molds. The harnesses were one piece harnesses that are simply two loops connected dorsally and ventrally by a short length of silastic. One loop fits behind the wings of the bird, while the other sits forward of the wings. Vandenabeele et al. (2013) tested these harnesses on mallards with promising results.

Through all of these studies, seabirds constitute a very minor role. Little work has been done investigating the effects of any style of transmitter attachment. Still, conclusions have been made throughout the scientific community that limited seabirds to

implanted transmitters. While mortality rates in instrumented birds have been higher than desired, the data collected from deployment is believed to be representative of the wild populations. However, because only implanted transmitters have been deployed in these birds, data sets are lacking in resolution. With wind farm impact assessment studies requiring very fine-scale habitat use and movement of seaducks, harness transmitters warrant a more in depth investigation in seaducks. This lack of data coupled with unacceptable mortality rates in Atlantic coast surf scoters makes them a prime candidate (A. Wells-Berlin pers. comm.).

The objectives of this study were as follows:

1. To develop innovative techniques for attaching external transmitters to surf scoters with the goal of eliminating mortality, limiting handling time and decreasing health, behavioral, and diving impacts imparted by the devices (Chapter 1).
2. To assess the performance of attached solar-powered GSM/GPS transmitter to ensure proper function and superior accuracy, frequency of location data as collected with implantable transmitters (Chapter 2).
3. To quantify the impacts of the methods developed in chapter 1 on the weight, blood and serum chemistry, behavior, and diving of outfitted surf scoters in order to assess the techniques as candidates for implementation in wild bird telemetry studies (Chapter 3).

The chapters that below articulate the research performed to address these objectives with our findings and recommendations that emerge from the data taken as an entirety.

Chapter I: The development of three transmitter harness types and attachment techniques.

Introduction

Traditionally, dabbling ducks have radio or satellite transmitters attached dorsally with Dywer two-loop harness made of either Teflon tape or with wire and PVC tubing (Dywer 1972, Pietz et al. 1993, Pietz et al. 1995, Barron et al. 2010, White et al. 2013). Only two studies have been published on the effect of this attachment method on diving and seaducks, citing abnormal behavior and altered migration (Perry 1981, Robert et al. 2006). The result has been the sole use of implantable PTTs in all seaduck telemetry studies (Robert et al 2006). Due to this, numerous studies have been carried out on the effects of implantable transmitters (Olsen et al. 1992, Iverson et al. 2006, Latty et al. 2010, Ford et al. 2011). Although the findings suggest that behavioral impacts on birds are low, the mortality rate associated with the surgery and implantation is as high as 50% in some species. Since the first report of negative effects of external transmitters on seaducks by Perry (1981), Robert and colleagues (2006) have been the only researchers to revisit this issue. Through this time, dabbling ducks have experienced a number of studies on the effects of both implantable and harness style attachments, among various other techniques (Greenwood and Sargeant 1973, Korschgen et al 1984, Wheeler 1991, Dzus and Clark 1996, Garrettson et al. 2000). Additionally, new and promising techniques are being tested on species outside of waterfowl (Vandenabeele et al. 2013). As new transmitter technologies become available, it is important to evaluate methods for externally attaching these transmitters in seaducks.

Although Teflon harnesses are accepted for use in dabbling duck species, numerous studies have noted negative effects (Pietz et al. 1995, Pietz et al. 1996,

Garrettson et al. 2000, Robert et al 2006). Skin abrasions, weight loss, increased preening behavior, and even mortality are common in this application (Barron et al. 2010, White et al. 2013). Another method that has been investigated was suturing of the transmitters onto the backs of ducks. Suturing appears to have little impact on health and behavior, but transmitters do not remain attached for long durations (Wheeler 1991). Recently, new methods involving soft and flexible pourable silicon are being tested (Vandenabeele 2013). In order to further the knowledge of attaching these transmitters to a species of seaduck, the surf scoter, we are describing the methods for attaching external PTT's using three different methods. Attachments include traditional Teflon harness, silicon harness, and suturing method.

Methods

Transmitter Preparation

Twelve Microwave Telemetry Solar-powered GSM/GPS 25-g transmitters were used. Five transmitters were attached using Teflon harnesses, 4 using the Silicon harnesses and 3 were sutured on. All attachments were performed at the Patuxent Wildlife Research Center on surf scoters from the captive population. All attachments were performed under the direction of the veterinarian located on site. Suture style transmitters had 4 tubes that ran width-wise across the base of the transmitters for attachment, while Teflon and silicon transmitters had one brass bar on the anterior end and one bar on each respective side at the posterior end. A self-setting rubber, Sugru (FORMFORMFORM, London, UK), was applied in 5 mm high rails along the length of the outside edges of the bottom of the transmitters. This served to raise the transmitter

off of the back of the birds to help prevent feather coverage and abrasion caused by the metal edges found on the bottom of the transmitters. As Sugru is a negatively buoyant material, it also helped to cause the overall transmitter to be negatively buoyant, in order to offset hydrodynamic drag introduced by the external transmitter. A transmitter with Sugru attached was placed in a graduated cylinder with 20 ml of water. Using equations 1 and 2, it was found to have a specific gravity of 1.12, making it slightly negatively buoyant.

$$\text{Equation (1): Buoyant Force (N) = Mass of Displaced Water (g) x Acceleration of Gravity (m/s}^2\text{)}$$

$$\text{Equation (2): Specific Gravity (SG) = Weight of Transmitter (g) / Buoyant Force (N)}$$

All transmitters were placed on study birds on the morning of 11 February 2014. At this time, birds were weighed immediately before and after instrumentation and the difference taken to reflect the true weight of the transmitter and attachment materials used in (Table 1). All methods were approved and complied with IACUC protocols through the University of Maryland and PWRC (UMD IACUC ref. # R-12-87).

Table 1: The pre-surgery weight of each study bird, the weight of their transmitter package, and the percent of their body weight that the package constituted is presented. The general rule is to stay under 5% of a bird's body weight.

Bird and Transmitter weights by treatment			
Treatment	Bird Weight (g)	Transmitter weight (g)	Percent Body weight (%)
Silicon	1012	42	4.15
Silicon	842	36	4.28
Silicon	866	30	3.46
Silicon	866	42	4.85
Suture	944	32.6	3.45
Suture	878	33.1	3.77
Suture	812	33.3	4.10
Teflon	1056	35.1	3.32
Teflon	736	30	4.08
Teflon	752	27.5	3.66
Teflon	958	26.4	2.76
Teflon	970	27	2.78

Suture Methods

Three captive surf scoters housed at USGS Patuxent Wildlife Research Center were randomly chosen for the suture treatment. The entire suture attachment was performed by a qualified avian veterinarian. Each bird was anesthetized, and the attachment performed. The birds were anesthetized with an initial concentration of 5% isoflurane and then maintained at 3%. A mask was used to administer the gas, until sedated, at which point the birds were intubated with size 18 tubes. Once under, the birds were laid dorsal side up with their wings spread down and out, causing their vertebral

column to protrude. The small dorsal protrusions, known as the dorsal processes, found on each vertebra, were used as anchor points. These dorsal processes are largest in the midsection of the vertebral column. First, the most posterior large process on each bird was found and lined up with the tube closest to the rear of the transmitter. Once in place, the dorsal process closest to the front tube in the transmitter was identified and a hand drill was used to bore a hole through the bone. Unify polyester surgical sutures, size 3/0, were passed through the transmitter tube, through the skin and hole in the dorsal process, and then brought out through the skin at the other side of the transmitter. Soft, flexible polyester was decided on because a preliminary study using stainless steel sutures reported high immune responses in study birds. The suture was then tightened and tied off to itself, creating a loop through the tube of the transmitter down through the skin and dorsal process. This procedure was repeated for the three remaining tubes. Upon completion, the transmitter was tested for snugness by pulling it gently in all directions. The goal was to ensure that the sutures were not so tight as to restrict the transmitter from moving, as movement associated rubbing might cause dorsal abrasion and suture tension can increase discomfort. Once satisfied that the transmitters were not too tight and that the sutures were sufficiently knotted, the birds were brought out from under anesthesia. They were held and their breathing monitored until they regained full muscle control and alertness, at which time they were returned to their respective pens.

Teflon Methods

Five surf scoters received Teflon tape harnesses. The transmitters used had three anchor positions; one on the front on the transmitter, and two at the rear of each side. The tag end of the Teflon tape (Bally Ribbons Mill, PA, USA) was anchored to the front

bar first. The end was pulled through and folded over on itself, and crimped to itself with a brass band. The tag end was cut at the crimped band, and cold shrink-wrap tape was wrapped around the band to cover any rough edges where abrasion may occur. The transmitter was held in place on the back of the bird, and the Teflon tape was pulled off of the spool and used to roughly measure the loop size before cutting so as to reduce wasted Teflon tape. The tape was cut with an extra 3 to 4 cm to allow working room. The process was repeated on the rear right transmitter attachment point. Next, an approximately 5 cm length of tape had each end folded into the middle to create a length of approximately 2 cm with a loop on each end. A brass band and cold shrink wrap tape were placed where the two ends overlapped in the middle. Each end of the long body loops were fed through either end of this piece, where it could act as a connector along the keel of the bird. Next, the transmitter was placed on the birds back, and the front loop was run around the chest of the bird, and connected on the front anchor point in the same manner and the others. The loop was tightened to the point where two fingers could still be easily inserted between the bottom of the transmitter and the body of the bird (Cumming et al. 2011). Finally, this was repeated for the rear loop on the transmitter. Once outfitted and researchers were satisfied with fit of the harness, the birds were released back into their respective pens.

