A Review of Acoustic Telemetry Technology and a Perspective on its Diversification Relative to Coastal Tracking Arrays

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Abstract Automated telemetry systems for tracking ultrasonically tagged marine fauna have diversified in information coding, signal reception, data handling and storage, and deployment architecture in response to niche development among equipment manufacturers. Technologies divide especially along issues of habitat type, spatial scale, and cost. Highly capable designs appropriate to spatial scales from sub-meter resolution to coast-wide migration have emerged. Due to technical constraints (e.g. coding algorithms, frequency) and proprietary interests, tags of one code scheme cannot currently communicate with listening devices from others, sometimes even among devices within a manufacturer's offering. Large-scale federally funded arrays are being designed as observatories to facilitate discovery and experiments and are committed to single-platform technology. Commitment to a single equipment design unifies such arrays but also contributes to inertia that hinders optimization or further development at the local level. Some solutions for cross-equipment communication exist at both the transmitter and receiver ends of the technology. Un-anticipated movement of tagged marine fauna through these arrays can yield important new insights but can also have negative effects on other users of the array. These possibilities should be considered and coordinated through collaborative administrations and as early as the proposal review process. This paper outlines the needs and constraints to engage scientists with each other and with manufacturers in dialog to mitigate negative effects of diversification without the loss of its benefits. An inability to unify disparate and independent hydrophone arrays risks tremendous lost opportunity to track fish in coastal marine and estuarine settings, as seen in case studies.

Keywords Acoustic telemetry · Technology · Coding · Tracking · Fish · Migration

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Introduction

Telemetry of marine fauna tagged with individually-coded acoustic transmitters has seen great strides in application and in capability, especially for fishes. Fishes studied with acoustic telemetry range from small and slow leafy seadragons (*Phycodurus eques*) (Connolly et al. 2002) to large and fast bluefin tuna (*Thunnus thynnus*) (Brill et al. 2002). Telemetry study sites also range in size from tens of meters (Connolly et al. 2002, Niezgoda et al. 2002) to estuarine wide (Eklund and Schull 2001, Heupel and Hueter 2001, Able and Grothues 2007a) or shelf wide (Welch et al. 2003, Lindley et al. 2008). Small-scale movement studies typically cluster hydrophones to overlap detection ranges over a study grid (e.g. O'Dor et al. 1998, Niezgoda et al. 2002, Simpfendorfer et al. 2002) while large-scale studies often utilize acoustic "gates" in constrictions between such areas or "curtains" of numerous hydrophones stretched across wide areas to capture the passage of acoustically tagged animals (Welch et al. 2003, Grothues et al. 2005, Lindley et al. 2008). Larger and potentially more expensive hydrophone arrays are in consideration for congressional support on all US and Canadian coasts (ORION 2005, Ocean Shelf Tracking and Physics Array, OSTAPA, Canadian Foundation for Innovation International Joint Venture Fund) and worldwide (Ocean Tracking Network, www.oceantrackingnetwork.org,).

Unlike most previous telemetry efforts that are driven by single-proposal users asking specific questions, these larger coastal arrays are planned as common infrastructure enabling many researchers to expand their tracking efforts beyond what could be justifiably budgeted on single-species/ single-habitat/ single-user questions. At the forefront of these efforts, the Ocean Tracking Network (OTN) boasts a $168-million budget that includes telemetry hydrophones and other ocean sensors and is promoted as having a life span of 20 years (www.OceanTrackingNetwork.org). Such projects will allow exploration as well as experimentation under broad thematic guidance such as "migratory resources" (O'Dor and Gallardo 2005) or response to climate change (Able and Grothues 2007b). In that sense, they are similar to construction projects for research vessels.

