

Effects of biofouling on performance of moored data logging acoustic receivers

Michelle R. Heupel¹*, Katie L. Reiss², Beau G. Yeiser¹ and Colin A. Simpfendorfer³

¹Center for Shark Research, Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, FL 34236, USA

²Western Illinois University, 1 University Circle, Macomb, IL 61455 USA

³Fishing and Fisheries Research Centre, School of Earth and Environmental Sciences, James Cook University, Townsville, Queensland, 4811 Australia

Abstract

Biofouling on scientific equipment deployed in marine and estuarine environments can have implications for equipment performance, and the type and amount of data collected. We examined the effects of biofouling on the performance of data logging acoustic receivers deployed in shallow coastal waters off Florida. Five treatment types of receivers were examined including old and new versions of VR2 (Vemco Ltd) receivers with complete, partial, or no antifouling paint. Receivers were deployed for 2 mo, and acoustic signal detection rates examined. All receivers had some extent of biofouling during the course of the study, and performance was variable among treatment types. Old version receivers did not perform as well as new version receivers in all cases, and significant differences were apparent in detection rate and receiver performance metrics. Reductions in receiver performance over time occurred for most treatments and were likely due to settlement of biofouling organisms including barnacles, annelids, tunicates, and ascidians. Biofouling appeared to affect receiver performance over time and should be taken into account in acoustic telemetry studies.

Introduction

Acoustic telemetry has become increasingly popular among scientists to study fish habitat use and movements. The omnidirectional Vemco VR2 receiver has become widely used because it is less expensive than more sophisticated systems that provide high resolution position accuracy (e.g., VRAP and MAP systems) and less time consuming than actively tracking animals (Voegeli et al. 2001). The passive tracking method provided by this technology also allows multiple animals to be monitored or tracked simultaneously (Voegeli et al. 2001, Heupel et al. 2006). Transmitters that send out an acoustic signal are attached to animals, and signals are recorded by a receiver to monitor animal presence and location. Because receivers detect an acoustic signal, it is important to deploy receivers in low noise environments and ensure they stay clean and clear of obstructions that could deflect sound.

*Corresponding author: E-mail: Michelle.Heupel@jcu.edu.au

Acknowledgments

We thank MML staff A. Ubeda and T. Wiley for their assistance with this project. Funding for K. Reiss' involvement in this study was provided via National Science Foundation Grant #OCE-0139392 (Awarded to J. Gelsleichter), which supports Mote Marine Laboratory's Research Experience for Undergraduates Program.

In designing telemetry studies using fixed station receivers such as the VR2 receiver, it is important that the path from the transmitter to the receiver remains as unobstructed as possible. There are numerous factors that can lead to a receiver failing to detect signals including suspended matter in the water column, rainfall, wave action, air bubbles, animal noise (e.g., snapping shrimp), water flow, and vessel noise (e.g., Voegeli and Pincock 1996, Klimley et al. 1998, Voegeli et al. 1998, Lacroix and Voegeli 2000, Thorstad et al. 2000, Finstad et al. 2005, Heupel et al. 2006). For example, rainfall can produce or increase noise levels of 15 to 25 dB (re 1 μ Pa) in the water column (Voegeli and Pincock 1996). In addition to these sources, there are other factors within the marine environment that can alter sound patterns and affect acoustic receiver performance. For example, soft-bodied biofouling organisms and decaying organic matter can absorb acoustic energy (Fitzgerald et al. 1947). Composition of the water column can also cause absorption because salinity has an effect on how much sound energy water absorbs (e.g., Voegeli and Pincock 1996) and stratification of the water column (e.g., thermocline, pycnocline) can also affect sound travel and transmitter performance (Heupel et al. 2006).

Most published studies using acoustic telemetry technology focus on the results from tracking studies and the meaning of the results in relation to the study species. Few focus on the acoustic equipment and its performance. Information on equipment performance is integral to understanding telemetry

results and should be a consideration in data analysis and interpretation. The location of receivers and conditions within the study site can also play a role in equipment performance and effects of biofouling organisms (Heupel et al. 2006). Some studies have examined how to improve signal detection of the receiver and/or how to design a study to maximize signal detection (e.g., Clements et al. 2005, Domeier 2005, Heupel et al. 2006). Research by Clements et al. (2005) found that the way receivers are moored can decrease detection efficiency of a receiver. This suggests that multiple factors are at play in understanding receiver performance. One non-telemetry study, however, has directly examined the effects of biofouling on acoustics. Fitzgerald et al. (1947) examined how biofouling affected sound in the marine environment off the Florida coast. Panels with and without antifouling paint were submerged in saltwater and allowed to foul. The percentages of transmission, absorption, and reflection were calculated revealing that biofouling does impact the way sound travels and how much sound a hydrophone could detect through a layer of biofouling organisms. The results of this study also suggested antifouling paint was effective in preventing biofouling and that panels treated with antifouling allowed more sound transfer than those without.