Silicon Methods

The silicon transmitters were placed on four surf scoters. Alumilite High Strength II (Alumilite Corp., MI, USA) was chosen as the silicon material due to its high tear strength, flexibility, and negatively buoyant properties. First, a mold was designed and tested before deciding on the final size. Before creating the mold, a piece of string was

used to get rough measurements for each length of the harness. The design of the mold was then chosen so that the harness was one-piece and could be easily slid into position by passing it over the head of the bird. The first prototype, shown Figure 4, was constructed by gluing $\frac{3}{4}$ " by $\frac{1}{4}$ " aluminum bar on its side to a plastic tray. The prototype was used to mold harnesses to test for size. The size desired was a harness that would fit snugly, yet allow two fingers to be easily passed between the body of the bird and the transmitter. The flexible nature of the silicon harnesses allowed for a one size fits all design. Once the correct size was determined, the dimensions of the mold were transferred into Autodesk 123D Design software (Autodesk Inc.). A 3D mold was printed on a MakerBot Replicator 2 (MakerBot, NY, USA). Figure 5 shows a mold with a completed harness sitting adjacent.

In order to attach the harness to the transmitter, the two outside ends and the top exterior of the loop of the mold had a $\frac{3}{32}$ " hole drilled. A 6 cm length of brass desoldering braid was folded in half and the tag ends fed through each hole in the mold, so that a small loop remained outside of the mold. The silicon was then poured into the mold and allowed to set for 24 hours. Once set, the harness was removed from the mold and attached to the transmitter. Brass jewelry rings went through each loop and then through the respective bar on the transmitter. This resulted in a one-piece transmitter and harness package. The rear loop was stretched around the wings of the birds and set into place. The front loop was guided around the head of the birds. Each harness was checked to ensure that it fit properly before releasing the birds into the pens.



Figure 4: The first prototype of the mold was constructed using aluminum bars glued to a plastic tray. The ends of the mold were left uncapped to allow for resizing.

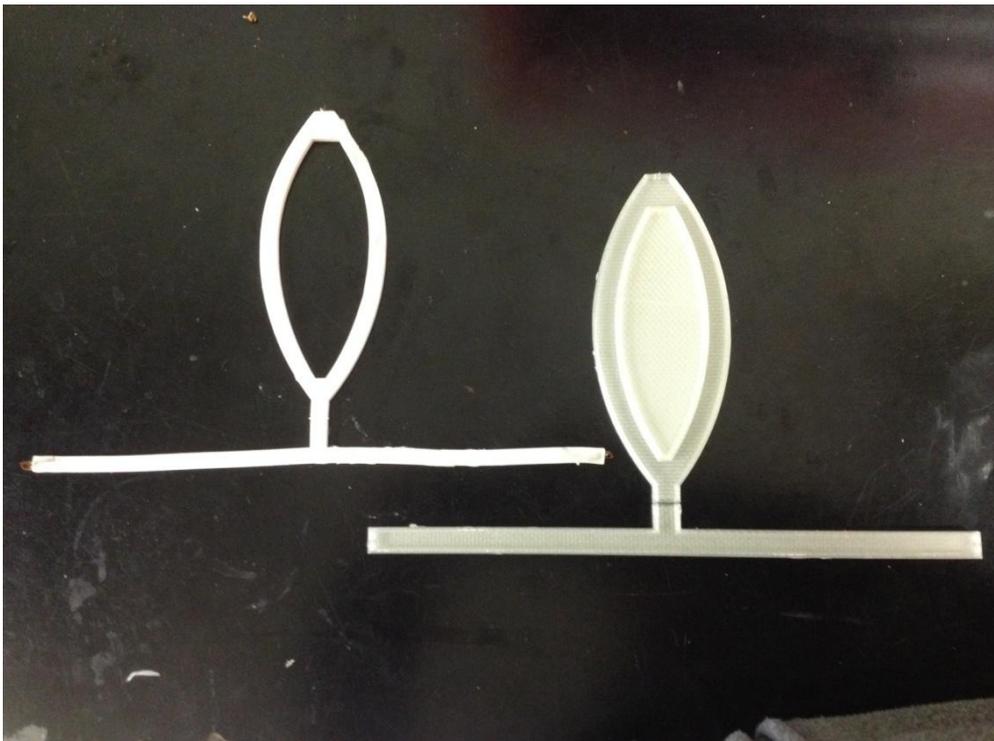


Figure 5: The finished 3D printed mold (right) and a finished silicon harness (left). Note small brass loops at the end of each side, and extending from the top of the harness loop.

Analysis

The development of these methods focused on the retention times and qualitative performance of each method through observations collected throughout the entire study period. Retention times were not relevant as transmitters were removed and improved as issues arose through the experiment. This was done to ensure that the behavioral, health, and diving responses of the birds could be fully examined. An exception was the suture transmitters because the surgical process was time consuming and exerted great stress on the birds. As such, when these transmitters proved unacceptable due to their failure, the involved birds were removed from any further study. The results are included here to indicate the problems that were observed with each treatment, and steps that were taken to improve the method. Only observations and changes made during the 60 days of trials will be considered.

Results

Suture

Two of the three sutured transmitters fell off before the completion of the 60 days. The first was removed on day 14, as three of the four sutures had broken. The second transmitter was removed on day 52. While only 2 of the 4 sutures were broke, the transmitter was moving freely enough to cause concern for injury. The third transmitters had one suture break on day 49, but the transmitter remained securely attached through day 60.

Overall the sutures broke at one of two places: either at the middle, from abrasion with the dorsal process, or at the corner of the transmitter for the same reason. Birds that

lost their transmitters displayed small scabs at the suture sites, which quickly healed. While there was some loss of waterproofing around the transmitter, no large abrasions were present due to wear from the sutures or transmitter.

Teflon

Four of the five Teflon harnesses remained intact for the entire 60 day period. These harnesses showed no sign of wear or potential for breakage at any point. The fifth transmitter was lost on day 28. The Teflon was worn through right at the left rear anchor point. It is unknown what caused the Teflon to break. All birds outfitted with the Teflon harnesses showed wet feathers and abrasions underneath the transmitter. While these were monitored, none showed signs of infection or severe health issues.

Silicon

All four silicon harnesses fell off on experimental birds for varying reasons. The retention times were 9, 12, 27, and 38 days. These were the days of initial failure for each bird, however, as the harnesses were either repaired or replaced upon breakage, some birds had harnesses fail multiple times. There were two different causes for harness breakage. The first was the opening of the brass rings that attached the harness to the transmitter. This allowed the braided loop to slip out and disconnect the transmitter and harness. This issue was repaired by simply replacing the ring. The second issue was the corrosion and breakage of the braided loop. These harnesses were either replaced all together, or had their loops soldered back into one piece. Birds exhibited similar feather wetting and abrasion issues as those outfitted with Teflon transmitters.

Discussion

Performing a telemetry study is an expensive and time-consuming endeavor. It is important that every bird marked survives, and that every transmitter remains attached. Researchers must investigate new technologies and ideas to ensure that the goals are met. Through our investigation of new transmitter preparation configurations and attachment methods, much insight into external transmitter attachment in surf scoters has been gained.

The use of Sugru to raise the transmitter and avoid abrasion differs from the traditional neoprene pad that is used. The neoprene pads are positively buoyant, and degrade quickly in UV light. They cover the entire patch of skin and feathers underneath the transmitter. The Sugru allowed for air and water to pass freely between the transmitter and body of the duck. The negative buoyancy of the material also helped to offset the drag introduced by the external transmitter. It has been shown that the metabolic expenditures of diving is mostly imparted by buoyancy (Lovvorn and Jones, 1991), and not hydrodynamic drag. As such, neoprene pads may be more energetically demanding than the transmitter. It was seen that in the Teflon and silicon harnesses, that there is abrasion caused by the Sugru. Once set, the Sugru is extremely rigid. While the design and principle of a negative buoyant and minimal coverage transmitter base is clearly advantageous, more investigation needs to occur with materials. A slightly softer material that retains the other properties may decrease the abrasion.

Retention times of each attachment methods were informative. The suture method, even with longer lasting materials, was not sufficient for long-term studies.

