Passive Acoustic Telemetry Technology: Current Applications and Future Directions

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Results of the VR2 workshop held on Catalina Island Nov 28 – Dec 1, 2005

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Table of Contents

Introductory statement………………………………………………………………...	3
Acknowledgements……………………………………………………………………	3
Abstract………………………………………………………………………………..	4
Summary of workshop………………………………………………………........	5
Section I…………………………………………………………………………	6
Section II………………………………………………………………………...	16
Section III………………………………………………………………………..	23
Resolution on coded acoustic tag…………...……………………………………………	26
Workshop participants………………………………………………………………...	27
Survey form completed by workshop participants……………………………………	29
Summary of survey results…………………………………………………………….	30
Table of study species…………………………………………………………………	37
Participant abstracts…………………………………………………………………...	39
Resource list……………………………………………………………………………...	88

Introductory Statement

The text contained in this document summarizes the outcomes of a workshop hosted at the Wrigley Institute for Environmental Science on Catalina Island Nov 28 – Dec 1, 2005. Prior to the Workshop participants were asked to complete a survey form to gauge their current usage and satisfaction with passive acoustic telemetry technology and define future goals for use. Abstracts were submitted by all participants as an example of their previous, current and future planned research. The survey form, summary of results and participant abstracts are included for completeness. Authors are listed alphabetically and do not indicate any seniority.

Acknowledgements

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Abstract

The development and popularity of VR2 automated acoustic receiver technology produced by VEMCO Ltd. of Nova Scotia, Canada has significantly increased over the last 5 years. This technology is currently being used by biologists worldwide to assess movement patterns, behavior, and site fidelity of fishes and invertebrates. However, while this technology has significantly increased our understanding of behavior of marine organisms in the wild, limitations in design and the dramatic increase in use has resulted in a number of potential problems for all users. Because of the identification coding design of the VR2 transmitters (rcode tags) can allow users to choose their own tag codes, and the number of distinct ID codes are limited, duplicate ID codes could be distributed and deployed in neighboring areas. In addition, the extent of movement of many marine organisms is unknown, therefore increasing the probability that a user may incorrectly identify a tag as being theirs when it may not be. On the other hand, because the VR2 receivers can be programmed to detect tags other than just the primary users, there lies tremendous potential for collaborative efforts among users to increase their areas of detection by sharing code numbers and reporting unknown codes to a registry of users. Therefore there is a strong need to assemble VR2 users from around the world, with engineers from Vemco, to establish a registry of users and discuss ways of avoiding coding conflicts and maximizing data sharing.

This document summarizes the results of discussions amongst VR2 users and Vemco staff. User concerns were addressed by Vemco staff and the current limitations and future directions of this technology were presented and discussed. Issues with current applications of the technology were evaluated and potential solutions were discussed. Problems regarding database use, data management, handling and analysis were explored and potential new venues for handling and displaying data were presented.

Summary of workshop

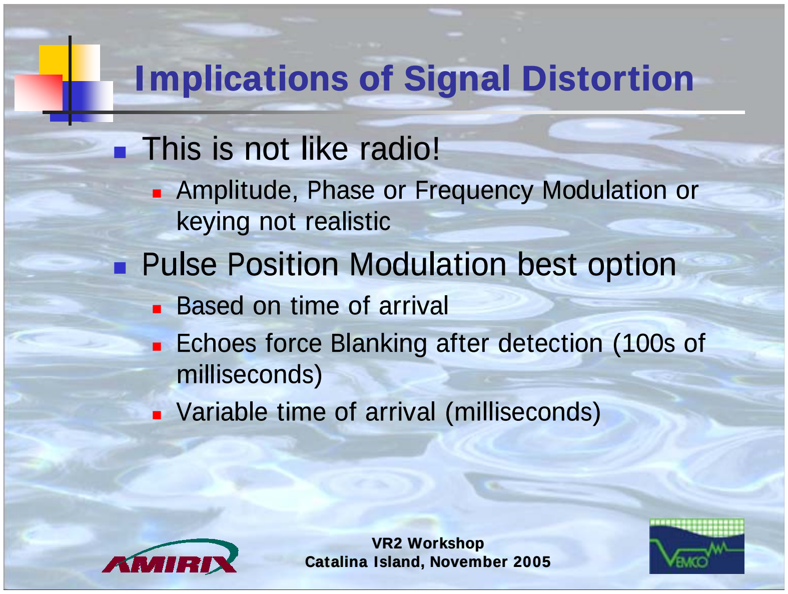
Summary

The workshop was divided into several sections. The first section included presentations by Amirix/Vemco staff to clarify the present state of the technology and future plans for that technology. The second section included discussions of database management and data manipulation. The third section focused on data analysis techniques and tools. These three sections and any other relevant information are included in this summary.

