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MANAGEMENT BRIEF

Comparison of Retention Success for Multiple Tag Types in Common Snook

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Abstract
Tags are commonly used to uniquely identify fish in order to estimate population size, harvest rates, and fish behavior. However, some tags have the propensity to be shed (lost), which can bias results. To examine the shedding rates of external tags and the potential bias this introduces for common snook *Centropomus undecimalis* we marked adult snook with an internal 23-mm half duplex passive integrated transponder (PIT) tag (as a permanent mark) and one of two external tags: a T-bar anchor tag (44 mm; Floy, FD-68B) or a dart tag (89 mm × 2 mm; Floy, FT-1-94). Fish were tagged along sandy beaches of the Gulf of Mexico in southwestern Florida during the spawning season in 2007–2009. Short-term (37-d) external tag retention success was 100% for both tags. However, long-term (391-d) retention success was low for external tags (T-bar = 76%; dart = 38%). Given the limitations of and trade-offs among tag types, choosing the most appropriate tag will continue to challenge researchers. Until more universal tags are developed, researchers must carefully consider the advantages and disadvantages of each tag type with respect to different project objectives.

Marking fish with unique tags is a useful way to determining survival, movement, fishing pressure, abundance, and mortality (Ombredane et al. 1998; Winner et al. 1999; Pine et al. 2003). Mark–recapture studies can be broadly classified into two categories based on recapture methods—research-based or angler-based recaptures—which may influence the types of tags used. For instance, researcher-based recapture studies will often use internal tags that have high retention success but require specialized equipment to detect recaptures. Research-based recaptures may also use external tags to gain passive recaptures through underwater fish counts. However, external tags are generally used in angler recapture studies. Angler-recapture studies that use external tags are less costly (i.e., cheaper tags and less effort spent by scientists to gain recaptures); allowing researchers to mark more fish and, thus, potentially increase recapture probabilities. The disadvantage is that external tags are often subject to biases associated with failure of reporting recaptures and higher tag loss (Muoneke 1992).

If tags are shed and these losses are unaccounted for, estimates of harvest rates and abundance may be conservative by failing to account for all of the tagged fish that were recaptured (i.e., fish that were marked and recaptured but lost their tags; Fabrizio et al. 1996). Thus, it is of particular importance to account for tag loss. Tag loss can be influenced by several variables, including tag type, target species, fish size at tagging, environmental conditions, and the period of time tags will be actively monitored (Booth and Weyl 2008). Tag loss (conversely reported as retention success) is traditionally estimated by two methods: (1) marking captive fish and observing tag loss over time (e.g., Harvey and Campbell 1989; Brennan et al. 2005; Adams et al. 2006), or (2) tagging fish simultaneously with multiple tags (e.g., Barrowman and Myers 1996; Clugston 1996; Hartman and Janney 2006). Using multiple tags facilitates identification of fish that have lost a single tag and is appropriate for studies of noncaptive fish. This method allows the animal to forage, avoid predators, spawn, and engage in other behaviors that may influence retention success, variables that cannot be observed in captivity (Booth and Weyl 2008). However, multiple-tag experiments require tagging many more fish and still provide only an estimate of retention success. Typically, multiple-tag experiments use an internal tag in conjunction with external tags.

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The objective of this study was to test the relative retention success of two external tag types (dart and T-bar tags) implanted in a popular estuarine game fish, common snook *Centropomus undecimalis.* We tested the retention success of each external tag type by tagging adult snook with either a dart or a T-bar tag and an internal passive integrated transponder (PIT) tag. The retention success of PIT tags was established as 100% in juvenile snook in a Charlotte Harbor (southwestern Florida) caging experiment, where every fish recaptured with an external tag also carried a PIT tag (Adams et al. 2006). Thus, PIT tags were used as a standard to test the relative retention success of the two external tag types. Adult snook were marked during the summer on Gulf of Mexico beaches of southwest Florida (part of a larger tag–recapture project examining movement patterns of adult snook during spawning season; Adams et al. 2009). Adult snook congregate around shallow beach areas to spawn in the summer, thus making a tag–recapture approach appropriate.

