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Leatherback skull from Suriname in the late 1960s with signs of injury from a jaguar. Photo credit: N. Mrosovsky.

Editorial

Articles

Announcements
Recent Publications

ISSN 0839-7708

Radio Frequency Identification Technology and Marine Turtles: Investigation of Passive Integrated Transponder (PIT) Tags and Readers

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The insertion of a Passive Integrated Transponder (PIT) tag into marine turtles provided one of the first means of permanent marking, and today the tags are used widely. PIT tags, also known as a Radio Frequency Identification (RFID) tags, are not subject to tag loss in the same way that external flipper tags are (but see McNeill *et al.* 2013), and therefore they provide a mechanism to track recaptures throughout the turtle's lifespan. Data obtained through recaptures can provide valuable scientific information regarding growth, movement patterns, incidental fishery interactions, and survival. As Radio Frequency Identification technology developed for use in many industries, PIT tag and PIT tag reader options also increased, resulting in compatibility issues that have complicated the ability of researchers to identify animals tagged by other investigators. If researchers are not aware of the incompatibilities that exist within this technology, there is a greater risk that opportunities to identify previously tagged turtles could be lost, along with the scientific value that those rare encounters provide.

The purpose of this paper is to explain the basics of RFID technology (*e.g.*, PIT tags) as applied to marine turtles, point out inconsistencies in the use of this technology by researchers using western North Atlantic leatherbacks, *Dermochelys coriacea*, as an example, and provide some guidance for future use. The technology is complex and here we barely brush the surface; books have been written on the subject (*e.g.*, Garfinkel & Rosenberg 2006). Certain technical terms used are defined at the end of the paper and are in bold type at first use.

For wildlife marking, there are three elements of an RFID system: the transponder (PIT tag) and the transceiver (PIT tag reader), both with antennas and specific radio frequency characteristics, and the database of assigned tag ID numbers and associated data. The transceivers used by marine turtle researchers are portable. Tags used for marine turtles are passive, deriving all their power from the incoming radio frequency (RF) signal from the reader. Tags used for marking animals today are excited in the low frequency (LF) bandwidth of 125-134.2 kHz with a wavelength of 2,400 m (Garfinkel & Holtzman 2006). A variety of tags have been used in marine turtles, but all have been **full-duplex** (FDX, versus **half-duplex**, HDX). The tag's small integrated circuit (microchip), which is attached to its antenna (Fig. 1), is energized by a reversing magnetic field of RF energy from the reader (the **excite field**). The tag transfers a binary signal of the unique ID, programmed by the manufacturer, to the reader. This is done by perturbing the excite

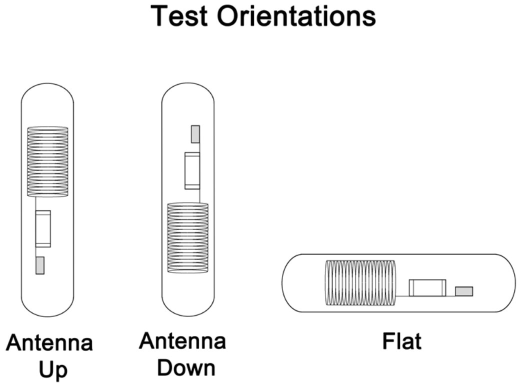

Figure 1. Passive Integrated Transponders (PIT tags) were tested in 3 different orientations, which placed a tag's antenna in different positions relative to the plane of the readers' antennas. Often the end of the tag with the microchip is obscured by epoxy internal to the capsule.

field from the reader; the **data modulation protocol** of the tag determines the **response frequency**. The reader recognizes the data modulation protocol, decodes the information, and sends the ID to a display. In some readers, the information may also be stored in the reader memory for future access. Initially, researchers matched their readers to their selected tag's excite frequency, modulation, etc. Today more manufacturers are offering **multi-mode readers** that enable the **detect**ion and **read**ing of some or all the tag types used for the permanent marking of marine turtles. However, there still are many **single-mode readers** in use among turtle researchers.

Tags that have been used in marine turtles are "promiscuous," capable of responding to any reader with the appropriate excite frequency range and readable if the reader recognizes the data modulation protocol. The earliest tags used for marine turtles were 400 kHz (FDX-A; *e.g.*, Fontaine *et al.* 1993), then 125 kHz (FDX-A) and 128 kHz (FDX-A) tags were used. Most recently, 134.2 kHz tags (FDX-B) have been deployed. In addition, some Caribbean leatherback researchers initially used secure (encrypted) tags from the distributor AVID (*e.g.*, McDonald & Dutton 1996). While compatible in frequency (125 kHz) and read protocols with many readers in use, the **decrypt**ion capability initially was available only on AVID readers. Unfortunately, other readers, even those of the same excite field range and modulation protocols, could not read encrypted tag.

Much has been written about tag-reader incompatibilities, especially in light of the use of RFID technology in companion animals (*e.g.*, pets; World Small Animal Veterinary Association 2012). In response, the International Organization for Standardization (ISO) issued Standards 11784 and 11785 (ISO 1996a,b). Those standards specify the ID code structure (ISO 11784), how the transponder is activated, and how the stored information is transferred to the transceiver (ISO 11785). An **ISO** tag's excite field frequency is 134.2 ±13.42x10^{-3} kHz, and it is becoming the standard tag used for companion animals worldwide and by marine turtle researchers. The ISO tag is available from most manufacturers, and for some manufacturers, this is the only tag now being marketed for use in wildlife.

A factor affecting the ability to excite and read a compatible tag is the reader's **near-field** read distance, which is a function of excite field strength, read antenna circuitry, and software. Read distance is especially important for leatherback turtles that historically have been tagged in the neck or shoulder area, where the needle usually is inserted perpendicular to the surface, placing the tag as deep as 4 cm (the length of the longest insertion needle in use by marine turtle researchers). A tag implanted beyond the read distance of a tag-reader combination cannot be detected. Tags implanted in nesting females on the beach may be within the transceiver's read distance capability at the time, but when the turtle returns to foraging grounds, fatty tissue underneath the skin surface may thicken (Davenport *et al.* 2011). A more robust body condition, particularly with leatherback turtles, effectively increases the required read distance, and may increase the potential that the tag might not be detected if the turtle is encountered away from the nesting beach.