As plans for national and international scale coastal arrays proceed, several acoustic engineering designs have emerged based on different individual tag coding and listening schemes and their supporting data handling architecture (e.g. O'Dor et al. 1998, Voegeli et al. 1998, Niezgoda et al. 2002, Grothues et al. 2005). Diversity in designs arises in part from competition among equipment manufacturers to capture particular sectors of the market related especially to habitat type and study scale. The ability to focus on problems within the boundaries of these temporal and spatial scales has yielded highly capable but differing designs, or niche diversification. As with species in ecological niches, this does not mean that different equipment designs do not function well in environments or scales other than those for which they are optimum; in fact, most or all continue to compete in a broader market. Unfortunately, transmitter signal codes that identify individuals in these different designs cannot currently be recorded by equipment from different manufacturers, or sometimes among equipment types from the same manufacturer. For this reason, marine scientists often make equipment choices based on factors other than optimization. These factors might include familiarity through professional contacts and advertising, budget constraints, and the presence of compatible equipment deployed by others nearby. The consideration of compatibility is critical for three reasons:

1) Equipment choice may influence the level of study success from the contribution of "outsiders" in an open system. This can occur because of the possibility that tagged animals will be detected in other locations at no cost to the project. This has been demonstrated already by contacts of tagged striped bass (*Morone saxatilis*) and hickory shad (*Alosa mediocris*), moving between compatible systems deployed in Maine (J. Carter, University of New England), New Jersey (K.W. Able and T. M. Grothues, Rutgers University), and Virginia (J. Olney, College of William and Mary), and also for striped bass and weakfish (*Cynoscion regalis*) moving between a different set of compatible systems in the Delaware Bay (D. Fox, Delaware State University), Massachusetts (M. Mather, University of Massachusetts Amherst), Corsons Inlet, New Jersey, (I. Eberly, Wetlands Institute) and the Navesink River estuary, New Jersey (J. Manderson, National Marine Fisheries Service, Sandy Hook).
2) Hesitancy to abandon investments made in deployment of one equipment type, or in a tagging effort using long-lived tags, promotes incremental small investments that ultimately produce inertia in equipment choice. This can occur even when transition to another approach would better fulfill the needs of researchers.
3) Both inertia and changes in scale-dependent optimization could be mitigated by cross-equipment communication. However, this presents both technical and proprietary challenges.

To date, hydrophone performance for equipment of several manufacturers has been examined individually in different settings, and the optimum sampling designs laid out in light of those results (Lembo et al. 2002, Heupel and Hueter 2001, Niezgoda et al. 2002, Simpfendorfer et al. 2002, Welch et al. 2003, Grothues et al. 2005, Heupel et al. 2006). However, differences in the performance of different designs relative to their intended or actual application have not been compared. Understanding the effects of several choices on the detection success of acoustic transmissions from tagged fauna is important to equipment choice and study design. Even the most thorough and recent review of telemetry array design in the literature (Heupel et al. 2006) focuses on a single coding scheme and so does not address several of the potential variables facing program planners.

A review of the factors differentiating performance among different equipment and the coding schemes underlying them elucidates the challenges and risks to achieving compatibility across equipment and also reduces the risk of ineffectual observatory configurations. To those ends, I review below some technical aspects relevant to equipment selection or fabrication with an emphasis on coding schemes and monitoring approaches. Even more importantly, this review should help inform users and thus drive the further development of these designs.

Technical Review

Coding Schemes

A coding scheme is the way in which an acoustic transmitter, henceforth "tag", conveys information to a receiver. The challenge is to convey a quiet (generally < 170 dB) signal with minimal attenuation and distortion by noise or coinciding signals from other tags, i.e. "code collision". Access to a receiver channel may be shared among multiple tags in time, frequency, or space. At least four coding schemes employ one each of these access-sharing strategies and are currently commercially available. These are (1) pulse-per-minute (PPM), (2) pulse interval coding (PIC), (3) phase modulation (PM) and (4) code-division-multiple-access (CDMA).