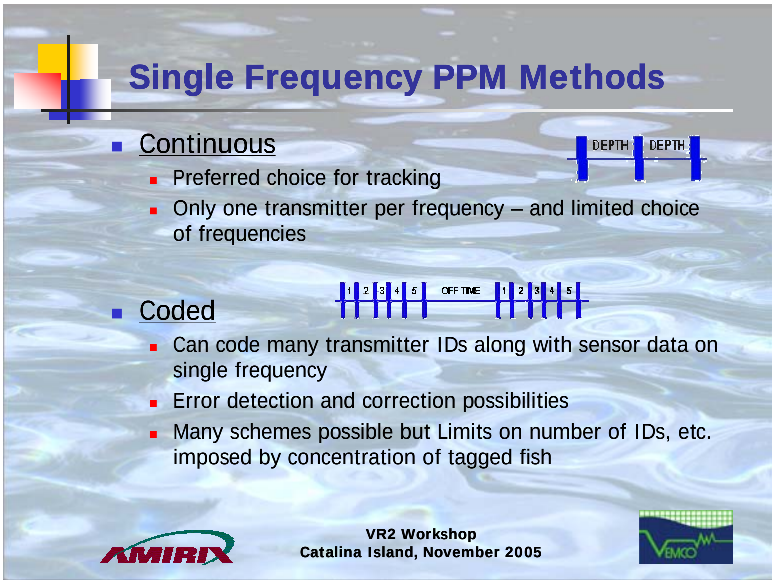
Section I

Summary of Presentation by Doug Pincock

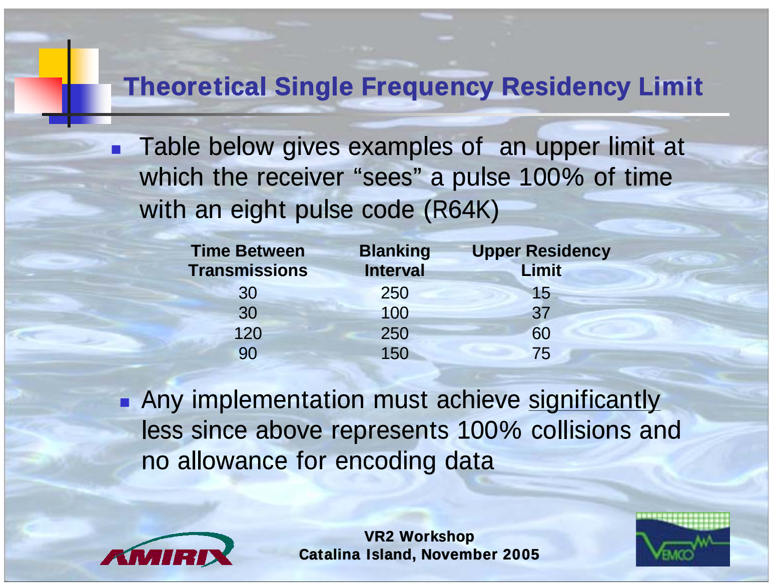
The Vemco VR2 is a single frequency receiver. This means that the unit can only hear on one frequency at a time; this system has advantages (simplicity, low power use, low cost) and limitations. In fact, it is the low power use of the receiver is the major feature that makes wide range deployment of receivers possible.