These issues (tag-reader incompatibility, encrypted tags, and read distances) have serious ramifications for the use of PIT tags in marine turtle research. For example, a single-mode reader may activate a tag within its excite field range, but will not be able to read the ID unless it recognizes the data modulation protocols of the tag's response. This means that if an animal is tagged and then moves to a different researcher's study area, the original tag may not be detected unless the second researcher is using a reader that is compatible with the original

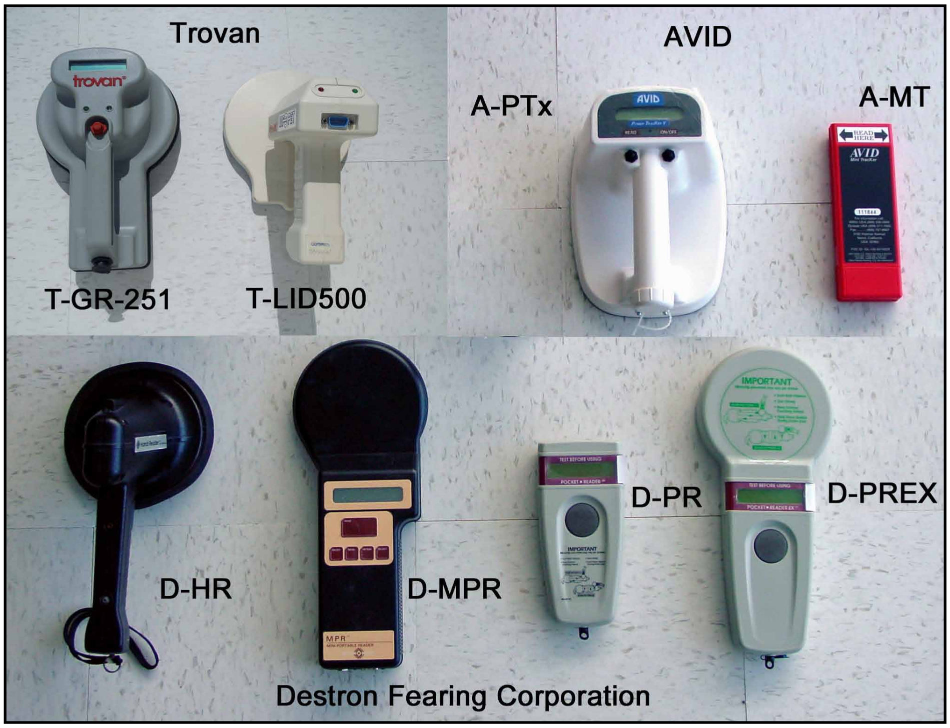

Figure 2. Portable RFID readers tested: Trovan GR-251 and LID-500, AVID Power Trackers and MiniTracker, and Destron Fearing Handi Reader, Mini Portable Reader, Pocket Reader, and Pocket Reader EX.

Location	PIT tags applied	Readers used	Sources	Comments
SOUTH AMERICA: Not PIT tagging or scanning in Brazil (J. Tome) or Colombia (D. Amorocho)				
French Guiana, Suriname, Guyana	Trovan ID100 128 kHz	Trovan LID500; Destron Pocket Reader EX tested 2005	L. Kelle, M. Hilterman, E. Goverse, P. Pritchard & A. Narain	Tested a modified Trovan reader (unsatisfactory); tested AVID Power Tracker IV (unreliable at reading Trovan tags); tested a Destron Pocket Reader (did not detect 90% of Trovan tags)
Venezuela	AVID unencrypted 125 kHz; AVID encrypted 125 kHz	AVID Power Tracker IV	H. Guada & S. Eckert	
CENTRAL AMERICA: Not PIT tagging or scanning in Panama (D. Chacon)				
Costa Rica	AVID unencrypted 125 kHz	AVID Tracker II and IV	D. Chacon	Gandoca and Black Beach
	AVID encrypted 125 kHz	AVID Tracker III	I. Abella Gutierrez	Reserva Pacuare; Not PIT tagging or scanning at Tortuguero (S.Troėng)
NORTH AMERICA: Not PIT tagging or scanning in México (L. Sarti)				
USA	Destron 125 kHz	Destron Pocket Reader and Pocket Reader EX	S. Epperly, H. Haas, L. Belskis, K. Dodge, C. Johnson & K.Stewart	NOAA Fisheries SEFSC and NEFSC research and observer programs; STSSN; Juno Beach nesting beach project; researchers are upgrading software version
		AVID MiniTracker Multi-Mode	C. Trapani	VAMSM has an AVID MiniTracker for their STSSN activities
	AVID unencrypted 125 kHz; Destron 125 kHz (future)	Destron Pocket Reader	D. Bagley	Archie Carr NWR; using older software version, but likely will upgrade
Canada	AVID unencrypted 125 kHz 2002-04; AVID encrypted prior to 2002	AVID Power Tracker IV (thru 2002); AVID Power Tracker VI since 2003	M. James	Has detected Trovan tags released from Guianas
CARIBBEAN: Not PIT tagging or scanning in Grenada (C. Lloyd)				
British VI	AVID unencrypted 125 kHz	Destron Pocket Reader	S. Gore & B. Godley	Reader has older software version (218-S53)
USVI	AVID unencrypted 125 kHz; AVID encrypted in early years	AVID Power Tracker II and IV	P. Dutton & R. Boulon	
Puerto Rico	AVID unencrypted 125 kHz; AVID encrypted in early years	AVID Power Tracker II and IV	C. Diez & P. Dutton; H. Horta is another contact	