A transmitter using PPM code passes identity information as the rate of repeat for a single pulse ("ping") at a fixed interval. It makes little attempt to divide channel access and is useful only when pingers are few and far between. This type of code is easy to produce and the steady ping is easy to follow using a mobile hydrophone. The code space (the number of individual codes possible) can be large but in practice is limited to the precision of listening gear (including the decoding algorithm) in deciphering them, especially in the presence of noise or echoes that might smear the difference between two different individuals. Its simplicity is antithetical to discriminating characteristics in the presence of multiple tags even by computers. For that reason, a pinger may not be recorded by the PIC-logging hydrophone of the same manufacturer and may even be shifted in frequency to prevent pollution of the band used by PIC transmitters.

PIC code is similar to PPM in that it uses discrete pulses, but expresses information as differences in the interval between several sound pulses that, as a set (or burst), constitute a signal. The burst needs to be un-interrupted, but must allow quiet time afterwards to allow for reception of other tag signals. PIC thus divides access to a channel by parsing time. A code set that contains more pulses (and the intervals between them) in one transmission event can encode more tags, but takes longer to transmit and will use more transmitter battery. In addition to identifying a tag, PIC can reliably pass data from sensors (such as thermistors or pressure sensors) in low noise conditions. An intolerance to code collision is mitigated in several ways. Individual intervals comprising one code transmission burst can be shortened, thus allowing more between-transmission time to detect other tags. The timing of code bursts for each tag can be made to vary around an average burst interval, so that tags overlapping in their transmission time at one point are not likely to overlap at the next burst. Finally, the code burst intervals of the whole tag set can be spread apart to open channel access. However, this spreading means that more quiet time must be given for a larger number of individually coded transmitters (i.e. code set). A tag from a large code set will transmit fewer times while it passes through the listening range of a hydrophone (Fig. 1), affecting the efficiency of detection for migrating fish and also making large code sets that use PIC impractical for use in mobile tracking (Grothues and Able 2007). Two different types of tags might be necessary for one fish when both types of data are sought and they would best use

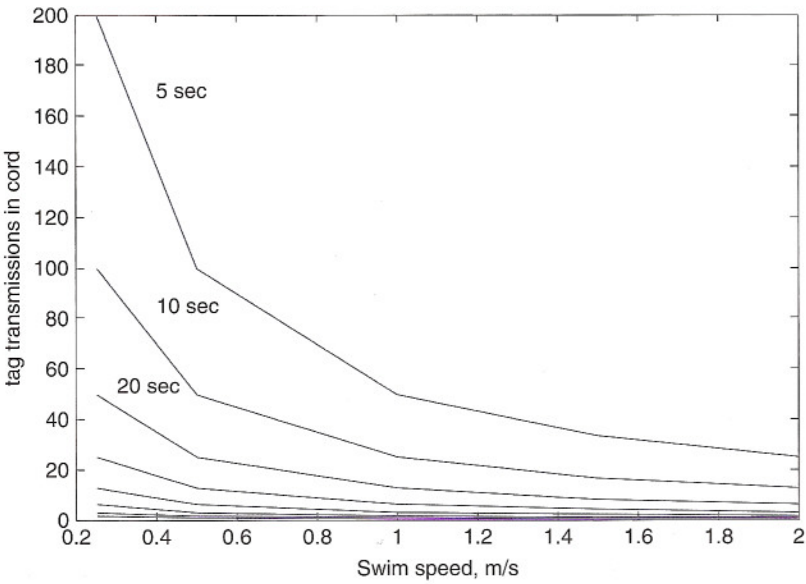

Fig. 1 The number of tag transmissions that will occur within the time required to swim a 250 m cord through a detection cell as functions of animal swim speed and transmission repetition rate (modeled separately for 5, 10, 20, 40, 80, 160, 320, and 640 s between code bursts) at 100% detection efficiency. Duration of the actual signal transmission time is held as negligible