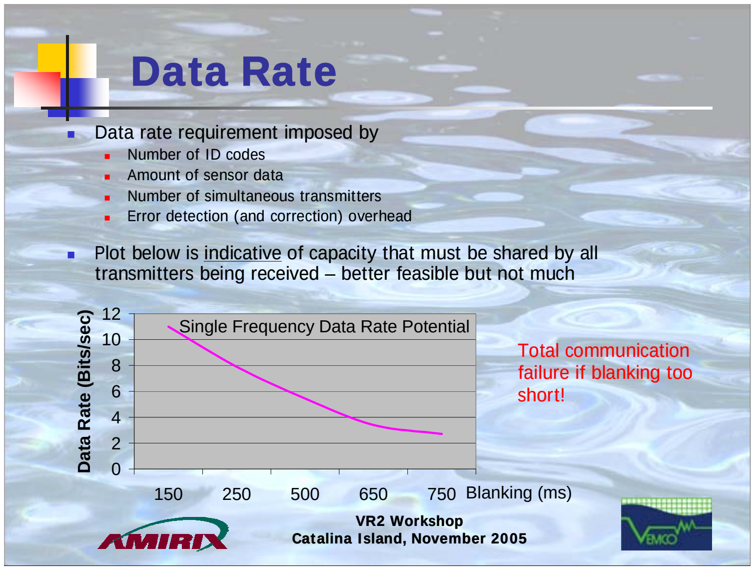
You cannot use amplitude or phase to record signals in water and echoes can cancel the signal. Therefore time between pulses (at a given frequency) is the only way to discern the signal. Variable Pulse Position Modulation (PPM) provides best option for data transfer:



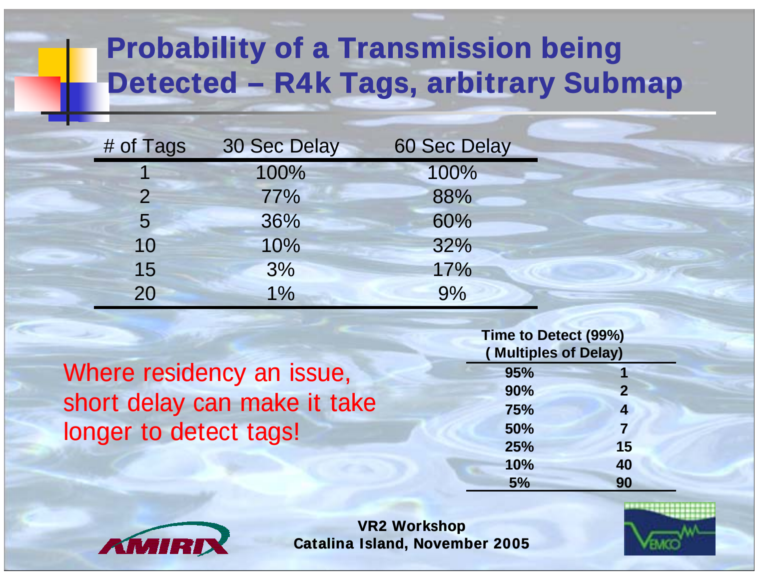
Blanking interval (i.e. the time after a pulse detection before the receiver will regard another pulse as valid) is required to allow for the echo and is a critical part of tag design.



Collisions are inevitable when more than one transmitter is present.



When a large number of transmitters are present at the same receiver a short delay is a problem. When looking at migration, short delays may be necessary, therefore repeat rate is critical to study design.



False detections:

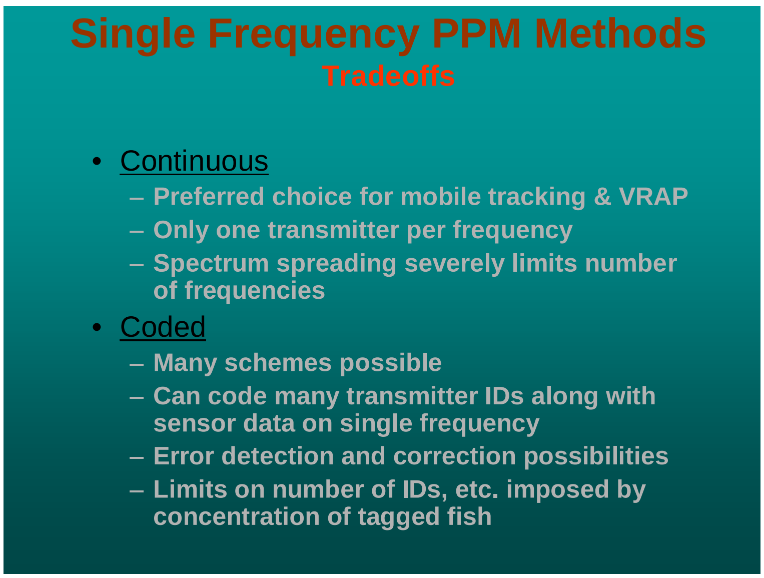
False detections occur when two tag transmissions overlap. All detections are valid, but pulses aren't all from the same tag. These are normally rejected by the 8 bit error detection code which is transmitted and recalculated within the receiver. Given that events of this kind are random, the use of 8 bit error detection implies that at least one in 256 of these false detections will appear valid. In actual fact, with the current coding scheme this probability is approximately 1 in 100. Therefore, we strongly recommend that a single detection of any code be ejected