Location	PIT tags applied	PIT readers used	Source	Comments
Trinidad & Tobago	AVID unencrypted 125 kHz; AVID encrypted in early years	AVID Power Tracker II and IV	S. Eckert & D. Sammy	
Anguilla	Destron 134.2 kHz (IdentiChip)	Destron Pocket Reader	J. Gumbs & B. Godley	Likely reader has older software version (218-S53) as supplier same as for BVI
	AFRICA			
Gabon	Trovan ID100 128 kHz	Trovan LID-500	E. Goverse	Tagging in neck

Table 1. Table begins on page 6. Passive Integrated Transponders (PIT) and readers used in leatherback projects in the West Atlantic Ocean and in Gabon through December 2004. Note that additional readers have since become available, and may be in use now, but this table does not reflect the changes made since the survey. For example, the French Guiana researchers also now use Trovan's GR-251 reader and Trinidad researchers now use Destron-Fearing Pocket Reader EX models. See Tables 2 and 3 for what was available as of December 2012.

data modulation protocols. Besides the lost opportunity to detect a marked turtle, the unnecessary implanting of an additional tag may result in interference with the original tag when energized (Garfinkel & Holtzman 2006; see discussion below). In most instances, a reader would display the tag presenting the stronger signal. Similarly, an encrypted tag may not be detected or read, or may not be decrypted, leading to the inability to identify a marked animal. Lastly, the near-field read distance needed for leatherbacks may be greater than the capability of some portable readers to detect a tag.

Leatherback turtles are perhaps the most far-ranging of all sea turtles species, mainly living a pelagic life, except for brief times when females are nesting or migrating through coastal waters (Turtle Expert Working Group 2007). An informal survey of virtually all North Atlantic leatherback researchers and of the U.S. Atlantic coast Sea Turtle Stranding and Salvage Network indicated that many different tag types and readers were in use at the end of 2004 (Table 1), and that incompatibilities likely existed. We compiled information about each of the tags (Table 2) and readers (Table 3) used by those surveyed. We tested each combination of tag and receiver for compatibility and read distance. Furthermore, we also tested new readers available after the survey was conducted. Similar studies have been conducted for tags and readers commonly used for companion animals (Lord *et al*. 2008a,b; see also www.rfidnews.com/GeneralRFIDNews/reader-evaluation/assets/Evaluation.pdf). Lastly, we discuss our results in light of the 2004 snapshot survey, provide information on what equipment was available 8 years later (December 2012; see Tables 2 and 3), and provide guidance to sea turtle researchers for the future.

We tested all seven types of RFID tags that were in use by marine turtle researchers at the time of the survey: AVID's 125 kHz encrypted and non-encrypted, and 134.2 kHz; Destron Fearing's (Destron) 125 kHz, 134.2 kHz, and 400 kHz; Trovan's 128 kHz (Table 2). We also tested eleven different reader models: AVID's Power Tracker II, IV, V, VI and MiniTracker; Destron's Handi Reader, Mini Portable Reader, Pocket Reader, and Pocket Reader EX; Trovan's LID-500 and GR-251 (Fig. 2, Table 3]. For each of the seven tag types, we tested three replicates (*e.g.*, three individual tags with unique IDs), each in three different orientations (antenna up, antenna down, and flat, see Fig. 1), yielding nine readings for each reader for each tag type. Except for Trovan's LID-500 and Destron's Mini Portable Reader and Handi Reader, all units were supplied directly by the manufacturer and had not seen field use. We found that battery charge was important and, thus, we always maintained freshly charged batteries in the units.

Trials were conducted on a wooden table, and all metal objects in close proximity to the testing station were removed to minimize interference (the experimental arena is depicted in Fig. 3). Each tag, secured within a plastic sleeve to achieve the necessary orientation, was placed on a base consisting of one ~3.2 mm deep vinyl tile and a second vinyl tile with a center well cut out to accommodate the tag. Two ceramic 4 x 4 inch tiles were stacked in each

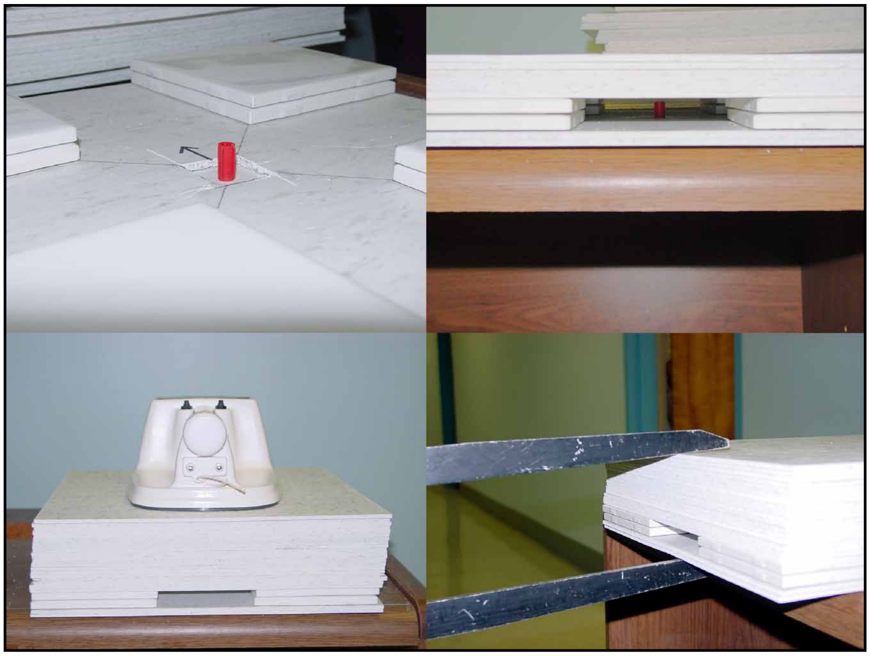

Figure 3. The experimental arena. The tag was placed in the red plastic cylinder to control the tag's position and orientation (see Fig. 1) and placed on a vinyl tile. Two ceramic spacers elevated the vinyl tiles that were stacked over the tag.