While the tensile strength of the polyester sutures was high, they were quickly worn through with abrasive rubbing. Carbon fiber sutures may hold promise in reducing this breakage. However, strong materials have the potential to cause structural bone damage as well. Teflon harnesses performed the best, with only one transmitter failing. The experimental silicon harnesses quickly showed their weaknesses. The poor construction of the attachments led to complete failure. The brass rings were too weak and gave out quickly. The brass desoldering braid also proved susceptible to corrosion. Meanwhile, the silicon application showed great promise, as the harnesses themselves showed no signs of weakness or degradation. Different materials, such as stainless steel braid and rings are being looked at as new attachment points in the silicon. If sufficient improvements in materials are made, these transmitters have every potential to exhibit the same retention properties as the Teflon transmitters. Additional studies need to be done on each of these methods to further the knowledge of possible materials and the limitations intrinsic in each.

Chapter II: Performance of External Solar Powered GSM/GPS transmitters

Introduction

The transmitters used to track waterfowl have evolved from simple devices that emit a UHF radio wave to extremely complex electrical circuits that communicate with satellites and transmit information through cellular networks. The primitive devices were limited to short range studies, as the researchers needed to stay within a limited range in order to detect the radio signals (White and Garrott 1990). It was common for birds to leave the range of antenna and never be found again (Perry 1981). Even when within range, exact locations were rough estimates calculated through triangulation. While this method was certainly useful for studies of a limited spatial scope, migration and range delineation studies were not feasible with these devices, let alone studies focused on understanding minute movements of waterfowl. As surf scoters inhabit offshore locations, conventional radio tracking is not possible for consistently tracking these species.

It was not until the 1980's that satellite transmitter technology progressed to the point that made small units possible (Britten et al. 1999, Meyburg and Fuller 2007). These first devices were coined Platform Transmitter Terminals, or PTTs. As GPS technology was still in its early stages, these devices operated through the Argos system (Meyburg and Fuller 2007). The Argos system is a software system currently installed on 8 polar orbiting satellites that only communicates with Argos compatible devices (Argos User Manual 2014). The Argos satellites use the Doppler effect to triangulate the location of the PTTs (Argos User Manual 2014). The result is relatively poor location

accuracy, with location accuracies of 500 m or less occurring only 10-15% of the time (Meyburg and Fuller 2007). While this technology made migration and range delineation studies feasible, it could not provide the frequent, fine-scale location data required to answer evolving research questions regarding precise habitat utilization.

The most advanced PTTs today are solar-powered GSM/GPS transmitters with a host of capabilities. The devices directly communicate with GPS satellites to determine location with an average location error of 18m. Up to 258,000 of these locations can be stored by the unit until a GSM cellular network is within range. The logged data is downloaded by the network and sent as a SMS message (<http://www.microwavetelemetry.com/bird/GSMspecifications.cfm>). The overall charging abilities and amount of sunlight needed to maintain the charge is not known with these devices. Additionally, Davenport et al. (2012) noted the high frequency in which waterfowl preened feathers over the solar panels of these devices. The goal of this study was to investigate the basic operating performance of this new technology. First generation Microwave Telemetry 25-g GSM/GPS solar-powered transmitters were tested. Temperature and battery voltages were compared for five transmitters while outfitted on captive birds to determine the effects of cold temperatures on the battery capacity, and the location data was summarized to provide a basic outline of operating performance. Additionally, we investigated the amount of solar radiation feathers could potentially absorb.

Methods

Five Microwave Telemetry 25-g GSM/GPS solar-powered transmitters were purchased for use in this study (PTT #'s 155, 157, 158, 159, and 160). Transmitters are 64.5 mm long, 23.1 mm wide and 17 mm high, with an 85.1 mm antenna protruding dorsally at approximately 30° (Figure 6). Specifications for the transmitters indicate a lifespan of up to three years, although some similar devices have lasted up to 9 years. The device can log up to 258,000 locations which translates to an entire year of data if locations are taken every two minutes, with an operating range between -15 and 45° C (<http://www.microwavetelemetry.com/bird/GSMspecifications.cfm>).

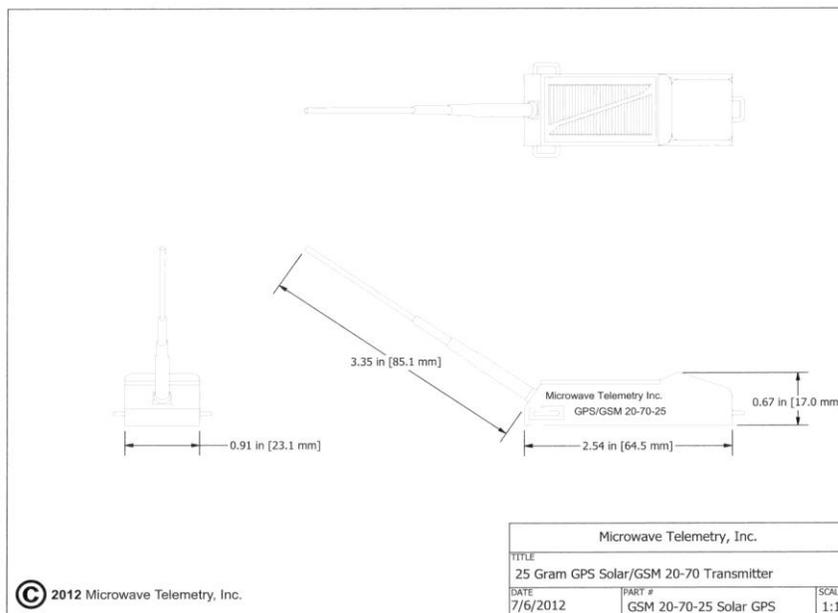


Figure 6: General schematic of Microwave 25-g GSM/GPS solar-powered transmitter.

Taken from <http://www.microwavetelemetry.com/25g%20gsm2.pdf>

Captive surf scoters (n=12) at the Patuxent Wildlife Research Center (PWRC) were used to test the effects of different external transmitter attachment methods. Twelve

birds were used in three different treatments; 5 birds receiving Teflon harnesses, 4 receiving Silicon harnesses, and 3 receiving sutured treatments. Birds were randomly assigned which received dummy (no processing ability) versus live transmitters. Devices were turned on in April 2013, and left on through the entire study period, which began in February 2014. All devices were left outside for 7 days prior to implementation to ensure a maximum charge. Transmitters 157 and 160 were attached using the silicon harnesses, 158 and 159 using the suture method, and 155 using the Teflon harness method. Transmitters were attached on February 11, 2014, and the study ended April 7, 2014 (55 days). Although the transmitters were left on indefinitely, only data transmitted during this time period are analyzed. Battery voltage and temperature data recorded in each transmission was used to test for a relationship between the two. Battery capacity is inhibited by cold weather, so we were investigating whether the cold temperatures associated with surf scoter wintering ranges may have a negative impact on the transmitter performance. Every data point for battery voltage and temperature was used in the analysis. If a suture transmitter fell off, it could not be re-attached and the data was omitted from analyses. Teflon and Silicon transmitters were promptly re-attached and the causes of the problem noted for harness improvement.

Over the course of 3 days, we measured the amount of solar radiation that one dorsal surf scoter feather blocked by taking readings with a pyranometer. We did this to understand the potential effect of feather coverage of the solar panels, as is often described in the literature. An Apogee Instruments MP-200 (UT, USA) pyranometer was used to take all solar radiation measurements (n=40). The sensor was laid on a level surface in direct sunlight and the reading recorded. Without disturbing the sensor, a

single dorsal surf scoter feather was placed directly on top of the sensor and the new reading recorded. These readings were randomly done throughout the day, to account for differing sun angles and cloud conditions. The percent radiation blocked by the feathers was calculated by dividing the amount recorded with feather coverage by the total amount recorded without feather coverage.

The Haversine formula was used to determine the distance each recorded location was from the actual known location of the transmitter. Without filtering out unlikely locations, the average location error for each transmitter was calculated. Equations 3-7 show the Haversine equations:

Equation (3) : Change in longitude ($dlat$)= known longitude – recorded longitude

Equation (4): Change in latitude ($dlong$) = known latitude – recorded latitude

Equation (5): $a = (\sin(dlat/2))^2 + \cos(lat1) * \cos(lat2) * (\sin(dlon/2))^2$

Equation (6): $c = 2 * \arctan2(\sqrt{a}, \sqrt{1-a})$

Equation (7): $d = R * c$ (where R is the radius of the Earth)

Analysis

As low temperatures can inhibit battery performance in many electronic devices, a linear regression was used determine if there was a relationship between the temperature and battery voltage of the transmitters. The mean battery voltage for the transmitters in each treatment was compared using a means comparison to determine if any difference existed. One suture transmitter (#158) fell off on day 14 and so only data from attachment until day 14 is considered for that transmitter. Additionally, a silicon harness (#160) only logged data on day 37 and day 55 for reasons unknown so was excluded.

Results

A total of 8450 data points were recorded between the 5 transmitters. Teflon transmitter #155 logged 2254 data points, for an average of 40.98 transmissions per day. Silicon attached transmitters #160 and #157 recorded 60 and 3344 data points, respectively. Without considering transmitter #160, the silicon averaged 60.8 transmissions per day. Suture transmitter #158 logged 514 locations over 14 days while #159 logged 2278 data points over 55 days, netting an average of 39.06 transmissions per day.