Callow and Callow (2002) suggest that controlling biofouling is a large and continuing problem, one that costs the US Navy up to \$1 billion per annum. They explain that within minutes of placing a surface into marine water, it will be covered in a molecular "conditioning film" consisting of dissolved organic material. Bacteria will colonize this film forming a biofilm referred to as "microfouling" or "slime." This slime is then colonized by the macrofouling community, which varies by location and season. These processes can occur quickly and affect marine-based equipment. Stationary receivers may remain in the ocean for months at a time. Over time, if the receivers are not treated with antifouling compounds and/or are not serviced and cleaned, biofouling organisms will settle and grow on the receivers. It is possible that the accumulation of biofouling organisms could block or obscure acoustic signals from a transmitter. Interference from the growth of organisms like barnacles on the receiver and/or mooring equipment could directly affect transmitter detection rates and therefore the data scientists are collecting. A recent article by Simpfendorfer et al. (2008) reported that biofouling may have caused declines in acoustic receiver performance in an estuarine setting. This article specifically examined receiver performance over time using several metrics. However, it is unknown if biofouling has compromised the results of other published research because this is typically not a consideration in data analysis and has not been commented on in published studies.

This study focused on the effects of biofouling on the performance of moored VR2 receivers. We hypothesized that if biofouling organisms were allowed to accumulate on receivers, signals from transmitters would not be as reliably

detected, affecting receiver performance, and collected data. The study examined the performance of two versions of VR2 receivers as well as examining performance differences when antifouling compounds were used in an attempt to decrease fouling and improve receiver performance.

Materials and procedures

Study site—The study was conducted in Sarasota Bay, adjacent to the Mote Marine Laboratory (MML) campus in a depth of approximately 3 m. Boats did not pass through the area frequently, so the site had low anthropogenic noise disturbance. Three replicate groups of receivers were deployed 40 m apart from one another. Replicate groups included new and old versions of the VR2 receiver. The old version has been produced since the late 1990s with a newer version available in 2004. The new version has a robust plastic case covering the hydrophone while the old version has a plastic body, but lacks the plastic case covering the hydrophone. The new version receiver is gradually replacing old versions as users replace units or expand studies, but old versions are still currently in use. Each replicate group of receivers included: (1) one old version VR2 with no anti-fouling paint (ONP); (2) one old version VR2 with anti-fouling paint (including painting the exposed hydrophone) (OP); (3) one new version VR2 with anti-fouling paint (NP); (4) one new version VR2 with no anti-fouling paint (NNP); (5) one old version VR2 that was partially painted with antifouling (hydrophone not painted) and the hydrophone coated in lithium grease (to slow and deter biofouling) (STD). This final receiver type was deployed in the same manner as previous research conducted by MML scientists. Once every 2 weeks, STD receivers were brought to the surface and cleaned following previous study procedures. Remaining receivers were not cleaned during the study but were brought to the surface for downloading. Receivers with antifouling were given three coats of Micron CSC ablative paint prior to deployment.

Nonpainted receivers were covered in duct tape to prevent damage to the receivers and ease of cleaning at the end of the experimental period. Differences in plastic composition of receivers (if any) were not considered because all unpainted receivers were covered in duct tape. The remaining receivers had duct tape around the data port to prevent biofouling in the download port that could have affected data recovery. Each STD receiver had a HOBO® Water Temp Pro data logger attached which recorded water temperature every 30 min. Two sets of two Vemco V16H RCODE transmitters that emitted a signal approximately every 45-75 s were anchored within the study site. These stationary transmitters were used to test signal detection by each receiver through time. Transmitters were deployed in mesh cases that were periodically cleaned of fouling during the project. Transmitters were deployed parallel to and offset from receiver groups (Fig. 1). This resulted in transmitters being between 18 and 67 m from receiver groups. This distance is well within the detection range of VR2

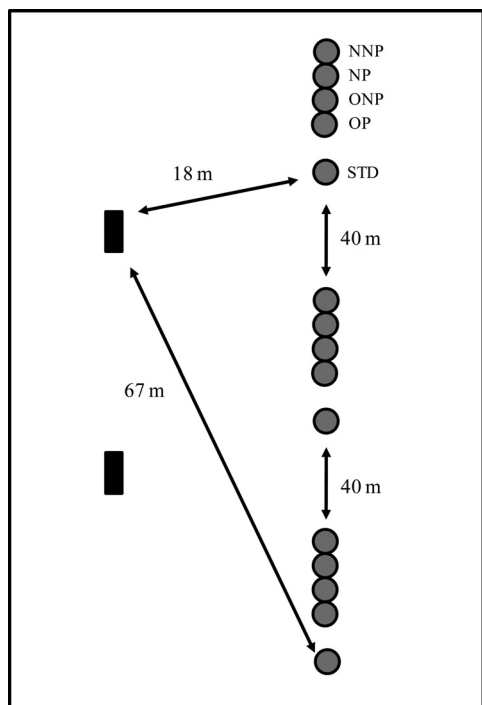


Fig. 1. Schematic depicting the location of acoustic receivers (gray circles) and transmitters (black rectangles). Receivers were placed side by side with the standard receiver slightly offset due to its different anchoring configuration. Order of receivers in each replicate may vary to that shown in the example: OP = old painted, ONP = old no paint, STD = standard, NP = new painted, and NNP = new no paint.

receivers (c. 500 m) given the high power of the transmitters used. Receiver groups and transmitters were deployed for 63 d from May 25 to July 26, 2006.