different frequencies so that the quick "mobile tracking" code does not pollute the frequency of the transmissions used for automated tracking. It would seem that, at the local level, an investigator can easily mitigate this divergence by selecting a quicker rate for automated telemetry and the CAFT series code set (Lotek Wireless, Inc., St. Johns, Newfoundland) can handle this due to a very short burst, with between-burst-intervals down to 2 s. However, this is a small set with 212 possible codes. For large PIC code sets such as the Vemco (a division of Amirix Corp., Shad Bay, Nova Scotia) 64 K code set, decreasing the quiet period actually decreases the chance of any one code being heard when several are present because code collisions take up more of the listening time. Further, decreasing the burst interval can inadvertently impact studies in adjacent compatible arrays. For example, striped bass implanted with transmitters of a high burst rate for tracking in Massachusetts estuaries migrated into Delaware Bay and occluded transmissions from tagged sturgeon (*Acipenser oxyrinchus oxyrinchus*) which were implanted with appropriately spaced (for that array) transmissions (D. Fox, Delaware State University personal communication). Further, in low transmission rate situations, the tag/receiver relationship should have high fidelity, which at least one manufacturer handles with an error check built into the code structure and decoding algorithm.

The simplicity of PIC code makes automated interpretation of signals in low noise relatively easy, which is reflected in low cost, low power-draw receivers. In fact, the low cost makes the deployment of numerous hydrophones configured at low gain a viable strategy for dealing with code collision; smaller listening ranges distributed over more hydrophones may parse the duty of listening to multiple tags when they are not too tightly clustered. Examples of PIC code are those used by Lotek Wireless, Inc. (St. Johns, Canada) in the CAFT and CART series tags interpreted by SRX series receivers (212 possible codes), R-code produced by Vemco with a current (to be expanded) code space of 64,000 and data transmission options (temperature, pressure), and the CT Transmitter series from Sonotronics (Tucson, Arizona) with thousands of codes but distributed over several discrete frequencies.

Ambient sounds such as moving sediment or bubbles can form spurious signals especially for PPM and PIC schemes (Grothues et al. 2005). Confidence that any signal is real is gained by applying a temporal filter to the collected data that requires a minimum number of signal repeats in a specified time before a fish is judged as "present". This can compound the problem of wide transmission spacing needed for these codes in high traffic environments because more received signals will be required for confidence. This also will interact with burst rate, duty cycle, swim speed, and listening range diameter (Fig. 2).

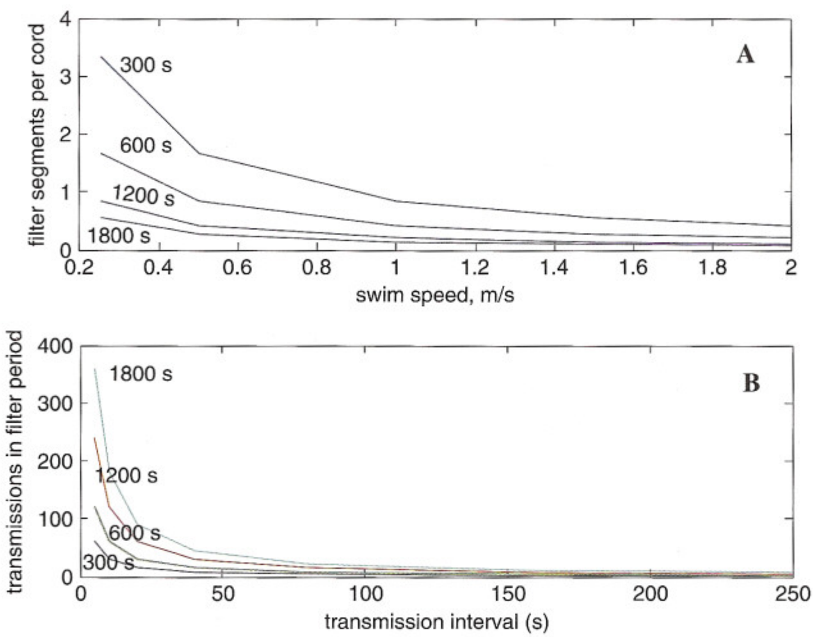

Fig. 2 (**A**) The number of complete temporal filter segments (of 5, 10, 20, or 30 min criteria) spent along a 250 m cord of a detection cell as dependent on the animal's swim speed. (**B**) Expected reception (at 100% efficiency) of transmissions that will occur within a filter period of 5, 10, 20, or 30 min criteria as dependent on the tag's transmission interval. The number of signals available for capture within a single filter criteria quickly converges when the time between transmissions is greater than 25 s, but remains at or above 15 for intervals as long as 20 s. At tag transmission intervals above 160 s, less than 3 transmissions happen within the 300 s filter period