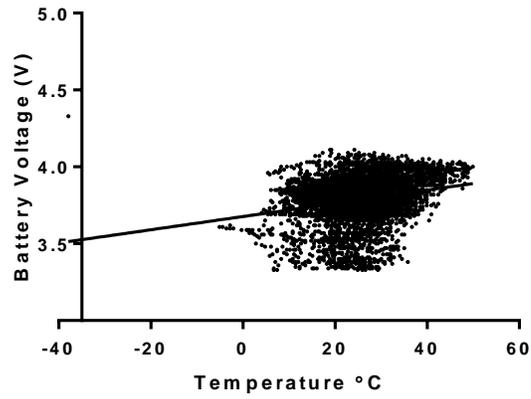
Battery voltage increased with temperature ($r^2=0.06$, $f=501.8$, $p<0.0001$, Fig. 7). Figure 7 shows the plot of the temperature recorded by the device and voltage recorded by the device, and their respective trend line. The temperatures recorded by the devices do not represent the ambient temperature; instead they represent the internal temperature of the transmitter. Silicon transmitters had a significantly higher mean battery voltage than did Teflon ($t=33.38$, $p<0.0001$; Table 2) and suture ($t=35.63$, $p<0.0001$, Table 2) transmitters. No difference was detected between the voltages in suture and Teflon transmitters ($t=-0.10$, $p=0.9944$). The percent solar radiation blocked by the single feather was 78.44%, with a standard deviation of 8.77%.

Table 2. The average battery voltages were calculated for the transmitters in each treatment and means comparison tests performed to determine differences. Silicon transmitters had a significantly higher battery voltage.

Battery Voltage	Treatment		
	Silicon	Suture	Treatment
Average	3.84*	3.75	3.75
S.D.	0.12	0.12	0.13

**Relationship between
Temperature and Battery Voltage of GSM/GPS Transmitters**

After Attachment



Before Attachment

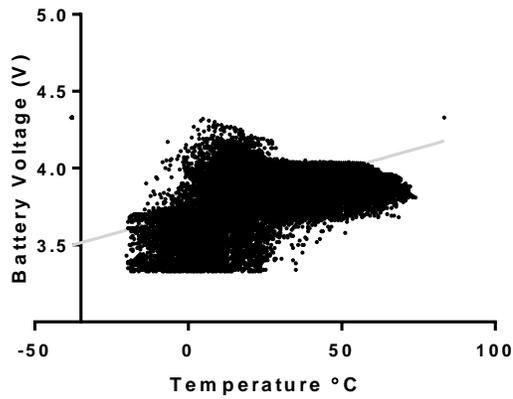


Figure 7. Plot of the temperature and battery voltage relationship. A linear regression was performed to determine the significance of the relationship after transmitter attachment.

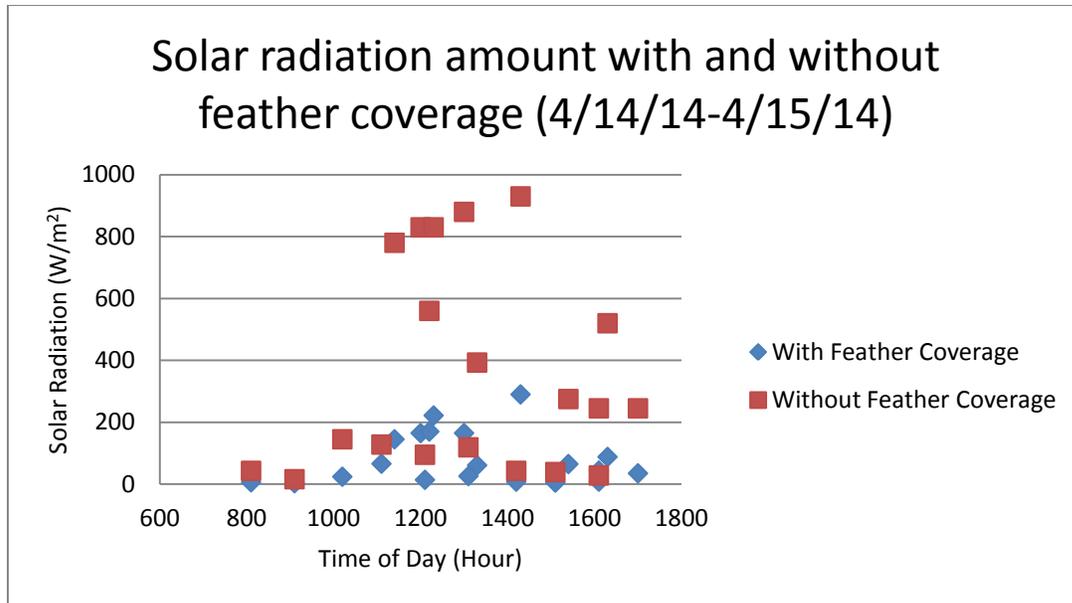


Figure 8: The recordings of solar radiation with and without feather coverage are shown by the time of day they were taken. The average amount of solar radiation blocked was 78.44%.

The location errors associated with the transmitters was higher than those suggested by the manufacturer. Table 3 shows the number of locations recorded and the average location for each transmitter.

Table 3: The average distance of the recorded locations from their known location in the seaduck research site.

Transmitter #	Transmissions	Average Error (km)	Treatment
155	327	148	Teflon
157	1382	144	Silicon
158	3045	3	Suture
159	794	59	Suture
160	3	0.598	Silicon

Discussion

Scientists have long sought to understand how anthropomorphic activities and development affect waterfowl populations. Furthermore, the goal is to understand how these human disturbances may affect populations in advance of their presence. Outside of anecdotal evidence, observations, and primitive telemetry, there are few efforts that could fully describe the daily movements and life histories of waterfowl. Direct observations require time and effort that simply is not feasible, while early satellite telemetry devices cannot provide the frequency and precision needed to answer these specific research questions. The problem is further exacerbated in seabirds, due to their distance from land, making them even harder to study. Now that researchers have an understanding of the surf scoters range and migration routes, there is a push to understand their daily movements within these ranges. Offshore wind farm proposals have accelerated the need for an understanding of their coastal movements within these proposed site areas. Realizing these study goals are very realistic in light of the new technology placed in the GSM/GPS transmitters.

With an average of approximately 30 locations recorded per day while outfitted on study birds, the transmitters logged ample information to gain a much clearer understanding of daily bird habits. Since the transmitters are external, one concern is that the battery charge will be depleted in extremely cold weather, as is often experienced by wild scoters on their wintering grounds. The positive relationship found between temperature and battery voltage indicates that colder temperatures do inhibit the battery performance of the transmitters, but without a calibrated temperature reading, it is hard to validate this. The manufacturer claims the temperature is the internal processing

temperature of the device, which may directly be related to the activity of the transmitter. Thus, the effect seen in the results may be due to the fact that the transmitters are programmed to transmit less at lower battery voltages. So the colder temperatures may in fact be a product of the lower voltages, and not the other way around. While temperature may have an effect, without accompanying solar radiation data and feather coverage information, it is hard to determine the true sources of low battery voltages. Low voltage may just be a product of cloudy days, or feather blockage of the solar panel.

The means comparison showed that transmitters attached by a silicon harness held slightly higher battery voltages. The effects of this can be seen as the transmitters with the lower average battery voltages (Teflon and suture) transmitted less than those with higher averages. With the low sample size, it is hard to really state if the existence of this difference is due to transmitter differences or transmitter attachment. This possibly indicates less solar panel feather coverage. As was seen, a single feather drastically reduces available light. At its strongest, solar radiation can reach 980 W/m^2 at noon on a clear day (Kopp and Lean 2011). Even on the brightest of days, only around 300 W/m^2 were passed through a feather. This amount of solar radiation is roughly equivalent to the intensity of the sun at noon with a layer of clouds underneath. The highest charging potentials were seen around midday, with values of solar radiation being greatly reduced at lower light hours. Lustick (1973) showed that birds with dark plumages do not pass radiation through a layer of feathers, but instead absorb the radiation in their feathers. This is believed to be an adaptive method of reducing energy expenditures for maintaining homeostasis by conductive heating. Our results showed that even a single feather absorbed a majority of the radiation needed to provide power via the solar panel.

One reason why feather coverage may have differed between the treatments is because the transmitters sat at slightly different location on the bird back. Silicon and suture transmitters tended to sit further posterior, while the Teflon transmitters tended to sit more anterior. This could allow a bird to cover the solar panel more easily with their head while sleeping. Also, it is easier for them to access feathers further back on their dorsal midline, than towards the midsection of their back, allowing for them to preen feathers over the solar panel. Thus, proper placement of transmitters may alleviate the issue. This may also be a cause for the increase in transmitter location error seen in the Teflon and silicon treatments. Blockage of the GPS, which sits at the anterior edge of the transmitter package, may have interfered with the accuracy of locations. The disparity between location errors is hard to explain through simple electrical differences between transmitters alone. The manufacturers' specification of an 18 m average error was met only in transmitter number 158. While the transmitter accuracy evaluation was a rudimentary investigation, it does warrant concern about the performance of some of these devices. A deeper look should be performed on devices under controlled conditions before they are outfitted to birds.