Due to the high numbers of detections, recorded data were downloaded from the receivers every 2 weeks. Pictures were taken of all the receivers to visually represent biofouling over time. Data were analyzed to examine differences in receiver performance through time and by receiver type. Analysis of covariance (ANCOVA) was used to investigate the effects of temperature on receiver performance and a heterogeneity of slopes general linear model (HOS GLM) was used to examine differences in declines in detection rate by type of receiver. Variability in detection rate by individual receiver was examined via Chi-square analysis and the effect of salinity and temperature was examined via regression analyses.

The number of expected detections per day was used to examine the performance of receivers by comparing the total number of detections recorded to the expected number. Number of expected detections per day was provided by the equipment manufacturer and was based on the number of transmitters used in the study and rate of signal transmission (repeat rate of transmitter). Estimation accounts for signal overlap/collision among transmitters that will result in no code detected by a receiver, and thus is less than the actual number of signals emitted by all transmitters. The estimated

potential number of detections per day per transmitter provided by the manufacturer was 4138.

The speed of sound in water was calculated to examine whether environmental conditions played a role in the number of detections recorded by individual receivers. The calculation was performed using a standard oceanographic relationship (<http://www.es.flinders.edu.au/~mattom/Utilities/index.html>).

The performance of individual receivers was assessed using three metrics developed for use with VR2 receivers (Simpfendorfer et al. 2008) using four summary data values stored by receivers. The summary data values used in calculations were number of valid synchronization codes (synchs), the number of codes rejected because of invalid checksums (checksums), the total number of pulses detected (pulses), and the number of valid codes detected (detections). The three metrics were code detection efficiency (detections/synchs), rejection coefficient (checksums/synchs) and noise quotient (pulses - [synchs × number of pulses in a code]). Since all tags used in this study were Vemco R4K tags (4096 possible code combinations), the number of pulses in a code was seven. Summary data were obtained when receivers were downloaded, with three download periods when data were available from all receivers. Performance metrics were calculated for each receiver for each period and compared between receiver types using analysis of variance (ANOVA). Duncan's post-hoc tests were used to identify groups of receivers that had significantly different ($\alpha = 0.05$) performance.

Pictures were taken of all 15 receivers every 2 weeks to examine biofouling over the study period. Biofouling organisms were observed and recorded over the course of the study based on this examination.

Assessment

There was a significant difference between the total number of signals detected per day between the five types of receivers (ANCOVA, $F = 19.64$, $df = 4$, $P < 0.0001$). The total number of signals detected was also significantly different between replicate groups of receivers (ANCOVA, $F = 80.30$, $df = 2$, $P < 0.0001$). There was variability in results across the three replicate groups, but ONP receivers performed worst in all groups (Fig. 2). Group 3 receivers performed more consistently than others, but typically fell within a similar range to the other 2 groups except in the case of the ONP receiver in Group 1. Temperature did not have a significant effect on signal detection across receiver type (ANCOVA, $F = 1.9168$, $df = 4$, $P = 0.166$). Analysis of receiver performance by type over time revealed significant differences in the rate of decline in the number of signals received between receiver types (HOS GLM, $F = 1.53$, $df = 4$, $P < 0.001$). Examination of rate of decline indicated ONP and OP receivers had the highest rate of decline, followed by STD and NP receivers. The only group to have a non-significant slope was the NNP receivers, which also had the lowest rate of decline (Table 1).

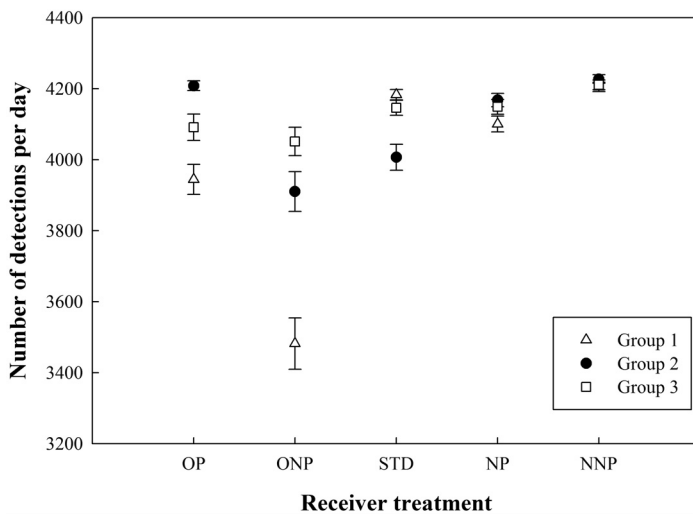


Fig. 2. Daily detection rate of receivers in the five treatments by deployment group where OP = old painted, ONP = old no paint, STD = standard, NP = new painted, and NNP = new no paint.