In a third coding scheme, PM signals express identity through changes to the phase of a single frequency carrier wave, technically changing the carrier frequency as a time derivative of the signal. Thus, PM divides access to a channel by parsing frequency. This improves on PIC in that the form of a sound wave, not just the number and timing of the pulses, can carry information to allow higher interpretability in the face of multiple codes (Ehrenberg and Torkelson 2000). However, the decoding computation has a significant power cost. Also, signal waves arriving at 180° out of phase may be confused. Using phase modulation with small amplitude waves requires inefficient spreading or even doubling of the frequency bandwidth, thus restricting the useful amplitude range. However, at higher amplitudes it is much more robust to noise and code collision interference than PIC. The potential to encode in a shorter signal (no within-burst quiet intervals) also makes PM code useful for fine scale triangulation studies. Hydroacoustic Technology, Inc., (Seattle, Washington) markets systems using a PM coding scheme with up to 50,000 codes.

In the fourth type of coding scheme, CDMA, information is also spread across sound pulses in a wider frequency band, but unlike PM, CDMA divides channel access in space. Signals sharing the channel use orthogonal carrier waves (as two people speaking one language converse despite simultaneous conversation in a second language by others in earshot). The receiver must know the carrier wave form to expect ahead of time so that it can extract the information. This makes extraction of a signal from a shared carrier wave very computationally expensive. The trade off is that the coding scheme is very tolerant to noise, echo, and multiple transmitting individuals. Therefore, numerous tags can be discerned even at high burst rates and the same animals may be studied using both mobile and passive tracking and among different researchers using the same equipment even if deployed in different sample schemes with different burst rates (Niezgoda et al. 2002, Cooke et al. 2005). Like PM, it also offers the ability to transfer data from sensors very quickly relative to PIC code. The burst rate is not limited by code space in practical terms. Because the burst interval need not vary over time to change a listening aperture for collision avoidance, the tags can be made to provide very stable timing. That makes it possible to triangulate multiple tags simultaneously or calculate their positions even from a single moving hydrophone (i.e. a virtual array, also called synthetic aperture) based on the difference between expected and actual arrival times for a signal. Thus, it is possible to derive a fish's position from a towed hydrophone or one mounted on an autonomous underwater vehicle (AUV). The robustness of CDMA is reflected in its choice for transmission of data in cellular phone traffic, which happens with simultaneous occurrences in the many thousands at the national level with little collision.

The power requirement of CDMA decoding results in shorter deployment times than PIC for un-cabled autonomous loggers, or higher battery use and cost, with larger logger case size and heavier deployment tackle, or more vessel support time for battery swap. A solution is to duty cycle the loggers with a wake-sleep cycle working on the space of seconds to hours or days. However, some duty cycles with relatively high sleep time may mimic the tag-curtain intercept problems that low burst rate causes for PPM tags on moving fish, if not within a study then at least between fish with different behaviors. A CDMA product is marketed by Lotek Wireless, Inc. as the scheme for their MAP unit with at least 80,000 available codes with data transmission options (temperature, pressure, movement).