Researchers need to understand the implications of this if they are working with any species that has a tendency to preen feathers over the solar panels. A controlled study needs to be conducted using exact measurements of solar radiation to determine the charging capabilities of various solar devices under varying light intensities and durations. A study of this nature is challenging, as the controlled conditions often limit GPS fixes and transmissions, biasing the data collected. While there are many studies that report on the location accuracy and precision, it would be beneficial to investigate

those parameters as a function of battery voltage and temperature (Britten et al. 1999, Adams et al. 2013). A complete picture of the operation and expected errors associated with any given battery voltage would be invaluable in filtering data.

Chapter 3: Impacts of three external satellite transmitter attachment techniques on blood chemistry, body weight, diving performance, and behavior of captive surf scoters.

Introduction

Satellite telemetry has become the primary method for studying long-range movement patterns in migrating waterfowl. Valuable information about migration corridors, breeding areas, molting areas, and site fidelity has been gathered through the use of these devices (Swanson et al. 1976, Silverman et al. 2013). The underlying assumption is that the attachment and presence of a transmitter does not result in biased location data. Multiple studies investigating the effects of different transmitter attachment techniques on the health, survival, and behavior of instrumented study birds have been performed to understand if and how the data may be impacted by the devices (Barron et al. 2010, White et al. 2013). As a result of these studies, two techniques for outfitting transmitters are accepted methods for waterfowl species (Robert et al. 2006, Barron et al. 2010, Ford et al. 2011, White et al. 2013). Dabbling duck species are often outfitted with Teflon harnesses that attach an external transmitter, while diving and seaducks are exclusively instrumented with transmitters implanted within the abdominal cavity (Robert et al. 2006).

Multiple studies investigating the effects of both attachment methods have shown deleterious effects (Barron et al. 2010, White et al. 2013). Multiple studies performed on both captive and wild waterfowl found that external transmitters exert negative effects, such as decreased feeding time, weight-loss, mortality, and lower survival rates

(Garretson et al. 2000, Barron et al. 2010, White et al. 2013). However, only two studies have explored the attachment of external transmitters to seaducks (Perry 1981, Robert et al. 2006). These studies, both performed on wild birds, also found augmented behavior and weight-loss. Meanwhile, investigations into implanted transmitters in both dabbling and seaducks saw less deleterious effects on study birds, with the caveat of higher mortality rates (Iverson et al. 2006, White et al. 2013). Nonetheless, Latty et al. (2010) deemed the effects of external transmitters were deemed too influential on the behavior of ducks that acquire food through diving, despite no formal diving study being performed. However, a study on implanted transmitters found that descent time and ascent time were increased in common eiders (*Somateria mollissima*)(Latty et al. 2010). Furthermore, the Seaduck Joint Venture (2014) notes there is evidence that the movements of birds are altered for the entire first year following transmitter implantation.

While implanted transmitters have been vital to the understanding of seaduck ecology, the limitations inherent in these transmitters do not allow for high frequency, fine scale data collection. As such, they are inadequate for answering current research questions in regards to fine-scale habitat utilization in coastal areas of proposed offshore wind farms. We chose to revisit the attachment of external transmitters in a seaduck, the surf scoter to further understand the effects of these transmitters on seaducks and to investigate new technologies in attachment material and transmitters that can better inform current research objectives.

The goal of this study was to specifically investigate the impact on behavior, health, and diving, using three different methods of externally attaching transmitters on surf scoters. We built activity budgets before and after attaching the transmitters and

then compared these by treatment to see if the transmitters augment behavior. Bird weight, blood and serum chemistry were analyzed to determine if the presence of transmitters had an effect on the health of outfitted birds. Finally, we analyzed actual dive times of the study birds in a dive tank to understand how external transmitter affected the diving of the surf scoters.

Methods

Attachment

Twelve adult captive surf scoters (8M:4F) housed at Patuxent Wildlife Research Center (PWRC) in Laurel, Maryland were used for this study. All procedures were approved and complied with IACUC guidelines, and were completed under the supervision of a veterinarian. The 12 surf scoters were randomly placed into three treatment groups. Sample size was limited by available transmitters and the number of birds available in the captive colony. Five birds were outfitted with Teflon harness transmitters. Four birds received silicon harness transmitters, and three birds had transmitters attached by sutures. Methods for attaching transmitters are described in Chapter 2. All transmitters attached were Microwave Telemetry Inc. (Columbia, Maryland, USA) 25g solar-powered GSM/GPS transmitters. Birds were instrumented on 11 February 2014 at the Veterinarian Hospital at PWRC. We chose to outfit birds at this time, as it coincides with the period when wild birds are trapped and tagged with auxiliary markers. All methods were approved and complied with IACUC protocols through the University of Maryland and PWRC (UMD IACUC ref. # R-12-87).

Health

Two baseline weights were taken prior to outfitting birds with transmitters. The first was taken 7 days prior to, and the second was taken immediately before, implementation. Birds were weighed twice a week for 8 weeks following the initial transmitter attachment. As surf scoters exhibit sexually dimorphic weights, data were normalized by analyzing the percent change in weight. Repeated measures ANOVAs were used to determine if significant changes occurred within treatments. Post-hoc Tukey's HSD tests were then applied to determine if differences existed between treatments (SAS 9.3). Weights of birds that lost their transmitters were only included in the analysis while the transmitters were attached.

Baseline blood work was taken 7 days prior to implementation. Subsequent blood work was taken at the same time every week for 5 weeks following attachment. Blood parameters measured were pack cell volume (PCV), total solids (TS), red blood cell count (RBC), uric acid, aspartate aminotransferase (AST), total protein (Tprot), creatine kinase (CK), and the heterophil/eosinophil ratio (H/E). Blood work was analyzed by a veterinarian technician according to approved protocol for avian blood (Harr 2002). Within treatments, each parameter was analyzed using repeated measures ANOVA. Post Hoc Tukey's HSD tests were then used to compare effects between treatments (SAS 9.3). All weights and blood samples were taken between 0900 and 1100 hours. All tests were considered significant at the 5% level.

Behavioral Measures

Behavioral observations were started about 3.5 months before transmitter attachment. A random number generator was used to create a randomized observation schedule of which birds would be observed. The schedule consisted of 4 observation periods per pen per day. Over 15 different volunteers were recruited to come at any time on a respective day and complete observations. A list of behaviors and a descriptive definition of each was supplied to each observer for the purpose of standardizing observations. Each volunteer was walked through the entire process, including the list of behavior descriptions prior to conducting the study. Observations were conducted in all weather conditions at random between the times of 0900 and 1700 hours to ensure representative samples and unbiased sampling. Sixty percent of the observations occurred in the afternoon, while 40 % occurred in the morning. The distribution within these times was completely random as the birds were sampled in random order. The observer approached a pen containing surf scoters, identified the subject bird by means of color leg bands, and started the observations. If the bird could not be identified from outside of the pen, observers entered the pen and located the appropriate subject. The first 5 minutes of observation were an acclimation period, in which no behavior was recorded. This was followed by 5 minutes of observation, in which instantaneous behavior was recorded every 15 seconds, resulting in 20 behavioral observations per bird for each observation period. Behaviors were categorized into 6 groups of behaviors: feeding, resting, locomotion, maintenance, courtship, and alert (Portugal et al. 2010). Table 3 shows the categories and their included behaviors. Behavioral observations were continued on a daily schedule for 60 days after the attachment of transmitters for a total

of almost 6 months of observations. Observations occurring before attachment totaled 114 observation periods, while the observations after attachment totaled 74 observation periods. Tukey's mean comparison tests compared the means of each category to determine treatment differences (PRISM GraphPad). We assumed no differences between observers. A q-critical value of 3.53 is the 5% significance threshold. All q values above this level are significant.

Table 4: The complete list of all observable behaviors and their respective categories. All behaviors occurring outside of these listed were recorded as others and assigned to the appropriate category.