Manufacturer	Model	Frequency	EN	Tag Size	Comments
Allflex USA, Inc.[1]	GPT12	134.2 kHz	No	12 x 2.1 mm	ISO FDX-B compliant (manufacturer code is 982); decimal: 15 digit code, hexadecimal: 13 character code
AVID Identification Systems, Inc. (AVID); Single Use Disposable Syringe/ Disposable Needle Assembly	**Encrypted A2028/A2024**	125 kHz	Yes	12 x 2.1 mm	9-digit code (000*000*000)
	Unencrypted A2128/A2124	125 kHz	No	12 x 2.1 mm	FECAVA (EuroCode); 10-characrter unencrypted code, 9 digits followed by "A" (000*000*000A on AVID readers and 000000000A on Destron readers)
	ISO compliant A2328/A2324	134.2 kHz	No	12 x 2.1 mm	ISO FDX-B compliant (manufacturer code is 977); decimal: 15 digit code, hexadecimal: 13 character code[2]
BIOMARK[1]	HPT12	134.2 kHz	No	12 x 2.1 mm	ISO FDX-B compliant (manufacturer code is 989); decimal: 15 digit code, hexadecimal: 13 character code[2]
Trovan	TX1400L TX1440L* **TX1406L**** TX1405	125 kHz	No	12 x 2.1 mm 12 x 2.1 mm 12 x 2.1 mm 14 x 2.1 mm	FECAVA[3]; 10 hexadecimal characters (*e.g.*, 442F664C1D), no longer distributed in the USA for fish and wildlife applications
	ISO compliant TX1410BE TX1415BE **TX1400ST** TX1440ST*	134.2 kHz	No	20 x 3.1 mm 23 x 3.4 mm 12 x 2.1 mm 12 x 2.1 mm	ISO FDX-B compliant (manufacturer code is 985); decimal: 15 digit code, hexadecimal: 13 character code[2]; no longer distributed in the USA for fish and wildlife applications sold under several names, such as IdentiChips in the UK *sterile wrapped for syringe implanter
	TX1400A	400 kHz	No	12 x 2.1 mm	10 hexdecimal character code (*e.g.*, 526F39503C), this frequency was once used for marine turtles, but read distance is short; discontinued
	ID 100 supplied in cannula needle **ID 100A** supplied in bulk	128 kHz	No	11.5 x 2.12 mm	Not distributed in USA; endorsed by IUCN Captive Breeding Specialist Group Distributed in USA; same transponder as ID100, but not in a needle; normal decimal display is 2 digits-4 hexadecimal characters-4 hexadecimal characters (*e.g.*, 00-06C0-B9AD)
	ID 162	134.2 kHz	No	11.5 mm x 2.12 mm	ISO FDX-B compliant (manufacturer code is 956); decimal: 15 digit code, hexadecimal:13 character code[2]; not distributed in USA

Table 2. Portable PIT tag readers used by or available to most marine turtle researchers as of December 2012. Tags tested are in bold font. xcept for the AVID Encrypted A2028/A2024 tags all other available tags are not encrypted. EN = Encrypted. [1]Biomark is the exclusive distributor for Allflex, BIOMARK, and Destron Fearing products in the United States. [2]Most portable PIT tag readers are set to display the decimal code. [3]FECAVA = Federation of European Companion Animal Veterinarian Association.