Due to randomization of delays between successive transmissions by each transmitter and the fact that different codes have different durations actual codes appearing as “false positives” are random, the probability of the same code appearing more than once within a few hours and not being valid is very low. Quantification of these probabilities will be provided in a future “White Paper” to be posted on the Vemco website.

The VR2 has limitations; it cannot detect signal strength, only hears on one frequency, but is low cost. The new VR3s were introduced to provide remote data loading to reduce logistical problems which make the retrieval of data expensive (ship time, divers, etc.) in many applications. Two versions are now available allowing data access through acoustic modem from a surface boat and Argos satellite respectively. These more expensive units have other improvements including reception on a second frequency, larger data memory and field upgradable firmware which allows additional and more complex coding schemes to be supported.

Summary of Presentation by Dale Webber

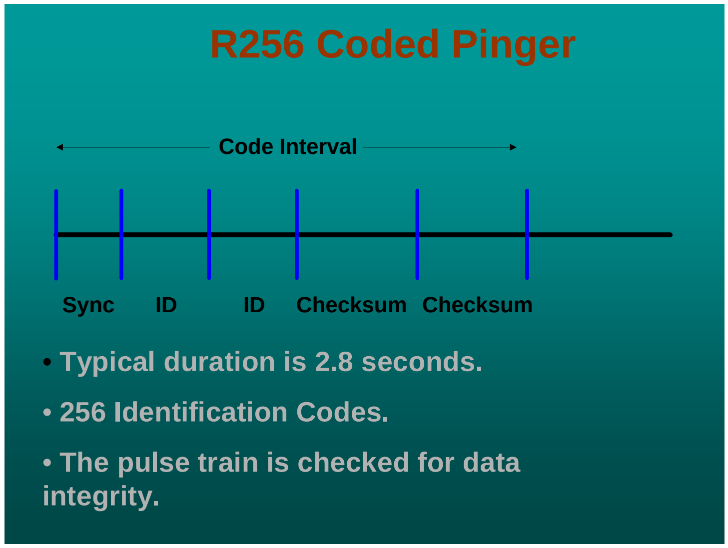
Transmitters can be coded in various ways and coding schemes provide trade-offs:

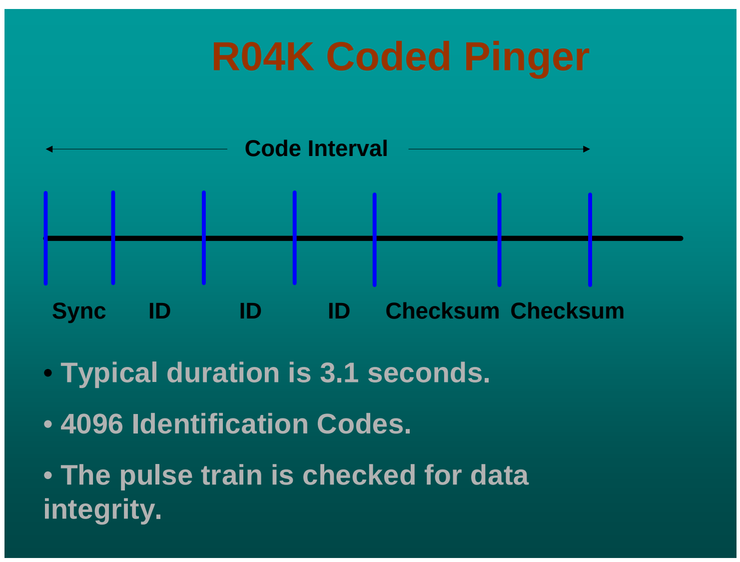


Coded tags provide advantages:

- More animals can be tagged
- Longer battery life is possible
- Can use low cost VR2 unit
- Can combine VR2 with VRAP system