Examination of the proportion of expected detections per day showed a gradual decline in the proportion of detections through time, except for NNP receivers (Fig. 3). Data from NP and STD receivers showed these receivers performed well with declines in detection only occurring a month or more after deployment. Although the STD receiver was cleaned it is important to note the mooring lines were not. Thus decreases in performance over time by this unit could be the result of fouling build-up on mooring structures. OP receivers started to show decreased detections after 2 weeks, but worst performance didn't occur until after more than 1 month of deployment. ONP receivers performed worst with detection decreases occurring from 2 weeks post-deployment and continuing from

that point. Although a group effect was present suggesting a placement effect, receivers were deployed so close together that this is unlikely. Variation in individual receiver performance was evident in the data and was presumably the result of varied biofouling on individual receivers (Fig. 3). Increases and decreases in performance may be the result of changes in the biofouling community on receivers as some individuals drop off and others recruit on.

Examination of detection rate of individual transmitters, rather than total number of detections per receiver, also showed variable patterns (Fig. 4). The pattern was similar to that for total receiver detections since transmitter and receiver performance were interdependent. Although significant differences were apparent in individual transmitter detections by receiver (Table 1), there was no evidence that an individual transmitter performed better or worse than others. This suggests that all transmitters performed equally over time and that any changes in detection rate were due to receiver performance, not transmitter performance.

Conditions within the study site revealed temperatures ranging from 26.1–31.1°C and salinity ranging from 30.2 to 35.2 parts per thousand. Examination of the speed of sound in water based on water column conditions (salinity, temperature, air pressure) revealed no significant differences in sound travel during the study period (slope = -0.076, $P = 0.120$, $r^2 = 0.189$). This suggests that signals should have traveled similarly through the region for the duration of the study and any environmental disturbance was likely to have been short term (vessel noise, rainfall) and would not have affected the overall results.

The noise quotient was not significantly different between receiver types (ANOVA, $F = 1.141$, $df = 4$, $P = 0.356$) or between periods (ANOVA, $F = 6.217$, $df = 2$, $P = 0.006$). The number of potentially valid code signals that were rejected as being

Table 1. Results of receiver performance including Chi-square results of number of transmitter detections per day by individual receiver with receiver treatment indicated and decline in detections over time in number of signals detected as shown by slope and standard error for each group.

Receiver type	Chi-square	P	slope	Standard error	P
OP	457.28	<0.0001	-7.58	1.11	<0.0001
OP	67.32	<0.0001			
OP	33.22	<0.0001			
ONP	481.82	<0.0001	-18.27	1.79	<0.0001
ONP	6533.37	<0.0001			
ONP	563.74	<0.0001			
NP	334.01	<0.0001	-4.15	0.65	<0.0001
NP	126.20	<0.0001			
NP	87.17	<0.0001			
NNP	25.57	<0.0001	-0.84	0.45	0.062
NNP	3.70	0.30			
NNP	91.12	<0.0001			
STD	300.42	<0.0001	-6.81	0.80	<0.0001
STD	216.31	<0.0001			
STD	2.57	0.46			