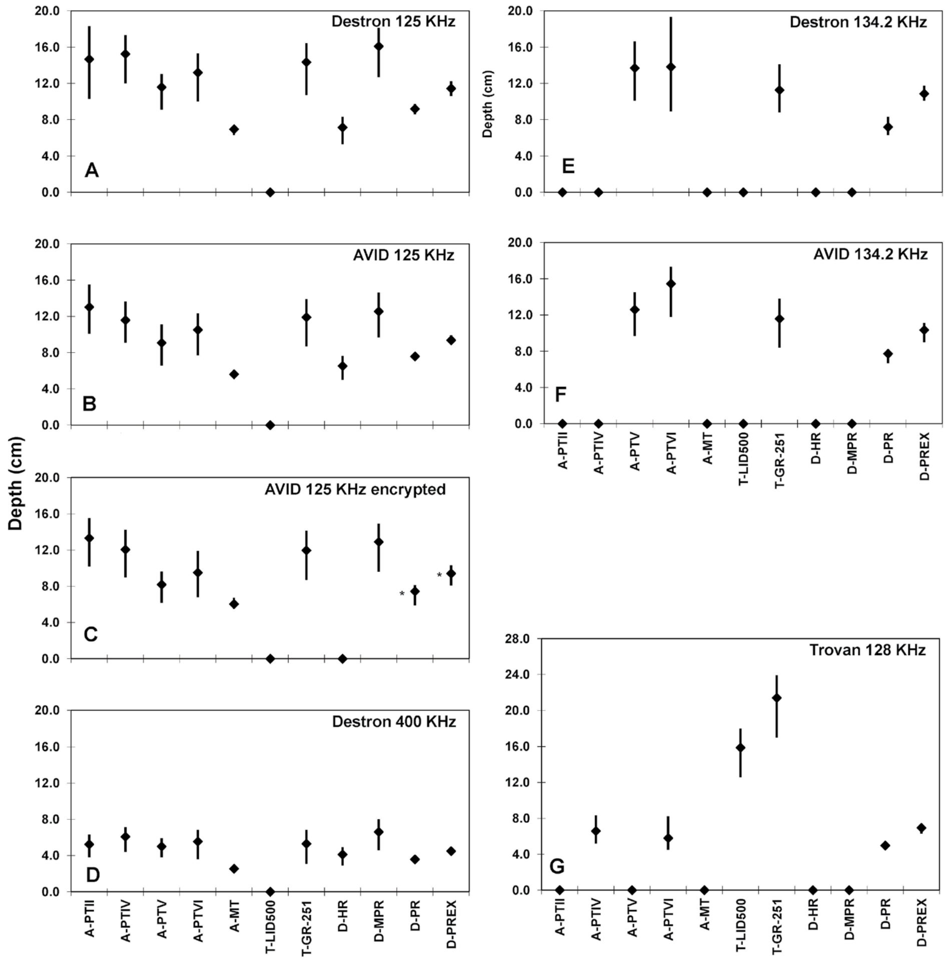

Figure 4. The average and the range of read depth readings for each reader/tag combination. Readers were tested with three tags of each type, with each tag in three different orientations, yielding 9 read depth readings for each reader tested. The readers tested were AVID's Power Tracker II (A-PTII), IV (A-PTIV), V (A-PTV), VI (A-PTVI), and their multi-mode MiniTracker (A-MT); Trovan's LID-500 (T-LID500) and GR-251 (T-GR251); Destron's Handi Reader (D-HR), Mini Portable Reader (D-MPR), Pocket Reader (D-PR), and Pocket Reader EX (D-PREX). Raw data are available from corresponding author on request or from the Southeast Fisheries Science Center website at http://www.sefsc.noaa.gov/turtles/PR_Epperly_etal_2015_MTN_Supplement.pdf

corner to allow space for the tag to be placed on end and support the stack of vinyl tiles on top. For each trial, additional vinyl tiles were stacked over the base in order to systematically increase the distance between the tag and the reader; he tag was scanned by moving the reader across the surface of the top tile. This process was repeated until the reader no longer could read the tag's ID. The top tile was then removed, and the tag was scanned until detecting the tag three consecutive times. The final tile depth was measured with aluminum slide calipers to the nearest 0.1 cm and recorded.

Measurements were adjusted to account for the thickness of the supporting bottom tile by subtracting 3.2 mm, and for the distance to the center of the tag by subtracting ½ the length or width of the tag depending on tag orientation; the tags were measured using dial calipers to the nearest 0.1 mm. From the data pooled for all tag replicates and tag orientations per reader, the minimum and maximum adjusted measurements were determined, and a mean read depth was computed.

Read Distance. The greatest read distance almost always occurred when the tag was oriented with its axis perpendicular to the plane of the reader's antenna, with the tag's antenna oriented upward toward the reader (Fig. 1). While there was little difference between the antenna-up or antenna-down orientation (usually <1 cm), there was a larger difference (usually ~1-6 cm) when the antenna-up orientation was compared to the flat orientation.

The Destron 125 kHz tags were read at a slightly greater distance than the AVID 125 kHz tags, encrypted or not (Figs. 4). Trovan's LID-500 was the only reader tested that could not detect any of the 125 kHz tags.

The Destron Handi Reader could not detect the AVID encrypted tags, whereas the other Destron readers tested could detect them, but could not decrypt them (Fig. 4). The Mini Portable Reader displayed "AVID," whereas the Pocket Reader and the Pocket Reader EX both displayed an ID of 16 **alphanumeric digits** (the true ID was nine **decimal digits**). The reader-decoded information was unstable (*e.g.*, the ID displayed would change) at the maximum read distance; however, when the read distance was minimized, the decoded information stabilized.

The 128 kHz tags were read by AVID's Power Tracker IV and VI, and by Destron's Pocket Reader and Pocket Reader EX, along with both Trovan readers tested (Fig. 4). Trovan's multi-mode reader, GR-251, had the greatest read distance with the 128 kHz tags than any other tag-reader combination (Fig. 4). The 400 kHz tags were read by all except the Trovan LID-500, but the read distance was the least of any tag tested (Fig. 4).

Only multi-mode readers (AVID Power Tracker V and VI, Trovan GR-251, and Destron's two Pocket Readers) could detect the ISO 134.2 kHz tags (Figs. 4). The read distances associated with AVID's ISO tag and Destron's ISO tag were comparable. In general, the multi-mode readers had a smaller read distance than comparable single-frequency readers of the same manufacturer for a given tag's excite frequency.

The AVID MiniTracker and Destron's Pocket Reader and Pocket Reader EX were the least variable in read distances for the 125 kHz tags. (Figs. 4). The two Destron readers also were the least variable in read distances for the 128 kHz and 134.2 kHz tags (Figs. 4).

Survey of Leatherback Researchers. The survey of leatherback researchers of the Atlantic Ocean Basin revealed PIT tags of three different signal modulation protocols (AVID and Destron's FDX-A response frequencies, Trovan's FDX-A response frequency, and ISO/FDX-B response frequency), in addition to an encrypted 125 kHz tag (Table 1). No one indicated they had used the 400 kHz tag for leatherbacks. Only North American researchers were using readers capable of detecting all three protocols, but only one of those projects was using a reader that could detect encrypted tags. Researchers in the Guianas and Gabon were using Trovan's 128 kHz tags, and were using readers capable only of reading the same. Throughout most of the Caribbean and in Trinidad, researchers mainly were implanting AVID's 125 kHz unencrypted tags, but historically they had implanted thousands of encrypted tags. Mostly they were using readers capable of reading the 125 kHz tags, encrypted and unencrypted, but not capable of reading tags from the Guianas, nor the ISO tags, which were rare at the time of the survey in 2004.

Many factors affect read distance: transponder design, transponder antenna orientation relative to the reader antenna, tag signal modulation protocol, tag size (in general larger tags have greater read distances), reader design (in general the larger the antenna and the more powerful the reader, the farther the read distance), and electromagnetic noise and metals in the near-field environment. Battery strength also was observed to cause variability in read depth measurements, and freshly charged batteries should be used to maximize reader performance. Because tag orientation affects read depth, one needs to know the orientation of the tags in preloaded needles and to pay attention to orientation when loading needles. There appears to be slight differences in the read depth performance of individual units of the same manufacturer and model, and for different tag replicates. However, these differences did not follow a predictable pattern, and they were relatively evenly distributed among the models and tag orientations. Software versions on the readers also affect the capabilities of the reader; the more protocols that a reader uses, generally the more time is needed to cycle through the protocols and read the tag. Researchers also should be aware that not all multi-mode readers detect and read all the frequencies we tested and that manufacturers may improve hardware or change software over time without changing their catalog order number.