Listening Schemes

All acoustic telemetry listening schemes start with a hydrophone suitable to the tag's signal frequency. Restricting the hydrophone's frequency is a first filter from noise or competing tag signals, so different manufacturers use different frequencies. Further, the frequency aperture (width) needs to vary as a function of the coding scheme. This is the first challenge to compatibility among equipment as widening the frequency aperture allows more noise for some schemes. Once received, a potential signal may be treated in several ways. Sound could be stored un-interpreted (raw), but in reality this is untenable because the sampling frequency needed to query ultrasound is so high as to require terabytes of storage for even short deployments. No manufacturers currently utilize this scheme. Sound may be interpreted as signals but not stored *in situ* (typical of simple mobile hydrophones), or interpreted and then stored as a code within an electronic package *in situ* (this is a data logger or logging hydrophone) or it may be sent ashore for interpretation and storage (these are wireless or cabled systems). Recovery of data stored in autonomous loggers must be collected by visiting the hydrophones either for physical retrieval or communication using an acoustic modem (e.g. Vemco VR3-UWM). However, some shore storage schemes require a receiver in addition to hydrophones (Grothues et al. 2005). Several manufacturers currently store data shoreside using cable (e.g. HTI and Lotek Wireless, Inc. MAP), radio wireless (e.g. Lotek Wireless, Inc. WHS and Vemco VRAP system) and cellular wireless (e.g. Lotek Wireless, Inc. MAP and Sonotronics CUB-1 systems). Daisy-chaining via acoustic spread spectrum modem to a cabled terminal or local storage node for modem transmission is planned for Vemco systems (D. Pincock, Amirix Corp., personal communication).

Data storage must be considered relative to data retrieval needs and constraints. Special needs include those for real-time data acquisition, triangulation capability, and security. Constraints include those of budget, vessel time, distance from shore, infrastructure, cable restrictions, and legal and practical buoy restrictions (Grothues et al. 2005). For example, buoy use is discouraged in habitats heavily utilized by marine mammals or extensive ship traffic. Thus, an autonomous logger (without antenna) is required. Data collection also interacts with power supply. Power hungry computation of CDMA and PM increases autonomous receiver, float, and anchor size, or must be retrieved more often or used with a power cable such as on an observatory node. An alternative is to duty cycle the receiver either to particular periods of interest (diel/diurnal or seasonal) or on the scale of seconds or minutes, or some combination thereof. While PIC dataloggers operate on a much cheaper energy budget, the addition of a two-way spread-spectrum modem to daisy chain the data will reduce the power savings and increase the unit size and cost substantially.

A surface antenna or cable is necessary not only for real-time data acquisition but also for triangulation at the small (down to sub-meter) spatial scale. This owes to the fact that independent internal clocks used to timestamp signals in a logger currently drift at a level unacceptable for triangulation, and so the loggers must have some hierarchical communication to ensure synchronization. Thus, one external clock may be imposed on several loggers, or loggers may communicate with a central receiver that delivers the time stamp to all signal receptions. The Vemco VRAP system does so by radio-communication with three wireless hydrophones (O'Dor et al. 1998). The Lotek Wireless MAP_600 system receives signals from multiple hydrophones via cable to a central receiver (Niezgoda et al. 2002), as does a Hydroacoustics Technology, Inc. product (Model 290/291). The Lotek Wireless, Inc. MAP_3050 wireless system may triangulate from an infinite number of autonomous loggers by imposing a single common surface clock on all loggers; however, the triangulation in that case is calculated post-processing rather than in real time. Geolocation by synthetic aperture is possible from a single autonomous moving hydrophone, as on the Rutgers University REMUS (Hydroid Inc., Pohaset MA) autonomous underwater vehicle (AUV) with a Lotek Wireless, Inc. MAP_3050 unit onboard.

Discussion

It is apparent that a wide array of options should be considered by telemetry users in marine habitat An understanding of the technology reveals why no manufacturer currently makes all combinations of code/receiver/data handling equipment. Yet, researchers' needs change as the animals in question move among habitats and change habits, and equipment compatibility is desirable especially when it is these habitat linkages themselves that are of interest (e.g. Beck et al. 2001, Gillanders et al. 2003).