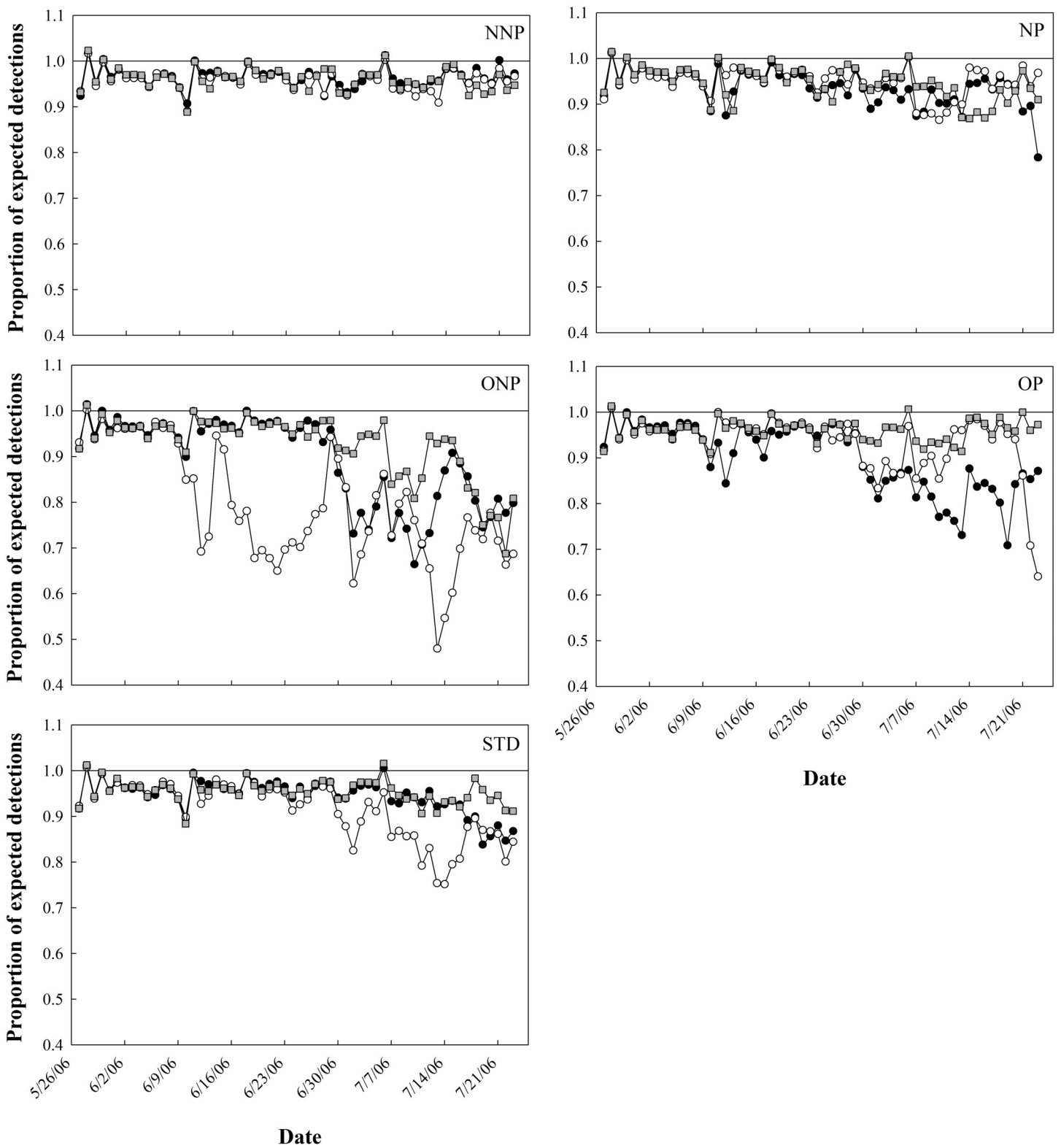


Fig. 3. Receiver detection histories based on the proportion of detections recorded by all units in each treatment in relation to the total proportion of expected detections (indicated by horizontal line). Expected detection rate was provided by the manufacturer based on potential signal overlap given transmitter type, ping repeat rate and number of transmitters present.