The various PIT tags in use have different ID display formats, and understanding these details may help ensure that the display on the reader is correctly recorded for accurate identification. The ID of the AVID 125 kHz encrypted tag is nine decimal digits (d), often read as ddd*ddd*ddd. The IDs of other 125 kHz tags are 10 **hexadecimal digits**; AVID's unencrypted tags are nine decimal digits + "A" (in AVID's "Euro" type microchip, the first digit is "1"). Trovan's 128 kHz tag IDs also are 10 digits in length, beginning with the decimal digits "00" followed by 8 hexadecimal digits, and often these are segregated with hyphens. The ISO 134.2 kHz tags have a more complex ID, with 15 decimal digits that include a combination of a three digit country or manufacturer code followed by a 12 digit unique ID, which is unique only when in combination with the first three digits of the code. Some readers display the three digit country or manufacturer code separated from the 12 digit ID code (*e.g.*, ddd.dddddddddddd), but all 15 decimal digits must be recorded as the complete ID. A further complication is that some readers have the capability of changing from a decimal digit display to a hexadecimal digit display (for example, the decimal display 982000149972677 may also be displayed in hexadecimal: 3D60008F066C5, a length of 13 digits). The standard for each tag type is recognized by the readers and displayed appropriately. Thus, some tag IDs may be displayed in hexadecimal, while another tag type's ID may be displayed in decimal. Some readers allow the user to modify how a tag ID is displayed, which adds some confusion if something other than the default is recorded.

A display or datasheet showing 16 alphanumeric digits indicates a problem (an encrypted AVID tag that was not decrypted; see above) as does 12 decimal digits (the first 3 digits of the ISO code are missing). Many of the ISO 134.2 kHz tags now come with labels showing both the 15 decimal digit and 13 hexadecimal digit tag codes, and researchers should record both; at a minimum they should record the default code displayed on their reader. If an encrypted tag is detected, it is possible to get the alphanumeric digits decrypted. Marine turtle researchers who need this service can work through the Cooperative Marine Turtle Tagging Program, which is managed by the Archie Carr Center for Sea Turtle Research at the University of Florida (accstr.ufl.edu/resources/tagging-program-cmttp/).

It is likely that the ISO 134.2 kHz tag will be used more frequently in the future. While this tag has become the international standard for marking animals, it is not without problems. Reading performance varies markedly among tags of different manufacturers and is not controlled by the standards (International Committee for Animal Recording 2012). Thus, the scientific community needs to create a screened list of approved manufacturers from which tags should be purchased for their research needs. Importantly, the ISO standards require the responsible countries and/or manufacturers to ensure that the 12-digit portion of the ID is unique for 30 years. That time

Figure 5. Location of fat pads in a juvenile leatherback sea turtle, *Dermochelys coriacea*: dorsal (left) and ventral (right). Photos provided by Jeanette Wyneken, Florida Atlantic University.

Manufacturer	Model	Frequency	Reads	Memory	Comments
AVID Identification Systems, Inc. (AVID) http://www.ezidavid.com	MiniTracker-AVID Only	125 kHz	unencrypted (AVID & Destron) & AVID encrypted (FDX-A)	No	9V battery
	MiniTracker-multi-mode	125 kHz 400 kHz			9V battery; One distributor refers to this unit as "MiniTracker Universal"
	MiniTracker II	134.2 kHz	FDX-B, but not HDX	No	9V battery
	Power Tracker II	125 kHz 400 kHz	unencrypted (AVID and Destron) & AVID encrypted (FDX-A)	No*	NiCad rechargeable battery (old units); NiMH battery (new units) *Data can be captured on separate platform using RS-232 interface cable provided with all Power Tracker units and Windows Wedge software, which is compatible with Windows 95/Windows NT through Windows 7 **Two models of the Power Tracker VI and one model of the Power Tracker IV that we tested failed to detect any of the Trovan tags (128 kHz) at any distance; manufacturer since has corrected this problem. However, there may be PT-IV models in the field that might not detect all Trovan tags
	Power Tracker III			Yes	
	Power Tracker IV	125 kHz 128 kHz** 400 kHz	unencrypted (AVID, Destron, & Trovan) & AVID encrypted (FDX-A)	No*	
	Power Tracker V	125 kHz 134.2 kHz 400 kHz	unencrypted (AVID & Destron) & AVID encrypted (FDX-A and FDX-B), but not HDX	No	
	Power Tracker VI	125 kHz 128 kHz** 134.2 kHz 400 kHz	unencrypted (AVID, Destron, & Trovan) & AVID encrypted (FDX-A and FDX-B), but not HDX	No*	
	Power Tracker VII	134.2 kHz	ISO complaint (FDX-B & HDX)		
	Power Tracker VIII	125 kHz 134.2 kHz 400 kHz	Unencrypted (AVID & Destron) and AVID unencrypted (FDX-A and FDX-B), but not HDX	Yes	
	MiniTracker Pole Reader	125 KHz 400 KHz	unencrypted (AVID & Destron) & AVID encrypted (FDX-A)	No	
Trovan www.Vantro.biz; www.Trovan.com	**LID-500 Hand-Held Reader**	128 kHz	Trovan (FDX-A)	Yes, although capacity varies among readers	rechargeable battery (separate 110v and 220v chargers)
	LID-570 Pocket Reader				IRDA-compliant interface (infrared link for data downloading); 9V battery; small, "palm"-size
	U-200 Mini Reader				rechargeable battery (separate 110v and 220v chargers); flashlight-shaped
	LID-571 Std. reader				9V battery
	LID-571 - ISO multi chip reader	125 kHz 128 kHz 134.2 kHz	Trovan products as well as Destron and AVID (not encrypted) FDX-A and FDX-B), but not HDX	Yes	
	GR-250	128 kHz	Trovan (FDX-A)	Yes	Rechargeable battery. Unit is "ruggedized"(water resistant)
	GR-251	125 kHz 128 kHz 134.2 kHz	Trovan products as well as AVID (encrypted and unencrypted), and Destron (FDX-A and FDX-B), but not HDX	Yes	Rechargeable battery. Unit is "ruggedized"(water resistant); decrypts encrypted tags