Coded transmitters work on pulse intervals for each tag as shown below:





Interpreting the VR2 file output:

Data in the header file can be of critical importance to interpreting receiver performance.
*01,Dataformat
>01,1.00
*02,Filename
>02,C:\Program Files\Vemco\VR2PC\Data\VR2 2401 20050207.000
*03,S/N (serial number)
>03,2401
*04,VR2 Model
>04,VR2-069.0k-1.03-2-1432-D(SN2401)
*05,ID String (defined study location set by user)
>05,ReefA
*06,Blanking Interval (pre-set in al VR2s)
>06,300
*07,Total deployments
>07,16
*08,StartTime(yyyy-mm-dd,hh:m:ss) (based on pc time upon receiver initialization)
>08,2005-02-05,18:59:04
*09,StopTime(yyyy-mm-dd,hh:m:ss) (based on receiver time stamp from memory – and therefore is subject to slight time drift)
>09,2005-02-07,11:41:38
*10,Percentage of Memory Full
>10,0 %
*11,Total Syncs
>11,12236
*12,Checksum invalid (= number of codes rejected)
>12,773
*13,Total pulses received (= number of pings detected)
>13,58550
*14,Total detections (= number of valid codes recorded)
>14,763
*15,PC Time at download(yyyy-mm-dd,hh:m:ss)
>15,2005-02-07,11:41:48
*16,Last battery replacement(yyyy-mm-dd,hh:m:ss)
>16,2005-01-24 17:27:49

Note:

- Receivers should be time synched upon deployment/retrieval and data files should be checked for time drift (especially in long deployment situations).
- The VR2 may be in a bad location if the total pulses received are high and detections are low.
- VR2 detection efficiency can be calculated based on the number of pulses recorded and number of codes detected

For example:
Each R4k detection = 7 pings
# Detects = 58550/7 = 8364
Efficiency = 763/8364 = 9%
1 SYNC/Detection
12236-8100 MaxSyncs = Min 4200 caused by collisions or noise
773 rejected because of poor timing (collisions, noise)

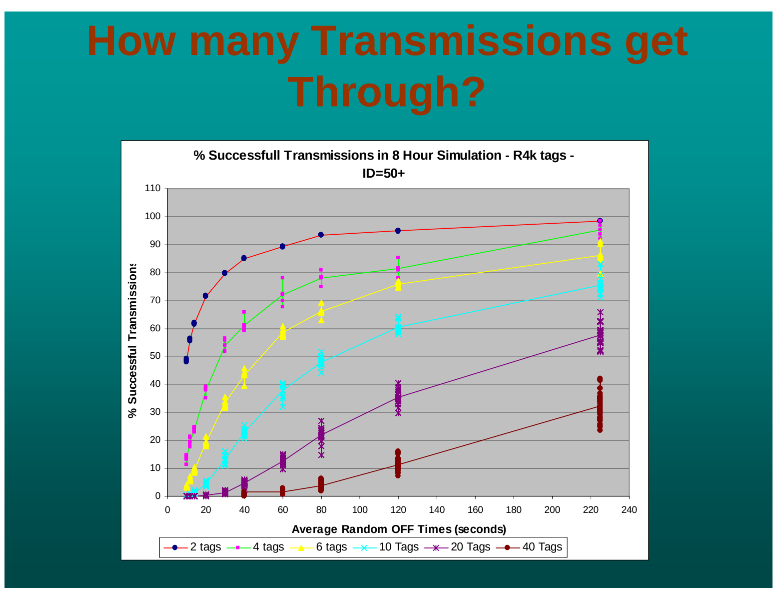
To account for time drift:
AssumeVR2 time drift is linear (This is a good assumption because, for the likely temperature variation across an array of VR2s, drift will be dominated (typically better than 90%) by differences in nominal crystal frequency