Behavioral Category	Maintenance	Locomotion	Feeding	Resting	Social	Alert
Behavior observed	Preening	Swimming	Feeding	Resting on water	Agonistic	Head Raising
	Preening at transmitter	Flying	Drinking	Resting on land	Antagonistic	Vocalization
	Bathing	Walking	Scoping	Sleeping on water	Courtship	
	Stretching			Sleeping on land		
	Wing Flap			Standing		
	Scratching					

Diving

Dive trials were completed in a dive tank at PWRC that measured 1.83m x 1.83m x 2.44m. Prior to collecting data, birds were placed in the dive tank 2-3 times a week for ~2 months to acclimate to the environment. Once we were satisfied that birds were comfortable diving, official trials to collect baseline dive data began, approximately two

months before transmitter instrumentation. A 1-m² box was constructed of PVC and served as the feeding zone on the bottom of the tank. Two ounces of meal worms were funneled onto the bottom inside the square using a length of PVC pipe. Once the meal worms sank to the bottom, the PVC pipe was removed and a pair of birds was placed in the dive tank. A small floating platform measuring 0.3 x 1 m was placed in the dive tank as a terrestrial haul out on which they could sit. All trials were completed between the hours of 0600 and 1000. Birds remained in the tank for one hour, and all dives were recorded. A camera mounted approximately 20 cm above the waterline on the back wall was angled downward at approximately 30° so that the video captured the entire dive tank including the water column. Each bird was recorded for 10 times in one hour blocks for a total of 10 hours before and after transmitter attachment. Video was reviewed to determine the dive descent time, ascent time, total bottom time, and total dive time. This was repeated for every bird for every dive. Only complete dives were included in analysis. For each dive parameter, repeated measures ANOVAs were used to compare dive differences within each treatment (SAS 9.3). Tukey's HSD comparisons between treatments were inconclusive as the model could not run with the available data because the number of complete dives performed after transmitter attach was largely variable.

Results

Health

All birds exhibited weight loss beginning immediately after implementation (Figure 8). The average percent change in body weight for each treatment ranged from –10.4% in the silicon treatment to a high of 5.7% in the suture treatment. The reductions

in weight were significant over time ($f=1.41$, $d.f.=34$, $p=0.1657$) for each treatment. There was no difference between silicon and suture treatments ($t=-0.67$, $d.f.=5.85$, $p=0.788$), silicon and Teflon treatments ($t=-0.39$, $DF=5.73$, $p=0.920$), or suture and Teflon treatments ($t=0.36$, $d.f.=5.96$, $p=0.931$). All treatments appeared to follow the same overall trend throughout the study period, with an initial decrease followed by a slow increase towards the baseline weights.

Blood parameters were measured at one week intervals for 5 weeks, after which point, it was determined that all levels were well within normal ranges and no more testing was needed. PCV ($f_{(5,33,5)}=3.13$; $p=0.02$), RBC ($f_{(5,36,5)}=2.49$; $p=0.0486$), uric acid ($f_{(5,36,4)}=6.87$; $p<0.0001$), Total protein ($f_{(5,35,2)}=3.41$; $p=0.0128$), and H/E ratio ($f_{(5,39,5)}=8.74$; $p<0.0001$) all showed significant effects related to transmitter attachment method. Of these, the H/E ratio is the only test which was significantly impacted by one treatment more than another ($f_{(10,40,2)}=4.11$; $p=0.0006$). The suture method had higher H/E ratios than both the silicon and Teflon methods.

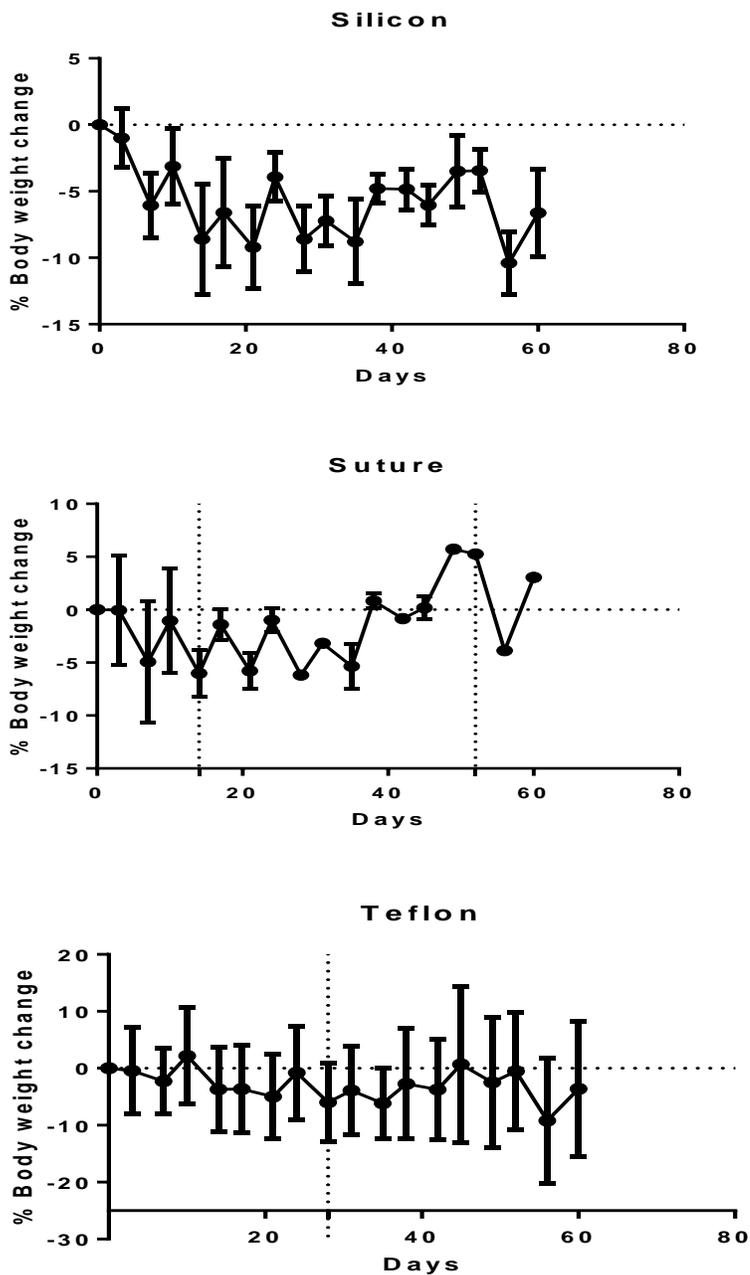


Figure 9. The average percent body weight change for each treatment was calculated after each weight taken. Vertical lines on the Teflon and Suture graphs represent days when transmitters were lost. Weight loss was significant for each treatment, however no difference between treatments existed.

Behavior

Maintenance, locomotion, and resting were the most sharply altered behavior (Figure 9). The percent time spent in maintenance activity by birds in the Teflon treatment went from 18.9% before transmitter attachment to 33.2% after attachment. This increase for the suture and silicon treatments was 25.1% to 27.8% and 18.9 to 31.6%, respectively. Only maintenance behavior for those birds outfitted with Teflon harnesses was statistically significant ($q=3.71$, $d.f.=25$, $p<0.05$). Time spent in locomotion activities decreased from 19.0% to 7.1% for the Teflon treatment, 23.8% to 11.8% for the silicon treatment, and increased from 14.6% to 16.2% for the suture treatments. None were statistically significant. Resting behavior increased from 45.9% to 56.6% in the Teflon treatment. The sutured birds showed smaller changes in resting behavior, with percent time changing from 51.2% to 49.1%. Silicon harnesses resulted in an intermediate effect on resting behavior with an increase from 45.9% to 50.6%. Again, these alterations in behavior were not significant. Other behavioral categories accounted for a very small amount of total time allocation both before and after transmitters were attached and did not significantly differ.