Manufacturer	Model	Frequency	Reads	Memory	Comments
Destron Fearing Corporation BIOMARK is the exclusive USA & Canada distributor of Destron Fearing Corporation's products for fisheries & wildlife applications www. biomark.com	**HandiReader**	125 kHz 400 kHz	unencrypted AVID & Destron (FDX-A)	No	unit no longer available for sale by BIOMARK
	Mini Portable Reader	126 kHz 400 kHz	unencrypted AVID & Destron (FDX-A)	Yes	special order only (supply dependent), supported but limited by supply
	Pocket Reader **Pocket Reader EX**	125 kHz 128 kHz** 134.2 kHz 400 kHz	unencrypted and encrypted AVID, Destron, & Trovan** (FDX-A and FDX-B), but not HDX; Readers purchased prior to 2010 can detect presence of AVID encrypted tags, but code displayed is not tag ID, and must be translated after-the-fact	Yes*	**Since the advent of internal memory in 2005, these models no longer detect Trovan tags (128kHz); software versions prior to 2005 [0218-S63 and A418-S63 (Pocket Reader) and A418-L63 (Pocket Reader EX)] detect Trovan tags; previous versions may not read 128 kHz or 400 kHz tags; contact Biomark for software capabilities and possible upgrades; Uses AAA (Pocket Reader) or AA batteries (EX); *Data can be captured on separate platform using RS-232 cable (standard) and HyperTerminal (w/ Windows); displays decimal format only; new software can be uploaded onto old units; read distances greater for EX model
	FS2001F-ISO	125 kHz 134.2 kHz 400 kHz	Unencrypted AVID, Destron, & Trovan; ISO compliant (reads FDX-A and FDX-B and HDX).	Yes	Stationary or portable unit (6 lbs); requires external antenna; supply dependent; support provided for the foreseeable future; can display ID codes in decimal and hexadecimal; Firmware upgrade available to detect and decrypt encrypted AVID tags; contact Biomark to determine if the firmware upgrade applies
	601 Reader	125 kHz* 134.2 kHz	Reads FDX-A, FDX-B and HDX tags	Yes	*Previous versions may not read 125 kHz; units sold after Sept 2011 can be sent back to the vendor to be upgraded to read 125 kHz tags; Upon detection of an AVID encrypted tag the reader displays "AVID DETECTED"; Uses a NiMH rechargeable battery or AA batteries; Previously produced by Allflex USA, Inc.
	HPR Plus	134.2kHz	Reads FDX-B and HDX tags	Yes	Stationary or portable unit; requires external antenna; data retrieval via USB port

Table 3. Table begins on page 11. Portable PIT tag readers used by or available to most marine turtle researchers as of December 2012. Readers tested are in bold font. The North American contact for each manufacturer also is indicated. Note that Biomark Inc. of Boise Idaho and Destron Fearing of St. Paul Minnesota entered into a merger in 2011 that specifically designates Biomark as the fish and wildlife representative for all (domestic and international) Biomark and Destron Fearing products.

frame is far less than the life span of marine turtles, which means that a manufacturer might duplicate a code used 30 years earlier, and thus there could be more than one turtle at large with the same ID, albeit with a small probability.

Marine turtles are long-lived animals, and the tens of thousands of tags with different protocols implanted thus far hopefully will remain in the population for many years into the future. The equipment incompatibility problem among leatherback researchers was especially acute in the greater Caribbean area, where most of the Atlantic nesting occurs. This unfortunate situation means that our knowledge about leatherback movements and fidelity to beaches in the Atlantic may be compromised by the incompatibility of tags and equipment being used

Leatherbacks are heavier when on the foraging grounds, where they accumulate blubber and peripheral adipose tissue (Davenport *et al.* 2011). The average depth of the blubber of leatherbacks on the foraging grounds is 3 cm (Davenport *et al.* 1990a in Davenport *et al.* 2011). However, fat deposition is greatest around the head, neck, shoulder and inguinal areas (Davenport *et al*. 2011). There are dense fat pads on the dorsal and lateral surfaces of the neck (Davenport *et al*. 2009), and there also is a large loose fat pad in the ventrolateral neck that extends along and dorsal to the shoulder (Wyneken, pers. comm. 2012; Fig. 5). These dorsal shoulder and neck regions are traditional PIT tagging sites for leatherbacks. There are no studies on the thickness of adipose tissue specifically over the PIT tagging sites, but there is agreement that fat accumulates subcutaneously and within the blubber during foraging, more so in the neck, pectoral and pelvic areas than in the shoulder and the flippers (Davenport *et al.* 2011; J. Wyneken pers. comm. 2012). Two researchers estimated the blubber thickness in the shoulder area based on their recollections and photos of dissections of single animals: (1) 2-3 cm thick for a 158 cm CCL male captured in a bottom longline in April 2007 off Miami, Florida (J. Wyneken, pers. comm. 2012; see Wyneken *et al.* 2007), and (2) 3-5 cm for a 159 cm CCL male entangled in a net in 1988 off Wales (J. Davenport pers. comm. 2012; see Davenport *et al*. 1990a,b); this turtle admittedly was not very robust for a northern foraging animal, with the observation of little fat on the dorsal and lateral surfaces of the neck (Davenport *et al.* 1990a). Thus, we suggest that it is necessary to anticipate some increase in blubber thickness in leatherbacks. Tag readers used for foraging leatherbacks need a read distance significantly greater than 4 cm, to accommodate the greatest needle length in use (4 cm) plus the fact that often the applicator is pressed into the skin when tagging, and to allow for some increase in blubber thickness. The read distance of tags injected into the flippers of juvenile cheloniids also will change as the turtle grows, but not to the extent that it changes in leatherbacks.