Possible solutions to among-technology compatibility can be resolved either as technical solutions or as business solutions. Technically, compatibility can be addressed either at the transmitter or the receiver, by having the tag transmit in more than one code or by having the receiver open to broader reception (multi-capable). Multi-capable hydrophones would give away advantages in size, power savings, cost, and thus utility. For completely different coding schemes, two or more receivers would essentially have to be bottled together. However, at least PIC schemes within a narrow frequency band could potentially be shared. Perhaps a logger could store signal patterns rather than only logging the identity of signals that have already been decoded. A researcher would then query the logger with interpreter software specific to the manufacturer of interest while the coding scheme remains proprietary (D. Pincock, Amirix Corp., personal communication). Another solution is the use of dual-mode tags broadcasting codes of two different systems, at different frequencies and useful at either end of the positioning-scale spectrum (L. Egan, Lotek Wireless, personal communication). Because the number of receivers is small relative to the number of tags in coast-wide studies, significant cost increases for receivers may be less in total cost than the use of dual-mode tags (or double tagging). Despite this, dual mode tags are particularly attractive in my opinion because they allow compatibility to be turned on or off simply by choosing to deploy or not deploy such a tag. All hydrophones will not hear all tags, only that subset that is intended for among-array collaboration so some isolation capability remains. Users should be less conflicted in their risk to try new technology knowing that they can still tap into common infrastructure when appropriate without a complete turnover in equipment. This also allows a bridge between models using different schemes within a manufacturer, allowing structured turnover of legacy equipment to new models.

A first challenge to the use of multi-capable equipment or the marketing of dual-mode tags is that of a vendor's risk to investment capital by sharing intellectual property. The development of pathways to cross-equipment communication that respect intellectual property is an important aspect to realizing this potential. Secondly, a vendor sharing code relinquishes control of tag deployment in a "protected" frequency and cannot guarantee performance of their own product where others might deploy numerous tags in that frequency. This could be mitigated by voluntary submission to regulation by an outside sanctioning authority such as the Ocean Biological Information System (OBIS, Grassle 2000), but vendors or scientists have little recourse against non-subscribers or abusers. The user community would be the ultimate loser and needs to sanction or censure itself. This could happen, for example, in the proposal review process. Finally, a manufacturer may wish to refrain from participating in cross-platform solutions for the simple but legitimate business concern that this may pre-empt a future development market move into a competitor's niche. Pathways must therefore include both technical means, such as the development of multi-compatible systems, and market incentive means from funding sources that make sharing financially attractive (Able and Grothues 2007b). These issues have been solved before, with a recent example being the shared access protocol of Bluetooth® technology that works for cell phone users on several different carriers. Users are encouraged to educate themselves on the effects and benefits of tag deployment on downstream experiments, including communication on tag deployment (codes, frequencies, expected expiration dates) with colleagues through both informal and structured means (such as OBIS). This cannot be left to manufacturers to track through sales records, because they cannot know when tags are stored, deployed, or traded. Proposal writers should demonstrate that they have researched tag and hydrophone deployments by others in their area and considered the downstream implications of their deployments, and reviewers need to ask for this.