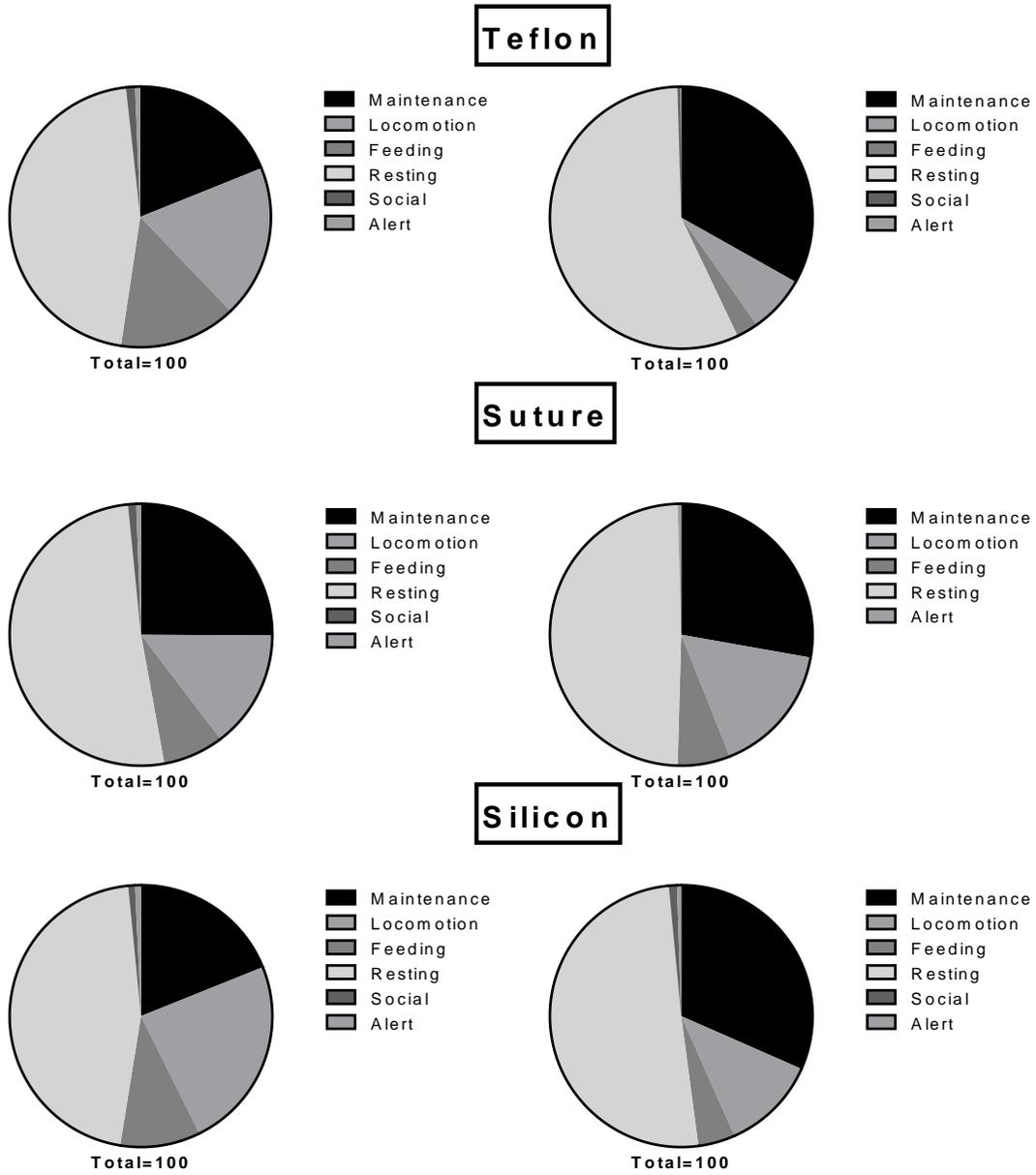


Figure 10: The baseline (left) time budgets for the surf scoters in each treatment are contrasted with the time budgets after transmitter attachment (right).

Table 5. The results of the means comparison for each behavioral category by treatment is presented in the following table. Teflon harnesses caused a significant change in maintenance behavior. d.f.=25. q-crit=3.53.

q Values for Tukey's multiple comparison tests						
Behavioral Category						
Treatment	Maintenance	Locomotion	Feeding	Resting	Social	Alert
Teflon	*3.715	2.136	2.402	1.013	0.095	0.095
Suture	0.474	1.34	0.424	2.03	0.194	0.014
Silicon	2.758	2.334	1.227	0.736	0.001	0.056

Diving

The number of dives performed by the majority of birds was greatly reduced after transmitter attachment (Table 4). The average number of dives per bird before attachment for the suture, Teflon, and silicon treatments were 93.7, 149.7, and 113 respectively. These sharply decreased to 25.7, 22, and 27 dives per bird. Additionally, one bird in the silicon treatment and two birds in the Teflon treatment only performed incomplete dives, excluding them from the analysis of the dive times.

The average descent and ascent times decreased for all treatments after transmitter attachment (Table 5). The analysis of the available dive times showed that total dive time ($f=1.83$, $d.f.=41$, $p=0.0032$) and total bottom time ($f=1.83$, $d.f.=41$, $p=0.0037$) were both significantly different for each treatment. Bottom time and total dive times increased for both silicon and Teflon treatments, whereas the suture treatment saw decreased bottom and total dive times. Ascent times ($f=0.98$, $d.f.=41$, $p=0.504$) and descent times ($f=0.77$, $d.f.=41$, $p=0.8472$) were not significantly different.

Table 6. The table represents the number of total dives performed by each bird before and after transmitter implementation. The data are broken down into number of incomplete dives and complete dives.

Treatment	Subject	Total dives before	Complete	Partial	Total dives after	Complete	Partial
Suture	Blue F6	45	44	1	21	18	3
Suture	Blue M5	186	118	68	33	12	21
Suture	Pink M6	50	39	11	23	18	5
Teflon	Green F5	65	49	16	9	0	9
Teflon	Orange F6	33	30	3	54	53	1
Teflon	White M3	351	78	273	3	0	3
Silicon	Blue M6	43	37	6	44	42	2
Silicon	Pink M3	229	94	135	4	0	4
Silicon	White M5	31	0	31	41	2	39
Silicon	Yellow F3	149	87	62	19	14	5

Table 7. Average dive times before and after transmitter attachment are presented to show the effect that each transmitter had on the dive times; repeated measures ANOVA was used to test for significant changes to the dive profiles.

		Average dive times (s)			
		Descent time	Bottom time	Ascent time	Total dive time
Suture	Before	5.33	13.39	5.02	23.75
	After	4.06	8.41	2.63	16.45
Teflon	Before	6.74	8.24	6.30	21.28
	After	5.29	16.78	3.71	25.78
Silicon	Before	5.90	9.16	5.13	20.30
	After	5.40	13.86	3.65	22.91

Discussion

Introduction of an external transmitter to any species of duck will never go completely unnoticed by the duck. Regardless of the method used to attach transmitters, we saw a marked reduction in weight for all study birds. This is consistent with most studies concerning external transmitters (Garretson et al. 2000). Stress and discomfort introduced by the device are believed to be the source of this weight loss (Garretson et al. 2000). Interestingly, all our study birds followed a pattern of oscillating weights between the Tuesday and Friday. Despite being weighed at the same time of day, Tuesday weights were consistently lower than those recorded on Friday for the first five weeks of the study. This pattern re-emerged for the final week of the study. It is hard to speculate why all the birds held to this same pattern. One possibility is that birds were not being fed ample amounts of food over the weekend, when volunteers provided the feedings. The low weights also corresponded with days that blood was drawn, although birds were weighed before having their blood taken. Weights were most likely further impacted by the rough winter that occurred during the study period. Temperatures were well below normal, with several days below 0° C. Perry (1986) showed that waterfowl experience an endogenous rhythm, where they lower body weight and metabolism rates to minimize energy expenditure during cold temperatures, but the extent to which endogenous reactions to the winter temperatures contributed to the weight loss of our birds is unknown.

Although not quantified, birds appeared to spend more time on land, which resulted in less opportunity to feed, as birds were fed on the water. This has been observed in past harness studies as well (Garretson et al. 2000) and may have been

exacerbated by the cold temperatures and large snow banks, as birds were often seen sitting in the snow banks high above the water. There were also some mornings with the ponds were partially covered with ice. Behavioral results do not support this conclusion however, as the time spent feeding did not significantly differ. Further study will be necessary to ascertain what aspect of the harnesses and attachments had the greatest impact. Suture transmitters undoubtedly had the least effect on weight, while Teflon and Silicon harnesses had similar weights. However, with low retention times and, the need for anesthesia and veterinarian assistance, suture transmitters are not practical. Overall trends did show that over time, birds began to regain lost weight, supporting the idea that birds acclimated to transmitters. Likewise, The Sea Duck Joint Venture (2014) operates under the assumption that implanted transmitters alter behavior for at least 60 days.

The need for an acclimation period for birds to adjust to wearing a transmitter was further supported by the blood work. While some parameters were impacted by all treatments, all values returned to normal limits by the 5th week of the study. The H/E ratio, a sign of foreign body infection and stress was significantly impacted with suture transmitters, showing that these birds had an elevated immune response to the sutures. There was no sign of actual infection though, as the levels quickly fell to normal. This differed from preliminary studies that used stainless steel, where the immune response was higher and sustained (G. Olsen, personal communication). Other blood work indicates that overall bird health was also impacted regardless of treatment (G. Olsen, personal communication). Uric acid can become elevated in periods of dehydration (Harr 2002). Like the weight loss, this may have been experienced because some birds appeared to spend less time on the water. Total proteins indicate overall health of the

bird, supporting the weight loss and behavior data, in that overall bird health was negatively impacted. Nonetheless, the fact that enzyme levels, AST and CK, were not impacted indicates that birds did not experience muscle degradation or serious fluctuations in physiological processes, such as capture myopathy (Dabbert and Powell 1993). In a study on implanted transmitters, Latty and colleagues (2010) found increased CK levels, indicating the possibility for myopathy. In fact, they found this may be the explanation for slower dive times that they saw in the implanted eiders. As we did not see any elevated CK levels, our birds may have been spared from the associated muscular degradation and subsequent diving effects. Still, the high H/E ratio could be an indication that stress was more of a factor in the diving differences seen in the suture birds.

The behavioral results are concurrent with previous studies. Teflon harnesses have been shown to induce more preening and resting behaviors (Perry 1981, Garrettson 2000, Robert et al. 2006). For the most part, our birds spent less time feeding and moving around, and more time preening themselves. The Teflon rolls up and becomes a thin rope-like material that appears uncomfortable. The silicon harness did not appear to have the same issue for the birds. The softer consistency of the material may be an important aspect for keeping the behavioral impacts lower. Time budgets were hard to analyze, as seasonal differences may be responsible for some of the changes in behavior. The lower metabolic rates associated with cold temperatures can help explain the increase seen in resting behavior, but not the increase in maintenance behavior. A study focusing on the behavioral effects of silicon harnesses using control birds, instead of a before and

after approach, will be more effective at ensuring an understanding of the effects on behavior.