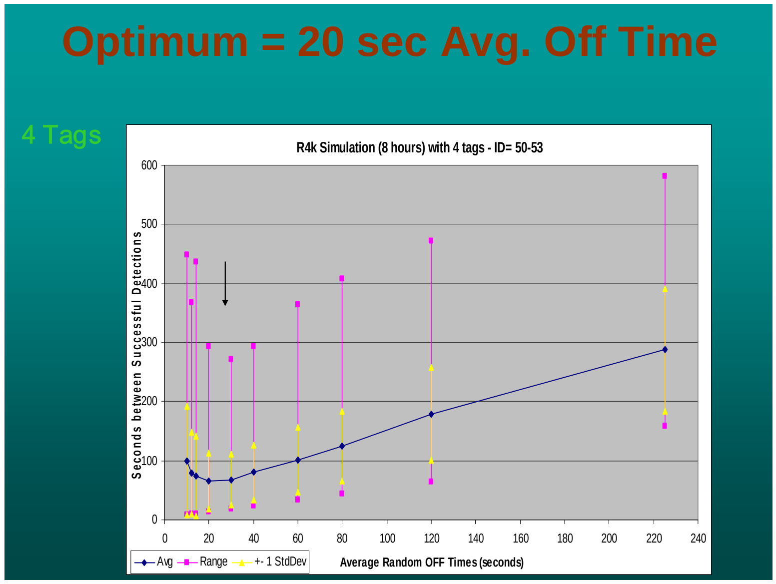
Actual detection time = VR2 Detect Time+((VR2 Detect Time-StartTime) * TIME ADJUSTMENT™)
Where: TM=(PCSTOP-VR2STOP)/(PCSTOP-PCSTART) = sec/sec

<u>Transmitter Deployment Experimental Design:</u>

What are the optimum off time settings? -Things to consider:

- VR2 spacing
- Number of VR2 fences
- Animal speed
- Residence time within detection range of a VR2
- Transmitter power output

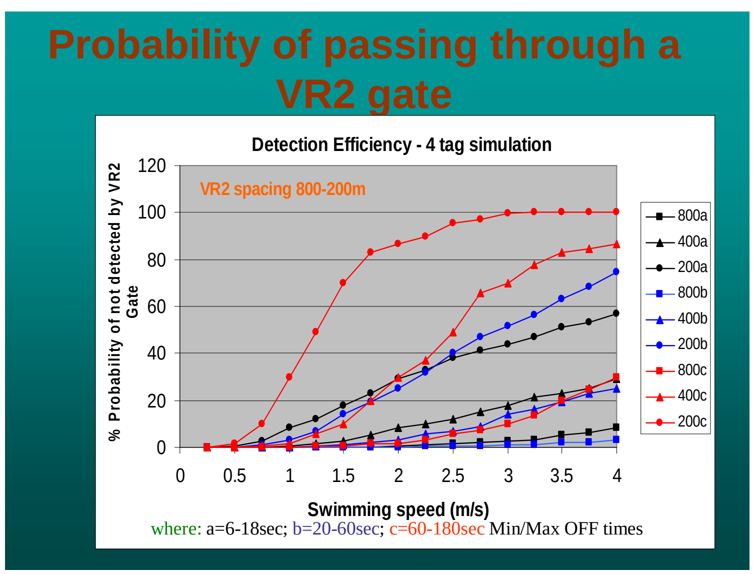




Optimum off times shift to the right as tag numbers increase.

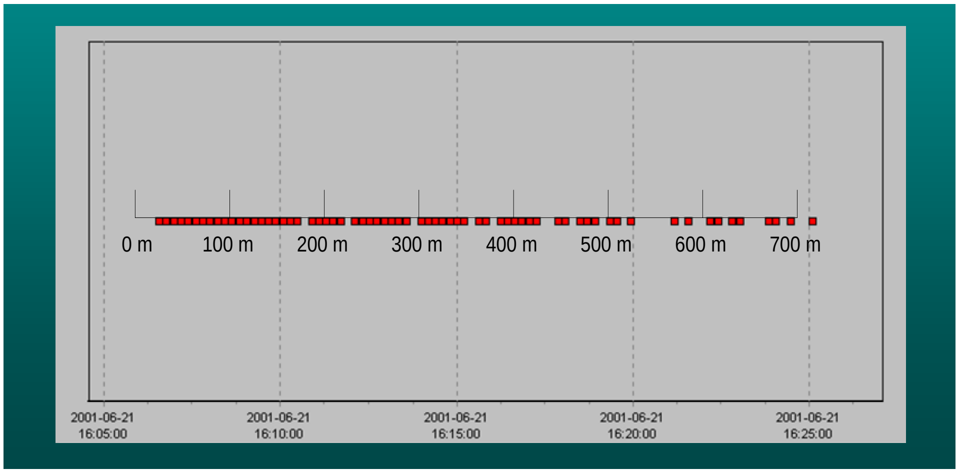
<u>Probability of detecting an individual as it passes through a VR2 gate. Users need to consider:</u>