METHODS

Study area.—Charlotte Harbor is a 700-km^2 coastal plain estuarine system in southwestern Florida. The Peace, Myakka, and Caloosahatchee rivers, as well as many smaller creeks throughout the drainage, transport large amounts of freshwater into the harbor (Hammett 1990). The climate is subtropical; mean seasonal water temperatures range from 12°C to 36°C, and freezes are infrequent (Poulakis et al. 2003). The estuary is separated from the Gulf of Mexico by a string of barrier islands, and tidal exchange is through Boca Grande, Captiva, Redfish, and San Carlos passes that separate the barrier islands. The Gulf of Mexico shorelines of the barrier islands are entirely sandy beaches. The passes are a mixture of natural sand and anthropogenically hardened shorelines. Common snook spawn in proximity to the passes, and at a few locations along the barrier island beaches during summer (typically May through September; Taylor et al. 1998).

Capture protocol.—From May through September 2007, May through September 2008, and June through September 2009, common snook were captured along the Gulf-facing beaches of three barrier islands—Cayo Costa (12.4 km long), Upper Captiva (6.8 km long), and Captiva islands (8.9 km long)—all located between Boca Grande Pass and Blind Pass (Figure 1). A shallow-draft boat with a forward mounted engine and a removable transom was used to set two types of center-bag seine nets (91.4 × 2.4 m with 19.1-mm mesh and 182.9 × 2.4 m with 15.0 mm mesh) around schools of snook that were spotted along the beach. We switched from the smaller to the larger net during our second summer of sampling to increase catches because snook were able to more readily avoid our smaller net. The entire length of beach of each island was searched for snook on each day the island was sampled, to the extent that time allowed. The procedure was to steer the boat along the beach and, when snook were spotted, one end of the net was deployed off the stern to secure it to the beach. The boat was then used to deploy the net around the sighted snook. The nets were hauled onto shore, fish being captured in the center bag. During summer, snook typically hold within 2 m of shore (at approximately 0.05–2 m depth), so this method is very effective at capturing multiple snook (mean catch per haul = 12, SE = 1.2). Once captured, the snook were placed in mesh holding pens (1.5 × 1 × 1.5 m) until tagging. Mesh holding pens were kept in at least 1.5 m of water. A maximum of 30 snook were placed in one pen at a time. Typically, fish were held in a pen for 15 min to 1 h depending on how many fish were caught per sample.

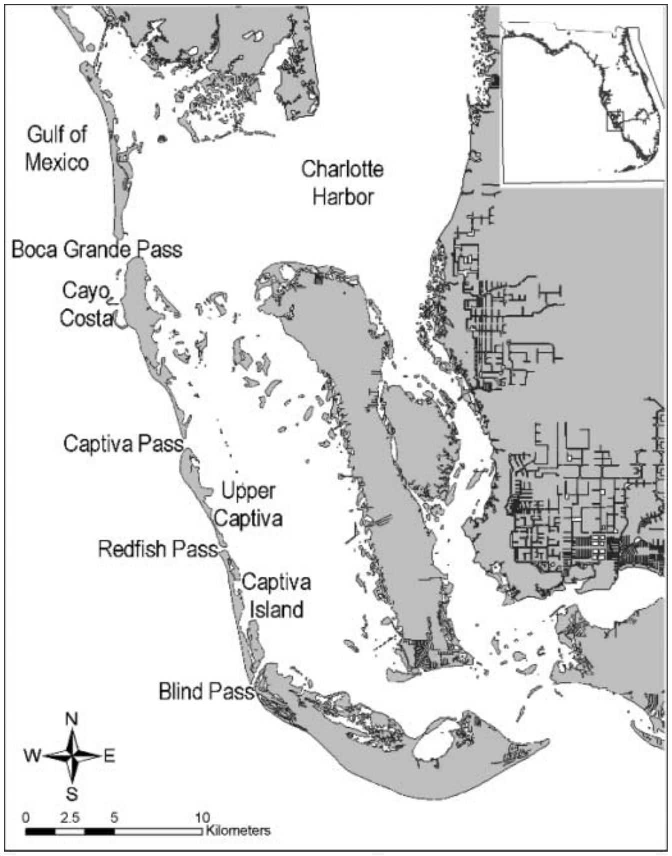

FIGURE 1. The area of the Gulf of Mexico in southwestern Florida from which common snook were collected.