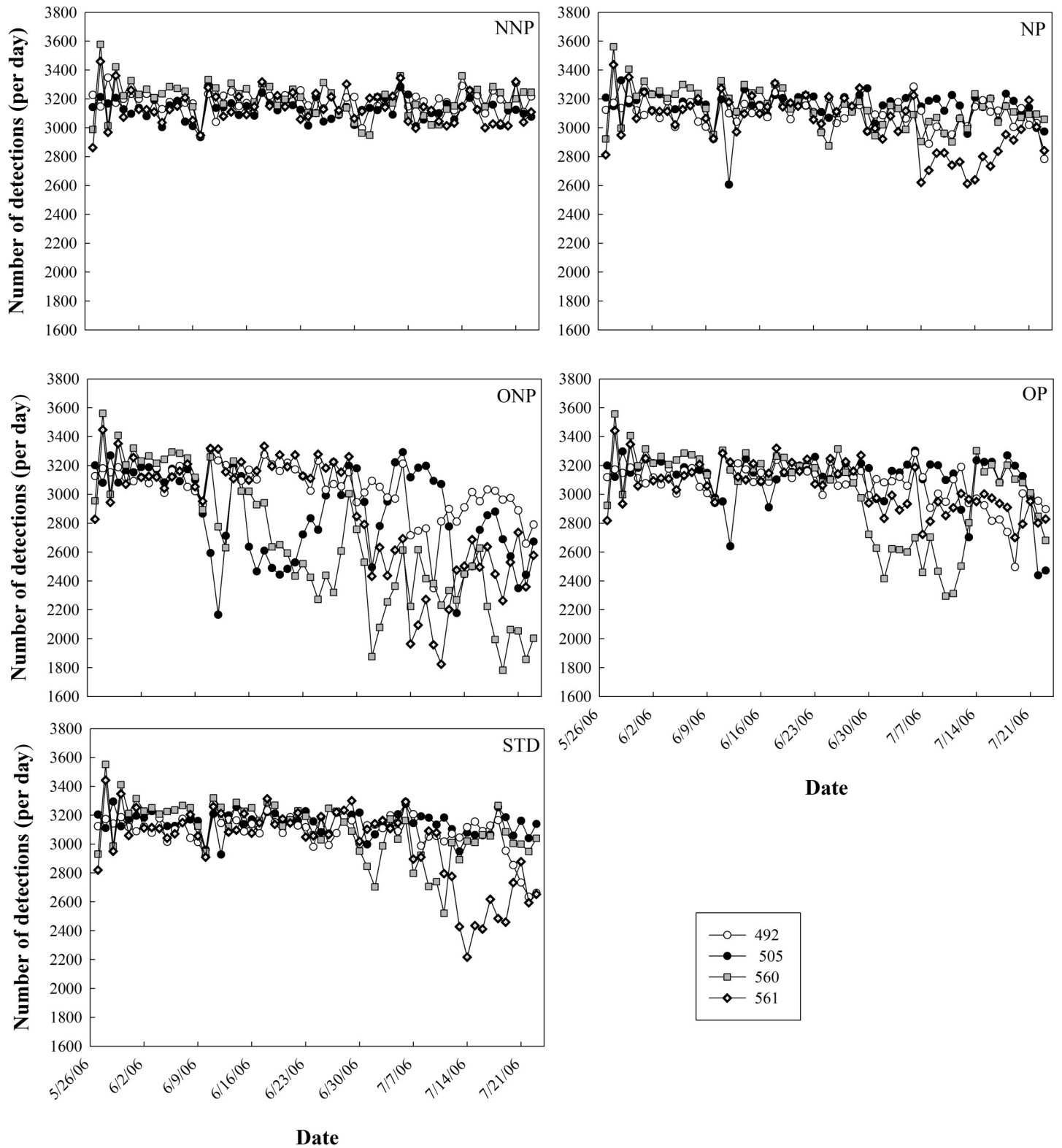


Fig. 4. Number of detections per day for each transmitter during the course of the study as recorded by receivers in each of the five treatment groups.

incomplete (invalid checksum) was significant by type (ANOVA, $F = 3.213$, $df = 4$, $P = 0.026$) and period (ANOVA, $F = 13.557$, $df = 2$, $P < 0.0001$). Further examination revealed that 6.6% of code detections were rejected due to invalid checksums for all types except ONP, which had a higher rejection rate of 7.5% (Duncan's post-hoc test). Finally, code detection efficiency was also significantly different between type (ANOVA, $F = 8.592$, $df = 4$, $P < 0.0001$) and period (ANOVA, $F = 6.428$, $df = 2$, $P = 0.005$). Further examination of efficiency data revealed code detection efficiency of 77.8% for all receiver types, with ONP receivers having lowest efficiency and NNP receivers having highest efficiency.

Biofouling was present on receivers from early in the study. After 2 weeks, all receivers were noted to feel slimy and have a coating on the surface. Within 1 mo of deployment, soft- and hard-bodied biofouling organisms were present on receivers without antifouling. Beyond this point, receivers continued to become increasingly fouled. Most of the organisms that attached to receivers were soft biofouling organisms (Fig. 5). There were numerous ascidians, tunicates, and annelids present within 1 mo of the receivers being deployed. Abundance of these organisms increased over time. Barnacles (*Balanus eburneus*) were also found on unpainted receivers within 1 mo and were attached to all hard surfaces including mooring equipment. Numerous barnacles were found on ropes, floats, and mooring equipment. Both soft biofouling organisms and barnacles were found on floats used to mark the location of receiver groups (Fig. 5). When the receivers were brought to the surface and downloaded at the end of the study noise from barnacles on the mooring equipment and receivers was obvious. Barnacle noise was produced by the movement of cirri in and out of the carapace plates. Receivers coated with antifouling had little or no visible biofouling during the study period aside from the slime coating.

Discussion

The performance of acoustic receivers in marine environments can be variable. Results from this study reveal that the condition of the receiver and the amount of maintenance conducted could affect receiver performance. The use of antifoul paint decreased the amount of biofouling and probably resulted in the higher performance seen in old version painted receivers. However, receiver design also appeared to play a role in detection performance with new version receivers outperforming all old version receivers regardless of treatment. It is unclear why differences in the receiver design or cases caused differences in equipment performance.

The effects of biofouling in acoustic oceanographic studies have been apparent for decades. Fitzgerald et al. (1947) examined the acoustic properties of marine fouling and provide a robust description of this process. They noted that within 3-5 mo, oceanographic equipment could be rendered inoperative due to heavy fouling by various types of organism including barnacles, annelids, tunicates, bryozoa, hydroids, mollusks,

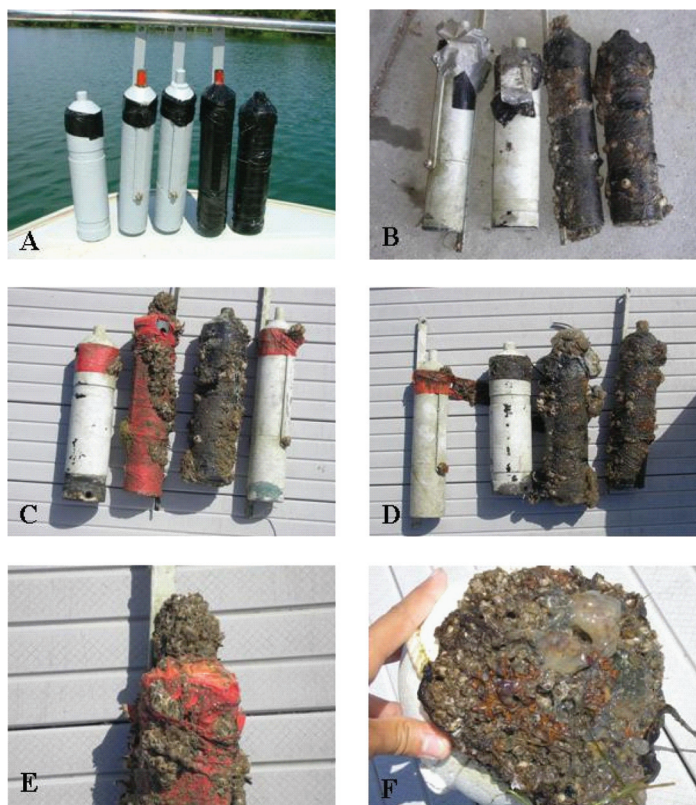


Fig. 5. Photographs of receivers in various stages of fouling. (A) receivers prior to deployment from left to right: new painted, standard, old painted, old no paint, and new no paint; (B-D) fouling evident on receivers from groups one to three, note presence of barnacles, ascidians, and tunicates are evident; (E) close-up photo of old no paint receiver showing biofouling on the hydrophone; (F) example of the biofouling community evident on mooring lines and floats.