- VR2 detection radius
- Min/Max random OFF times
- Animal swimming speed
- Number of animals within range



VR2 Range Test Recommendations:

- Time synchronize laptop computer to your watch
- Initialize the VR2(s)
- Mount VR2(s) on the mooring
- Use multiple VR2's at different depths, if desired
- Mount the pinger on a weighted rope using a short string or monofilament
- Tune the VR60/VR100 to the transmitter frequency
- Place the hydrophone in the water
- Drift slowly away from the mooring
- Use the boat radar to measure distance or use range finding binoculars
- Use the VR60/VR100 audible signal to listen for the transmitter
- Record "time" & "distance to VR2 buoy" at the end of the pulse train
- Continue to record the distance until you have exceeded practical range
- Plot VR2 Detections
- Overlay Distance to VR2 Buoy



Range testing tips/comments:

- Do not overload the system (do not use too many tags)
- Do not use many tags with short off times
- Use tags with the same power output as tags used in your study
- Use Fixed OFF times
- Do not take the last detection as your maximum range
- Look at the VR2 header file information
- Call Amirix/Vemco for advice

Amirix/Vemco response to surveyed users requests for changes to VR2 technology

Request: Smaller CHAT tags that can communicate with VR3

Reply: CHAT tag size will be decreasing in the future, but the VR2 and VR3 will not be able to communicate with it. This will still require another receiver.

Request: Ability to monitor and include environmental data in data stream

Reply: Request a list of sensors that would be useful to users and could consider integration. The VR3 can have a waterproof connection that would, with appropriate firmware modifications, allow it to be connected to another piece of equipment (e.g. hydrolab). Another possibility, if there were a common requirement, would be the incorporation of the sensor(s) directly into the unit.

Request: Truly unique ID codes (w/o extended pulse codes)

Reply: Change to 64K tag code will resolve this problem without significantly increasing the overall pulse train length. In the future, we will be offering more complex codes which would offer more codes and improved error detection. This will come slowly, but before the current 64k space is a limitation, as we need to fully evaluate performance of new, longer schemes and introduce an upgraded VR2 to support them.

Request: Integrated transponder in receiver to aid in recovery

Reply: This is a possibility, but was not discussed seriously as an option. Comments were made regarding acoustic releases and their use with VR3 technology. Vemco is taking away the message that a low cost, reliable acoustic release is the preferred approach.

Request: Ability to download in harsh conditions (e.g. PDA)

Reply: A new self contained water-resistant or smaller data downloader could be developed for use in harsh conditions to alleviate the need to carry a laptop in the field. Vemco will seriously consider providing this solution with features to be defined following more user feedback.

Request: Ability to download without retrieving receiver

Reply: VR3s have acoustic modems and may have acoustic releases, this is a future movement for this technology, but is not available for the VR2

Request: Smaller, more powerful transmitters

Reply: More emphasis has been put on “smaller” than “more powerful.” Small transmitters size of course use small batteries, which usually set the limit on the amount of power that can be generated. Note, however, that design and manufacturing improvements over the last year and continuing are resulting in some efficiency improvements so that the output power specification of some of the products is increasing.

Request: Mortality transmitter

Reply: A reliable sensor would have to be developed, so input from biologists is needed and encouraged to help if this is a real need.

Request: Ability to provide positional data

Reply: The bottom line is that the VR2 is not equipped to do this and cannot be altered to do so.

To elaborate:

1. A very rough estimate of position within a grid of receivers could be determined if the receivers provided a signal strength indication. The receiving technology within the VR2 does not permit this. However, it would be possible with a different version which would be larger and more costly – say a few thousand dollars per receiver

2. More precise location – on the order of a metre or better in some environments – would depend on receivers having their real time clocks precisely synchronized to each other. This is unrealistic for autonomous underwater receivers but this situation changes if the receivers can be interconnected or if they are on the surface (as is the case with VRAP and potential successor products)

We anticipate that future products will address both possibilities above – time frame depending to some extent on user interest.