Tagging and recapture.—Upon capture and before tagging, each common snook was checked visually for external tags and with an Allflex International Organization for Standardization-compatible radio frequency identification portable reader (Model RS601) for internal tags. Untagged snook were tagged internally with a half duplex PIT tag (TIRFID 2000, Texas Instruments; 23 mm) and externally with either a T-bar anchor tag (44 mm; Floy, FD-68B) or dart tag (89 × 2 mm; Floy, FT-1-94). Before tagging, snook were moved from the holding pens to a large cooler with a seawater and Alka-Seltzer mix (1–1.5 tabs/4 L seawater) to immobilize and minimize stress on fish (Currens et al. 2007). Once immobilized, standard lengths (SL) of fish were measured, and a PIT tag was inserted into the abdominal cavity through a 3-mm incision (Adams et al. 2006). Each PIT tag uniquely identified each fish via a 16-digit identification number recognized only by a PIT tag reader. The T-bar and dart tags were inserted into the musculature below the first dorsal fin. T-bar tags were used from May 1, 2007, to July 11, 2008; dart tags were used from July 13, 2008, to September 4, 2009. Each external tag was imprinted with an identification number and phone number to report a recapture. We recorded SL, external tag identification number, PIT tag number, and latitude and longitude of the collection site for each tagged fish. After tagging, fish were placed in a pen for approximately 5 min to allow for recovery and then released at the site of capture. Because no stressed behavior was observed for any of our tagged fish (i.e., inability to retain equilibrium, abnormal bleeding, etc.), and PIT-tagging experiments with juvenile snook (more vulnerable to tagging-related injuries due to their smaller size) showed low or no mortality (Adams et al. 2006), tagging-induced mortality was assumed to be minor in this study.

Data analyses.—Relative tag retention success was calculated using the number of fish containing a given external tag type relative to the total number of fish examined containing a PIT tag. Variance in tag retention was estimated using the equation

$$\prod_{\text{EX}} \left(1 - \prod_{\text{EX}}\right) / (R_P + R_{\text{EXP}} - 1),$$

where for a given period, $\prod_{\text{EX}}$ is the retention success for an external tag type, R_{EXP} equals the number of recaptured fish retaining both an external tag type and a PIT tag, and R_P is the number of recovered fish with a PIT tag only (Seber 1982).

RESULTS AND DISCUSSION

During the three summer periods, we marked a total 831 common snook (mean = 437 mm SL, SE = 2.1, range = 316–851 mm) with both T-bar and PIT tags and 829 snook (mean = 418 mm SL, SE = 1.7, range = 307–792 mm) with both dart and PIT tags. We recaptured 81 T-bar-tagged and 47 dart-tagged snook. Short-term (<37 d at large) tag retention was 100% retention ($n = 21$) for both external tag types (Table 1; Figure 2). This was expected and was similar to findings in previous studies (Waldman et al. 1991; Timmons and Howell 1995; Wallin et al. 1997). Longer term (247–391 d) retention success for both external tag types, however, dropped significantly (76% of T-bar tags and 38% of dart tags retained), significantly lower retention success for dart tags (chi-square test: $P < 0.001$, df = 1; Table 1; Figure 2). The study encompassed a total of 792 d during which T-bar tagged fish were in the system (i.e., the duration between the first and last recaptured fish for each tag type) and 391 d that dart tagged fish were in the system. We report retention success for T-bar-tagged fish at large up to 792 d in Table 1 to show that tags continue to be shed after 391 d at large, not as a means to compare retention success across tag types. A review of 15 articles that examined long-term retention success of external or internal tags on 16 different fish species (Table 2) indicated that our observed differences between external tag types are consistent with other findings. This is a cause for concern if such

TABLE 1. Relative retention success of three different tag types (T-bar anchor, dart, and passive integrated transponder [PIT]) in common snook captured on seaward-facing beaches in the Gulf of Mexico from May 2007 to August 2009.