There are no studies done on captive diving waterfowl with which to compare our diving data. Studies on wild birds found that dive frequency was decreased, just as was seen in our birds (Perry 1981, Robert et al. 2006). Once outfitted, the birds were extremely reluctant to dive. As the diet of the birds was not restricted, there was no true advantage for the birds to dive. They were able to feed as much as they needed inside their pens. The birds seemed very uncomfortable upon diving as well. On many instances, birds would partially dive, and quickly return to the surface. However, food was not restricted before attachment, so this effect cannot be proved. When the birds did dive, they only saw a difference in the length of time they spent on the bottom and total dive time. Lovvorn and Jones (1991) showed that buoyancy has a larger impact in determining dive energetics than drag. With negatively buoyant transmitter packages, birds likely spent less energy remaining on the bottom, explaining why we saw slightly longer bottom times. Furthermore, drag is not a factor when remaining on the bottom. When birds did dive, they dove just as before, with multiple dives back to back. Further study needs to be done, where diets are restricted and better video equipment is used. Video equipment can be used to determine dive angles, foot-stroke frequencies, and more exact dive times.

Differences in the results of each attachment method indicate which methods hold promise as attachment methods. Suture transmitters, despite having the least deleterious effects, are not cost-effective as they do not remain attached. Teflon transmitters, which have been extensively studied, showed the same maladies previously reported, in the

form of alterations to behavior and health. Silicon harnesses, with their softer and more flexible material, imparted less behavioral impacts, with all else being equal with Teflon harnesses. This technology has promise, and much more work needs to investigate the silicon harness. Captive studies can help to determine the best silicon materials and design, while shedding light on potential impacts on behavior and diving. These should not be seen as replacements for doing actual studies on wild birds in true survival situations.

Conclusion

Implanted satellite transmitters are used in seaducks to track migration routes, breeding, and wintering grounds. However, high mortality rates, handling stress, and inadequate small-scale location data necessitates the use of external transmitters. As such, two main assumptions must be met in order for a transmitter attachment technique to be considered feasible. First, the transmitter must not impart behavioral changes that will influence the data collected. Within this, the technique should not cause a high rate of mortality in the study birds. Secondly, the transmitter must remain attached for the duration of the study period. As these devices are expensive, retention time less than one year is not cost effective. Techniques to insure these assumptions are met with backpack transmitters have been studied in depth in dabbling ducks. There have been few studies in diving ducks, which have additional parameters that must be considered including patency of the transmitter with salt water, pressure changes during diving. This research contributes to the development of methods and technologies for backpack harnesses containing transmitters that will be functional at frequencies and sensitivities critical for tracking seaducks.

Because past studies have contraindicated the use of external transmitters in seaducks, researchers have limited their research about seaduck habitat use and migration patterns using internal transmitters. However, implantable transmitters cannot match the frequency and accuracy of the solar-powered GSM/GPS transmitters. The transmitters used in this study recorded locations every two minutes to provide an average of 13.1 transmissions/day to 63.0 transmissions/day. In comparison, implantable transmitters

used in past studies were turned on for 10 hour blocks, followed by 13 hours of off time and the locations were accurate within 1 km only 10-15% of the time. A detailed analysis of the location data was beyond the scope of this project, so we cannot comment on the location precision associated with the transmitters. Nonetheless, the basic data show that the devices are much better suited to answer fine-scale research questions. An in-depth modeling study of both types of transmitters is needed to fully evaluate the performance of both types of transmitters in wild birds that would yield the best practical transmitter performance. This would also lend insight into how the two transmitters affect behavior and health. Data on survival rates, behavior, and movement data on birds from the same population that are outfitted with transmitters simultaneously is critical and would directly compare transmitter performance. Clearly, it is also important to investigate the potential effects of transmitters in a controlled, captive setting.

No study published thus far has claimed that PTTs of any design prevent behavioral or negative health impact on instrumented waterfowl. The driving idea behind the attachment technique is to understand the effects, and then utilize whichever method incurs the smallest impact, while still meeting the two aforementioned assumptions, and sufficiently informing the research needs. In past studies, implanted transmitters met these goals; while their high mortality rates were essentially ignored. As implantable transmitters become obsolete in answering new research questions about fine scale movements and habitat use, external transmitters have re-emerged in the equation. In the first study of its kind on surf scoters, we examined the health, behavioral, and diving impacts of external transmitters on captive birds. Our results indicate that while further

study is needed to understand the extent of transmitter effects and improve on innovative new attachment methods, these devices can remain on seabirds for effective tracking.

The suture transmitters, although appearing to have the fewest negative impacts on the study birds, were not retained long enough for suturing to be considered a viable option. The attempt to anchor the sutures in the vertebrae did not increase the retention time above lengths seen in previous studies (Wheeler 1991). Additionally, the increase in the H/E ratio indicated a strong immune response to the presence of sutures, or possibly the presence of bacteria. This is worrisome for stressed birds in the rough winter conditions experienced when these birds would be captured in the wild. While these are suitable for short-term studies, it is advisable not to implement this technique when attempting studies longer than a month or two. Further investigation into new materials may be worthwhile to determine if the immune response differs. For instance, in a preliminary study on lesser scaup, we saw high and sustained immune responses to stainless steel sutures (McBride et al. unpublished data). Carbon fiber sutures are another option that may be worth considering in similar studies.

The preliminary design of the silicon transmitter harnesses had many positives and negatives. The size and fit of the harness, along with the flexibility of the material, resulted in fewer negative impacts on the birds than those seen with Teflon. While both harnesses resulted in similar weight loss patterns, only Teflon significantly impacted behavior. The inability of Teflon to stretch likely caused more discomfort and increased maintenance behavior in those study birds. On this same note, the harness was unable to adjust to the natural fluctuations in body size that birds experience throughout their lives. Lipid reserves of birds are predominantly stored in their breast area, where it will directly

impact the fitting of any harness. The flexibility and soft nature of the silicon harnesses can mediate this effect, allowing for a snug, comfortable fit throughout these weight fluctuations. Regardless, both techniques were not without negative effects. The weight loss exhibited in both treatments was significant. While a 15% reduction in body weight is not likely to be lethal, in a harsher environment, it is certainly worth consideration. It is very hard to mimic natural conditions and even harder to understand how captive bird behavior might translate to wild birds. While it is true our birds were exposed to the same elements as wild birds, the amount of energy they required to feed was negligible. It is imperative that a similar investigation occur on wild birds. Blood work results indicated that, while there was a negative impact on the overall health of the birds, more drastic physiological impairments were not present. Bird blood chemistry took over 4 weeks until it returned to normal levels. Again, while this may not be extremely concerning in laboratory settings, it is unknown how it will impact birds in the wild.

Through the results and the observations made throughout the study, we deemed the silicon as holding the best promise for moving forward with external transmitters in seabirds. The initial method with which we attached the silicon harnesses to the transmitters was considered a failure. The brass desoldering braid corroded quickly and broke in many cases. Our next attempt using stainless steel braid proved futile as well. The stainless steel was too stiff, causing the silicon to tear and break free at the attachment points. Additional techniques, including Kevlar string and other pliable, corrosion resistant materials are being discussed.

The design of our diving study provided insight into more long-term effects that transmitters may have on diving. As the birds received subsistence at regular intervals in

their pens, they were not required to dive for survival. This may be one reason that they dove much less frequently after receiving transmitters. However, as they received the same treatment before transmitter attachment, the presence of transmitters certainly did affect their behavior. The study birds seemed uncomfortable diving, and on many occasions resurfaced immediately after beginning a dive. When birds did dive, their ascent times and descent times were unchanged. However, the amount of time they spent on the bottom increased. In theory, because they are carrying a negatively buoyant transmitter, they should require less energy to dive and remain on the bottom. This may explain why they remained on the bottom longer. Drag becomes less of a concern when feeding, as birds are moving laterally and not vertically through the water column. Furthermore, as the ascent is passive, no energy above the normal levels should be required to resurface. The idea that a negatively buoyant package could actually offset the drag and decrease the actual energy required for a dive is indeed promising, yet unsubstantiated. A thorough investigation of the dive energetics associated with transmitters is essential. Berlin (2006) has a baseline energetics model for surf scoters that can be replicated for instrumented birds to investigate this question.

As technology and research needs evolve, scientists must be willing to diverge from traditional methods of tracking diving birds. The capabilities of new solar-powered GSM/GPS transmitters far exceed implantable devices. Innovative techniques, such as the silicon harnesses, need to be tested and verified before full-scale implementation. Our recommendation is that silicon harnesses be refined and tested on captive birds, while simultaneously be deployed in wild populations. There are endless materials that can be used as substitutes and an even further suite of methods that can attach the

transmitters to the harnesses. Through collaboration and diverse invention, researchers can insure that external devices are attached in manners that minimize negative effects and meet all assumptions required for the collection of substantive and insightful ecological data.

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