and algae. More recent studies have also recognized the importance of deterring biofouling on marine-based equipment (e.g., Clare 1998, Afsar et al. 2003), and this is an ongoing problem for marine scientists (e.g., fouling of anchored ocean observatory equipment, remote water quality meters, etc). Similar to the results of Fitzgerald et al. (1947), the present study revealed heavy biofouling on nontreated equipment. The older version receiver with no antifouling paint was the most affected by biofouling. This group of receivers had the heaviest coverage of biofouling and worst performance of any of the five treatments.

All receivers were covered with a variety of organisms including hard- and soft-bodied forms. These organisms can create noise that may affect the ability of an acoustic receiver to "hear" detections. In addition, sound waves can be reflected off hard surfaces like the shells of barnacles (Fitzgerald et al. 1947), deflecting signals emitted by transmitters, and decreasing the likelihood of detection by a receiver. Soft-bodied organisms present on the receivers also could have absorbed incoming sound waves. The presence of biofouling organisms on receivers appeared to affect detection rate and performance

over time. All receiver types performed equally at the beginning of the experiment, but within 2 weeks of deployment, performance differences were evident. Receivers in the ONP group performed worst with detection rates declining after approximately 2 weeks, while NNP receivers performed best showing only slight declines in performance over time. These results are somewhat contradictory. As expected, the old version receiver with no antifouling paint performed worst. However, the new version receiver with no antifouling paint performed best. Differences in old versus new receiver version may be explained by improvements to the technology and case design of the receiver. New units have a more robust case and an enclosed hydrophone, making it less directly exposed to fouling. This change to the technology means that new version receivers may be less susceptible to biofouling, at least in the short-term. Differences in detection rates between NNP and NP receivers are difficult to explain. Although differences were small, new version receivers without antifouling paint performed better than receivers with antifouling. There is no obvious reason for this discrepancy aside from a potential paint effect. This was not tested. No paint effect was observed in old version receivers so it is unclear whether paint was a factor in receiver performance. In addition to overall trends across receiver treatments, there was also variability in detection rate among receivers within treatments. This is most likely due to variability in fouling on various receivers.

Although STD receivers performed similarly to NP receivers, the observed decline in performance by STD receivers was not expected. These receivers were routinely cleaned, and therefore, it was assumed that detection rate would not decline. The decline observed was similar to one where minor fouling occurred. This decline is likely due to the presence of biofouling organisms on mooring lines and anchoring equipment. Mooring lines are in close proximity to the hydrophone and therefore could have affected signal detection. This decline does not appear to be related to environmental conditions since similar declines were not observed in NNP receivers. Based on these results, future research should consider whether mooring lines or structures near the receiver hydrophone should also be cleaned or antifouling painted to reduce biofouling interference.

Environmental conditions within the study site were stable during the study period and did not have any effect on receiver performance. Examination of salinity and temperature revealed that transmission of sound through the water column did not vary significantly during the study period and could not have affected detection rate. Therefore declines in detection over time do not appear to be the result of water column conditions. This study was conducted in the peak of summer in Florida waters and would have produced lowest environmental variability and highest biofouling rates.

All transmitters appeared to have performed equally suggesting any differences recorded were due to receiver performance. Declines in detections of individual transmitters were

inconsistent across receivers with different receivers missing detections from different transmitters. It was important to rule out transmitter failure or performance declines, if present, to ensure results did reflect receiver performance rather than transmitter problems. Examination of receiver performance metrics, measures of the signals being processed by receivers, revealed significant differences among treatments. The number of potential signals rejected due to invalid checksums was different among receiver type and over time. This suggests that through time as receivers became more fouled acoustic signals from tags contained more errors and hence were more likely to be rejected by the internal error-checking algorithm. Errors in signals may have been caused by extraneous acoustic noise or disturbance of signals (Simpfendorfer et al. 2008). This also affected code detection efficiency and thus overall receiver performance. However, noise coefficients were not different among receiver type suggesting that external noise did not cause the differences in detection rates between receivers. This suggests the observed results were a reflection of the ability of signals to get through to the receiver (i.e., through layers of biofouling).