	Number of snook at days posttagging					
Tag-related variable	0–37	38–72	73–246	247–391	392–443	444–792
Snook tagged with T-bar and PIT tags						
Number recaptured with T-bar and PIT tags	8	13	13	21	16	10
Both tags intact	8	12	13	16	2	2
T-bar only	0	0	0	0	0	0
PIT tag only	0	1	0	6	14	8
T-bar tag retention	1	0.92	1	0.76	0.13	0.2
Variance of estimate	0	0.01	0	0.02	0.01	0.02
Snook tagged with dart and PIT tags						
Number recaptured with dart and PIT tags	13	18		16		
Both tags intact	13	10		6		
Dart tag only	0	0		0		
PIT tag only	0	8		10		
Dart tag retention	1	0.56		0.38		
Variance of estimate	0	0.01		0.02		

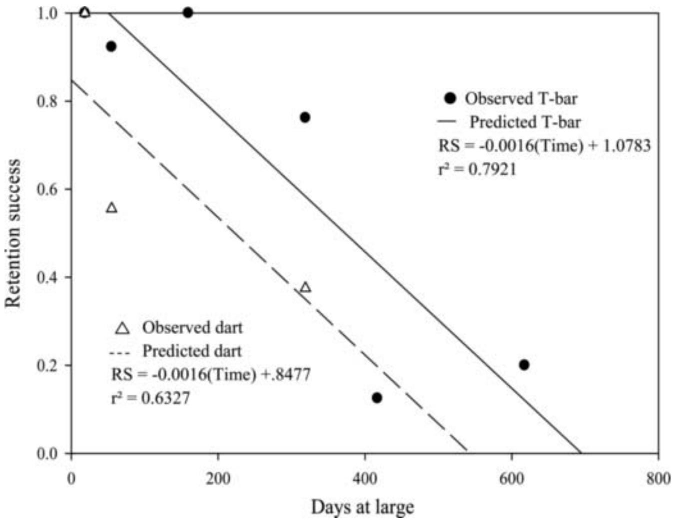

FIGURE 2. Tag retention success (RS) among common snook for T-bar tags (circles) through 792 d at large and dart tags (triangles) through 391 d at large. Data were aggregated into the time intervals described in Table 1. Fish were assumed to be caught on the median day within each interval.

tags are used in multiple-year studies to estimate fish movement patterns, such as in our larger companion snook study.

The habitat-use patterns of common snook probably contributed to the low retention success for both external tag types. External tags can become caught or snagged on structurally complex habitats and pulled from the fish or become damaged and lost (Franzin and McFarlane 1987). All of our fish were marked during summer spawning season on Gulf of Mexico barrier island beaches, and the high short-term retention success may have been partly reflective of this low-complexity habitat. After spawning season, adult snook return to structurally complex shoreline habitats provided by red mangrove *Rhizophora mangle* (Taylor et al. 1998; Adams et al. 2009), where tags may become entangled in mangrove prop roots. This may have contributed to our higher long-term tag loss and may be an especially important consideration in movement studies that use external tags within heterogeneous landscapes, such as estuaries. For instance, if one habitat type promotes relatively higher tag loss, its use and importance may be underestimated.

External tags are also subject to epibiotic accumulation, which causes tag loss through impaired hydrodynamics and the increased chance of snagging (Muoneke 1992). For example, Dicken et al. (2006) noted that 75% of dart tags used on sand tiger *Carcharias taurus* had epibiotic growth, and one shark that was at large over 859 d accumulated 41 g (dry weight) of biotic growth on a single tag. The extra drag caused by epibiotic growth may reduce the ability for externally tagged fish to effectively forage and avoid predators, potentially altering fish behavior. In our study, epibiotic growth was noted on most of the external tags, and the amount of accumulation was similar across tag types. However, epibiotic growth increased in volume with days at large, which may have contributed to lower long-term retention success (Figure 3). Anecdotally, we noticed that externally tagged fish with notable epibiotic growth on the tag showed a weaker escape-response to our net boat than did unmarked fish (R.E.B., personal observation). In contrast, in regions where epibiotic growth may be limited, tag-induced changes in fish behavior have not been observed. For example, an Atlantic cod tagging study conducted by Otterå et al. (1998) in an archipelago in western Norway, where epibiotic growth on tags was almost nonexistent, found no effects of external tags on predation rates, growth rates, and behavior of tagged fish.

The effect of the tag pulling on the musculature and skin may also increase tag loss. Muoneke (1992) speculated that this open wound may increase tag loss because of the tag's tendency to rotate as the fish moves, never fully allowing the wound to heal (Winner et al. 1999). In our study, many of the snook recaptured with an external tag had open sores surrounding the tagging site, which increased in severity (i.e., increased diameter of lesion and irritated area) with days at large. These wounds were also notably worse on fish that were marked with T-bar tags, probably due to the less rigid base of T-bar tags allowing the tag to spin more freely. These sores may increase shed rates as constant irritation of the tag may drive fish to actively attempt to remove it, altering fish behavior (Muoneke 1992).