Some of the multi-mode readers tested (*e.g.*, Destron Pocket Reader, Pocket Reader EX, AVID Power Tracker VI, Trovan GR-251) read all signal modulation protocols tested at a minimum of ~5 cm, but the readers with the lowest read depths may not be adequate for detecting and reading tags in foraging leatherbacks. In general, the multi-mode readers had a smaller read distance than comparable single-mode readers of the same manufacturer for a given signal modulation protocol. Portable readers with the greatest read distances in the environment we tested are heavier and larger than other models (Fig. 2), an important tradeoff to consider in field projects.

It is important that PIT tags are implanted in muscle to encapsulate and to minimize migration in the body where they might not be detected (Wyneken *et al.* 2010). Tags are enclosed with bio-compatible glass, which, along with the injection process into muscle fiber, is expected to generate a fibrous encapsulation. Some tags have a partially coated surface (*e.g.*, a porous polypropylene polymer sheath) to promote connective tissue encapsulation and prevent migration (Rao & Edmundson 1990). However, the smooth glass surface and tubular shape could facilitate migration if the tag is placed in a location in which encapsulation is slow or absent. The tags are more likely to migrate when placed in fat or blubber, which surrounds the neck of leatherbacks. Tags also must be placed within the read distance of the transceivers being used and in an easily accessible location. The triceps muscle complex is ideal for all marine turtle species as it is easily accessible and offers some protection for the glass tag (Wyneken *et al.* 2010). The triceps is not active throughout swimming movements and, thus, is less prone to irritation by the tag (Wyneken pers. comm. 2004). All three heads of the muscle are accessible in cheloniids; both the dorsal and ventral aspects of the muscle are accessible in *Dermochelys*, but not the anterior aspect because of stiff and tough connective tissue along the flipper's leading edge. Furthermore, the accumulation of blubber over the dorsal aspect of the muscle in leatherbacks is minimal (<2 cm; Wyneken pers. comm. 2012). Thus, implanting a tag in the triceps muscle of any marine turtle would place the tag in a relatively shallow position and in muscle in which it can encapsulate. There is some risk in placing the tag more distally in leatherbacks due to the increase chance of loss due to predation or scavenging of debilitated or dead turtles, but that risk is offset by the greater probability of detecting the tag in the shallower location; the triceps is proximal to alternative flipper locations used for cheloniid turtles. Chapter 6 of the NMFS SEFSC Sea Turtle Research Techniques Manual (2008) details this tagging location for cheloniid and dermochelyiid turtles. Also, sterile-wrapped tags with disposable needles should be considered to reduce the possibility of disease transmission. There are additional considerations when planning a tagging project that are not discussed here; for more information see Balazs (1999).

To reduce the chance that tagged turtles could go undetected, leatherback researchers need to communicate about equipment compatibility and consider standardizing equipment, use multi-mode readers, and tag using a shallow location, such as the triceps muscle, for implanting PIT tags. We do not believe that the read distance for any of the readers tested were insufficient for reading tags in cheloniid turtles because tags placed in those species are inserted into the shoulder, triceps muscles, and flippers, and are inserted at a shallower needle angle than in leatherbacks. There are equipment incompatibility issues for the cheloniid species, also, indicating the need for all marine turtle researchers to use multi-mode readers capable of reading all frequencies.

When using a multi-mode reader, the researcher should move the reader slowly to allow the reader to cycle through each signal modulation protocol and properly detect any tag in its field. Researchers within a region should be aware of tagging locations used regionally, and search each of those areas on an animal. Multiple tags in close proximity can "**collide.**" Thus, because turtles may infrequently carry multiple tags, the tagging sites should be scanned multiple times and from different angles, and scanning should continue when the reader detects a tag, when practicable. This is especially important when using readers with short read distances or readers that are slow to cycle through the different protocols.

DEFINITIONS

alphanumeric digits: numbers 0-9 and characters A-Z

collide: to interfere with or block signals or detection; there are many variables in the possible interactions in the magnetic coupling fields with two or more tags, and these can have a great impact on the readers. Each reader is designed differently and it is difficult to predict the results of a given tag combination's collision.

data modulation protocol: the perturbation of the excite field and the response frequency/frequencies. The frequency of the response is unique among the manufacturers for FDX-A tags (e.g., Trovan's FDX-A transponder return frequency is 1/2 the excite field frequency, whereas Destron and AVID FDX-A transponders have two return frequencies: one at the excite field frequency minus 1/10 that frequency, and excite field frequency minus 1/8 that frequency), but is the same for the FDX-B 134.2 kHz tags (e.g., excite frequency minus 4.194 kHz).

decimal digits: numbers 0-9

decrypt: to provide the correct ID for a secure, encrypted tag

detect: to indicate the presence of a PIT, regardless of the reader's ability to display the ID

excite field: the field of low frequency energy within which a tag can be activated; typically transceivers transmit a range of frequencies, not just a single frequency, and thus can excite a tag other than what it is optimally designed to detect and read. The excite frequency sometimes is called the carrier frequency.

full duplex (FDX): the transceiver can send a signal to the tag and simultaneously receive information from the tag; often a suffix of "-A" or "-B" is added. "A" denotes a data modulation protocol with the response frequency well-removed from the excite/carrier frequency. "B" denotes a protocol with a response frequency close to the excite frequency (AEG *et al*. 1992)

half-duplex (HDX): the transceiver must pause to receive a signal from the tag

hexadecimal digits: numbers 0-9 and characters A-F

ISO: International Organization for Standardization developed standards for RFID technology used for animal identification (11784 for the transponder and 11785 for the transceivers)

multi-mode reader: transceiver able to detect more than one data modulation protocol

near-field: the distance within a small number of wavelengths from the antenna; the energy field in which low frequency RFID devices operate

read: the ability to detect a tag and display an ID, regardless of whether the ID has been correctly decrypted

single-mode reader: transceiver able to detect only one data modulation protocol

response frequency: the frequency on which the tag responds to the transceiver; it is determined by the tag's data modulation protocol.

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