Overall, antifouling paint effectively kept receivers free from most biofouling organisms during the study period. Fitzgerald et al. (1947) also found that antifouling paint helped decrease the amount of sound energy absorbed. For example, an acoustic panel allowed to foul absorbed 65% of transmitted sound energy while a panel with antifouling paint only absorbed 8% of sound energy. The presence of antifouling paint on the panel increased the transmission of sound energy from 29% to 79% suggesting that treatment with antifouling compounds can increase acoustic equipment performance. This study also demonstrated this result when examining the old version receivers, suggesting antifouling paint is probably highly effective for use with this version of the equipment. Variable results from new version receivers suggest that antifouling paint may not be as necessary over the time period tested. Differences in performance between the two new version treatments were small enough that users may expect similar results regardless of antifouling treatment. Replacement of older units with new versions that appear to be less susceptible to biofouling will help alleviate this problem for telemetry users, but field testing of receiver performance should be conducted. It is worth noting that this was a short-term project and that longer deployments (months to years) would result in greater amounts of biofouling and may eventually cause decreases in detection rates of non-painted units. With many studies deploying receivers for periods of months to years before recovery, biofouling may be a serious issue and should be taken into consideration when using both old and new receiver versions. In addition, biofouling organisms can be difficult to remove and may cause damage to the equipment upon removal. Based on these observations users may consider using antifouling compounds. Acoustic receiver users should be aware of the pitfalls of biofouling and how detrimental these organisms can be to receiver performance.

Comments and recommendations

The use of acoustic receivers for monitoring fish movement patterns is becoming increasingly popular. Deployment of this equipment comes with numerous potential problems including biofouling. Here we examined the performance of acoustic data logging receivers that were allowed to accumulate biofouling organisms to determine their effect on receiver performance. Receiver performance varied and was at least in part due to the presence of biofouling organisms, with performance typically declining in response to increased biofouling. New version receivers performed best in this study regardless of treatment type and users with old version receivers may consider upgrading to the new version which performed better. Equipment users should be aware of the potential effects of biofouling and realize that longer term deployments may result in greater rates of fouling and declines in receiver performance. Antifoul paint and/or regular cleaning and maintenance may be required to maintain receiver performance and should be a consideration in study design.

References

- Afsar, A., R. De Nys, and P. Steinberg. 2003. The effects of foul-release coatings on the settlement and behaviour of cyprid larvae of the barnacle *Balanus amphitrite amphitrite* Darwin. *Biofouling* 19:105-110.
- Callow, M. E., and J. A. Callow. 2002. Marine biofouling: a sticky problem. *Biologist* 49:1-5.
- Clare, A. S. 1998. Towards nontoxic antifouling. *J. Mar. Biotechnol.* 6:3-6.
- Clements, S., D. Jepsen, M. Karnowski, and C. B. Schreck. 2005. Optimization of an acoustic telemetry array for detecting transmitter-implanted fish. *N. Am. J. Fish. Manage.* 25:429-436.
- Domeier, M. L. 2005. Methods for the deployment and maintenance of an acoustic tag tracking array: An example from California's Channel Islands. *Mar. Tech. Soc. J.* 39:74-80.
- Finstad, B., F. Økland, E. B. Thorstad, P. A. Bjørn, and R. S. McKinley. 2005. Migration of hatchery-reared Atlantic salmon and wild anadromous brown trout post-smolts in a Norwegian fjord system. *J. Fish Biol.* 66:86-96.
- Fitzgerald, J. W., M. E. Davis, and B. G. Hurdle. 1947. Some acoustic properties of marine fouling. *J. Acoustic. Soc.* 19:332-337.
- Heupel, M. R., J. M. Semmens, and A. J. Hobday. 2006. Automated acoustic tracking of aquatic animals: scales, design and deployment of listening station arrays. *Mar. Freshw. Res.* 57:1-13.
- Klimley A. P., F. Voegeli, S. C. Beavers, and B. J. Le Boeuf. 1998. Automated listening stations for tagged marine fish. *Mar. Tech. Soc. J.* 32:94-101.
- Lacroix, G. L., and F. A. Voegeli. 2000. Development of automated monitoring systems for ultrasonic transmitters, pp. 37-50. *In* A. Moore and I. Russell [eds.], *Advances in Fish Telemetry*. Lowestoft: CEFAS.
- , ———, and A. B. Collins. 2008. Variation in the performance of acoustic receivers and its implication for positioning algorithms in a riverine setting. *Can. J. Fish. Aquat. Sci.* 65:482-492.
- Thorstad, E. B., F. Okland, D. Rowsell, and R. S. McKinley. 2000. A system for automated recording of fish tagged with acoustic transmitters. *Fish. Manage. Ecol.* 7:281-294.
- Voegeli, F. A., and D. G. Pincock. 1996. Overview of underwater acoustics as it applies to telemetry, pp. 23-30. *In* E. Baras and J.C. Philippart [eds.], *Underwater Biotelemetry*. Univ. of Liege.
- , G. L. Lacroix, and J. M. Anderson. 1998. Development of miniature pingers for tracking Atlantic salmon smolts at sea. *Hydrobiologia* 371-372:35-46.
- , M. J. Smale, D. M. Webber, Y. Andrade, and R. K. O'Dor. 2001. Ultrasonic telemetry, tracking and automated monitoring technology for sharks. *Environ. Biol. Fish.* 60:267-281.

Submitted 16 September 2007

Revised 11 March 2008

Accepted 4 June 2008