Two alternative sources of bias may have contributed to the low estimates of tag retention in this study; low sample size and failure to account for fish that had lost both external and internal tags. Although sample size (related to recapture rate) was rather low in our study, those numbers are typical for tag–recapture studies, especially for estimations of long-term retention success (Table 2). For example, Hartman and Janney (2006) used a sample size of 14 fish to calculate long-term retention success of two external tag types implanted in largemouth bass over a period of 393 d. Buckmeier and Irwin (2000) used a sample size of nine to calculate long-term retention success of visual elastomer tags in channel catfish, as did Timmons and Howell (1995) similarly use a sample of nine spaghetti-tagged blue catfish at large for over 360 d. Further, it is possible that we failed to account for fish that lost all tags. However, since PIT tag retention in general is very high (97–100%; Harvey and Campbell 1989; Clugston 1996; Dare 2003) and it has been measured at 100% in juvenile common snook over a period of 6 weeks (Adams et al. 2006; Table 2), we find that our assumption of 100% PIT tag retention in this study was valid.

Since both external tags were exposed to similar environmental conditions and both had similar construction with respect to the portions extending outside the fish, we suggest that the high rate of dart tag loss observed in our study was due to improper attachment during tagging. Improper attachment is a major component of tag loss, and accounted for 88% percent of tag loss in brook trout *Salvelinus fontinalis* (Keller 1971). In our study, the applicator needle used to insert the dart tags dulled very quickly in the field (R.E.B., personal observation), causing the tag to miss its target location between the pterygiophores, which may have decreased retention success (Muoneke

TABLE 2. Summary of tag retention success for three different tag types from 15 peer-reviewed articles covering 16 fish species. Asterisks indicate studies that pooled data from multiple years or locations. The methods used to estimate tag shedding rates (column 2) are as follows: RR = relative retention rate, CL = conditional likelihood model, ML = maximum likelihood model, NLM = nonlinear model, CMM = conditional multinomial model, and NR = not recorded. The table is organized in descending order, from the tag type with the highest retention success (passive integrated transponder [PIT] tags) to the tag type with the lowest retention success (dart tags); within each tag type, studies are presented from highest retention to lowest.