Conclusion -Case Studies

The importance of considering the advantages and challenges inherent to equipment choices in coastal systems is illustrated by case studies of migratory fishes that move between continental shelf and estuarine habitats. For example, striped bass exhibit a dichotomy in movement between seasonal migration along the North Atlantic western margin (1000 km scale) and punctuated high fidelity (meter–scale) to specific habitat features on either terminus of these migrations. About 20% of large adult striped bass tagged with transmitters in the southern New Jersey study area are seasonally resident with high fidelity to spatially restricted habitat for months at a time; however, all of these fish leave the estuary over the course of two years (Able and Grothues 2007a, Ng et al. 2007, Grothues et al. in press). Study of striped bass migration has progressed to the stage where understanding of experience during these dual habitat utilization modes is important to further advancement (Secor 1999, Grothues et al. in press). In another example, spawning winter flounder (*Pseudopleuronectes americanus*) are being tracked in sub-meter resolution using CDMA-coded transmitters to identify behaviors relative to managing dredging impacts (author, B. A. Phelan, NOAA/NMFS, E A. Bochenek, Rutgers University, unpublished data). The ten hydrophones and antenna are expensive and grouped to overlap in a narrow spatial range of approximately 2 km^2, in which fish spend only a small portion of their time within the estuary. At one seventh of the cost of those hydrophones and their antenna, PIC logging hydrophones could be used to monitor the general distribution and residence time in the estuary of those same fish, which puts behavior inside the smaller array into context. These fish are too small to carry two external tags. Ironically, two systems (Lotek Wireless, Inc. MAP and Vemco VR2) were applied in two years within the Navesink River estuary study site for two different studies owing to different resolution and budgetary constraints (see http://marine.rutgers.edu/navesink and http://sh.nefsc.noaa.gov/fishecology/fishtag.html).

This pattern of residency punctuated by seasonal migration may be shared by many species, especially by diadromous, or estuarine spawning fishes for which adult growth and spawning grounds differ greatly in environment (Able and Grothues 2007b, Sackett et al. 2007). These include some of the most important commercial or threatened species. Telemetry at the large spatial and temporal scales has relied on a fixed hydrophone array (Grothues et al. 2005) and benefited from interception by compatible WHS_1100 (Lotek Wireless, Inc.) arrays in Maine (J. Carter) and Virginia (J. Olney), while fine scale study is accomplished through mobile telemetry that, while instructive, does not allow synoptic or uninterrupted study of multiple individuals (Ng et al. 2007). However, at least five other telemetry efforts utilize Vemco VR2 hydrophones within the demonstrated range of these same individual fish (D. Fox, Delaware State University; M. Mather, University of Massachusetts, Amherst; B. A. Phelan and J. Manderson, NOAA/NMFS, New Jersey; J. Musick and M. Fabrizio, Virginia Institute of Marine Science; T. Savoy, Connecticut Department of Environmental Protection), and one coincides with a MAP array, further, some include or focus on the same species in their efforts. We now understand that compatibility of these hydrophone arrays or their tags and collaboration among institutions would have yielded an important and extensive, though serendipitous, data source on the movement of these individuals across study sites.

Numerous other species, in particular Atlantic sturgeon, bluefish (*Pomatomus saltatrix*), several coastal shark species, and several sciaenids make coastal migrations that could be simultaneously studied by a unified telemetry array along the eastern US coast (Grothues and Able 2007, Grubbs et al. in press). Already, the movement of green sturgeon (*Acipenser medirostrus*) on the US west coast benefited from the recording of individuals moving between California and Alaska in an ensemble of Vemco VR2 arrays that "were operated as part of studies of species other than green sturgeon…in the coastal ocean…in rivers, bays, or estuaries" (Lindley et al. 2008). These findings, surprising in light of tagging data (Erickson et al. 2007), came from after-the-fact collaboration. Furthermore, green sturgeon were also found in a separate study to exhibit the same seasonal dichotomy described for striped bass above, with seasonal residents using very constrained fresh water pools for 6–8 months but suddenly becoming migrant, and migrants again becoming seasonally resident in other rivers (Erickson et al. 2002). In that case, a "dual-mode" approach to measures at different scales involved tagging individuals with both radio and acoustic tags. Dual tagging is practical and cost effective in fish that, like sturgeon, attain lengths of 2 m and live for years; it is less so for small fish such as Alosine shad or flatfish that are never-the-less economically important. A single tag packaging both radio and acoustic transmitters with a common PIC coding scheme (combined acoustic radio tag, CART, Lotek Wireless, Inc.) and interpreted by the same receiver/processor/logger, (SRX_400), represents the first commercial incarnation of the dual mode concept. It allows mobile telemetry of river systems from airplane or vessels and passage monitoring from shore or moored stations in fresh and marine environments for anadromous species with a single tag.

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