Species	Method	Days at large	Recapture sample size	Tag type	Percent retention	Reference
Largemouth bass *Micropterus salmoides*	RR	450–720	22	PIT	100	Harvey and Campbell (1989)
Atlantic sturgeon *Acipenser oxyrinchus*	RR	1,825	7	PIT	100	Clugston (1996)
*Brown trout *Salmo trutta*	RR	0–210	358	PIT	96.62	Ombredane et al. (1998)
*Northern pike *Esox lucius*	RR	0–365	140	T-bar (Floy FD-68B)	98.77	Pierce and Tomcko (1993)
Striped bass *Morone saxatilis*	RR	0–365	64	T bar (Floy)	98	Dunning et al. (1987)
Northern pike	RR	0–365	140	T-bar (Dennison 08966)	97.42	Pierce and Tomcko (1993)
Paddlefish *Polyodon spathula*	RR	0–365	38	T-bar (Floy FD-6813B)	97	Timmons and Howell (1995)
Bigmouth buffalo *Ictiobus cyprinellus*	RR	0–365	19.4	T-bar (Floy FD-6813B)	97	Timmons and Howell (1995)
Smallmouth buffalo *Ictiobus bubalus*	RR	0–365	41	T-bar (Floy FD-6813B)	97	Timmons and Howell (1995)
Red drum *Sciaenops ocellatus*	RR	111–423	NR	T-bar (IEX tags)	91	Winner et al. (1999)
Lake trout *Salvelinus namaycush*	CMM	365	190	T-bar (Floy FD-67 [C, BC, &F])	80–90	Fabrizio et al. (1999)
*Atlantic cod *Gadus morhua*	CL	0–365	210	T-bar anchor	81–87	Barrowman and Myers (1996)
Sharptooth catfish *Clarias gariepinus*	ML	472	22	T-bar (Hallprint TBA-1)	83	Booth and Weyl (2008)
White bass *Morone chrysops*	NLM	560	165	T-bar (Floy FD-68BC)	81.4	Muoneke (1992)
Common snook *Centropomus undecimalis*	RR	247–391	21	T bar (Floy FD-68B)	76	This study
Blue catfish *Ictalurus furcatus*	RR	0–365	9	T-bar (Floy FD-6813B)	74	Timmons and Howell (1995)
Channel catfish *Ictalurus punctatus*	RR	172–270	7	T bar (Floy FD-68B)	71	Buckmeier and Irwin (2000)
*Lake trout *Salvelinus namaycush*	NLM	0–365	640	T-bar (Floy FD-68BC)	65.6	Fabrizio et al. (1996)
Largemouth bass	RR	207–600	14	T bar (Floy FD 68B)	42.9	Hartman and Janney (2006)
Barramundi[a] *Lates calcarifer*	NLM	0–365	91	T bar (Floy FD-67)	31	Davis and Reid (1982)
Sharptooth catfish	ML	646	48	Dart (Hallprint PDL-1)	98	Booth and Weyl (2008)
Paddlefish	RR	0–365	38	Dart (Floy FT-4)	95	Timmons and Howell (1995)
Red drum	RR	111–423	NR	Dart (PDX tags)	89	Winner et al. (1999)
Blue catfish	RR	0–365	9	Dart (Floy FT-2)	69	Timmons and Howell (1995)
Smallmouth buffalo	RR	0–365	41	Dart (Floy FT-4)	47	Timmons and Howell (1995)
Common snook	RR	247-391	16	Dart (Floy FT-1-94)	38	This study
Barramundi[a]	NLM	0–365	278	Dart (Floy FT-4)	31	Davis and Reid (1982)

[a] Also known as barramundi perch.

FIGURE 3. Epibiotic growth on a T-bar tag implanted in a common snook after 792 d at large. [Figure available in color online.]

1992). In contrast, Booth and Weyl (2008) found that T-bar tags had lower retention success than dart tags principally due to the anchoring mechanism not locking properly behind the pterygiophores. These contrasting findings underscore the need for proper tag selection for the species of interest. Annual variability in abiotic conditions might also have influenced the tag retention success of the two tag types. Interannual variability in abiotic conditions (e.g., temperature salinity and dissolved oxygen) may alter common snook movements and habitat use (Blewett et al. 2009), possibly affecting retention success. However, the larger (4-year) companion study of which this project was a part showed that snook expressed greater than 97% site fidelity to Gulf-facing beaches during spawning (Adams et al. 2009; Adams et al. 2011). Thus, we speculate that their behavior remained relatively constant across years and would not have contributed to different retention success among external tag types.

Other tag types are available that are not exposed to the external processes that affect external tags. For example, Brennan et al. (2005) implanted (subdermal) coded wire tags (CWT) in juvenile common snook and found that CWTs had 100% retention over a period of 1 year. Other subdermal tags such as visual implant elastomer (VIE) tags have similar retention success, but fish cannot be uniquely identified beyond a limited basis, thus limiting the capability of gaining data on factors such as individual growth or movement. Moreover, although both CWT and VIE tags are visible to the naked eye, they are relatively inconspicuous (Hartman and Janney 2006), thus using anglers as a means to gain recaptures may not be feasible. Most other permanent marks, such as PIT tags, are internal, and are not detectable without specialized equipment such as hand-held readers. These readers are relatively expensive (US$500), such that providing anglers with readers to gain significant recaptures may not be feasible. However, they can also be detected with remote detection equipment in difficult-to-sample habitats (e.g., Adams et al. 2006) and are appropriate for long-term studies.

Tag loss in general can result in the underestimation of both harvest rates and population sizes. Although models are available to adjust for tag loss (e.g., Seber 1982), retention success can drop to less than 50% after 365 d at large (Table 2),; which can significantly decrease the power of mark–recapture models (Fabrizio et al. 1996). Given the limitations and tradeoffs of different tag types, choosing the most appropriate tag will continue to challenge project needs, and until more universal tags are developed, researchers must carefully consider the advantages and disadvantages of each tag type in light of project objectives, methods, and focal species and their habitats.

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