** An additional statement was made by Doug Pincock warning against prevalent use of pingers or coded tags with delays less than 15 to 30 seconds because they will unduly interfere with (or, with pingers for example, prevent completely) reception by receivers within range. Therefore users should be extremely careful in placing short delay, long life tags in fishes that may travel long distances.

Based on discussions from this workshop Amirix/Vemco are willing to provide the following to users:

- A database of current users and the regions they are working in (*unless the user is opposed to inclusion due to privacy issues*)
- A web page where users can post scripts for database management, table templates and other free- or shareware software for handling VR2 or telemetry data
- Proposed a transition to a 64K code map to avoid transmitter overlap issues
- Improved data format and data exported from VR2s as various outputs such as a relational database format (while still maintaining the comma delimited format if preferred). *This will be ready in the fall of 2006.*
- A resource page on the Vemco website to include relevant documents and literature.

Section II

Analysis of VR2 data

The data collected by VR2s is very simple – code number and time-date stamp. Thus it is important for researchers to carefully consider the purpose of their use of the equipment and develop testable hypotheses to which the data should be applied. Because of the flexibility of the technology, and the fact that it can be arranged in many different ways it can be used to study a wide variety of biological phenomena. These investigations fall into two broad categories:

1. Relatively small scale projects that are designed to investigate specific hypotheses.
2. Larger scale projects designed as observational platforms.

These two approaches are not mutually exclusive, but analysis of data can be different in each. In addition, animals tagged for the smaller scale projects can feed into the larger scale observational projects.

Due to the wide variety of biological phenomena investigated and the recent development of this technology, there have been few publications that have described data analysis techniques, and investigators have often had to develop novel approaches. A literature search identified 29 papers in peer-reviewed publications that had used VR1s, VR2s or VR20s. These studies investigated a variety of biological phenomena, including:

- Residency or site fidelity (24 out of 29)
- Out-migration or movement (6/29)
- Mortality (6/29)
- MPA related research (5/29)
- School fidelity/aggregation (6/29)
- Habitat use/home range (3/29)
- Philopatry (2/29)

The results of the user survey presented at the workshop included an even wider variety of topics.

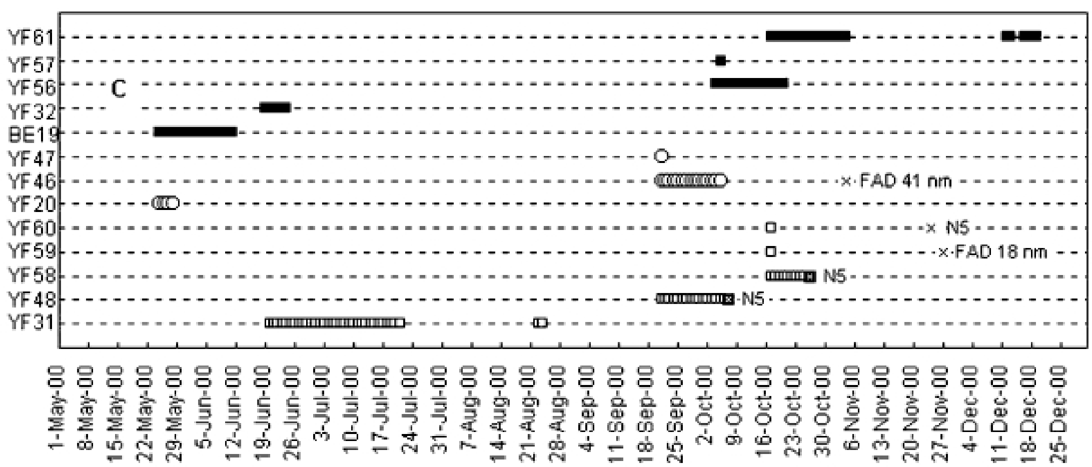
Analysis of VR2 data requires that the raw output from receivers be turned into something that can be displayed or tested with statistical procedures. Ideally an investigator would formulate a hypothesis or hypotheses that they would use the data from their receivers to answer. For example, Arendt et al. (2001) used VR1 data to test the diel presence of tautog on wrecks in Chesapeake Bay by comparing the numbers of detections between day and night. However, in some cases it is easier to qualitatively interpret the data visually.

VR2 data can be analyzed at different levels, from purely descriptive to heavily quantitative. To illustrate this diversity of analytical approaches an example based on residency studies is provided below.

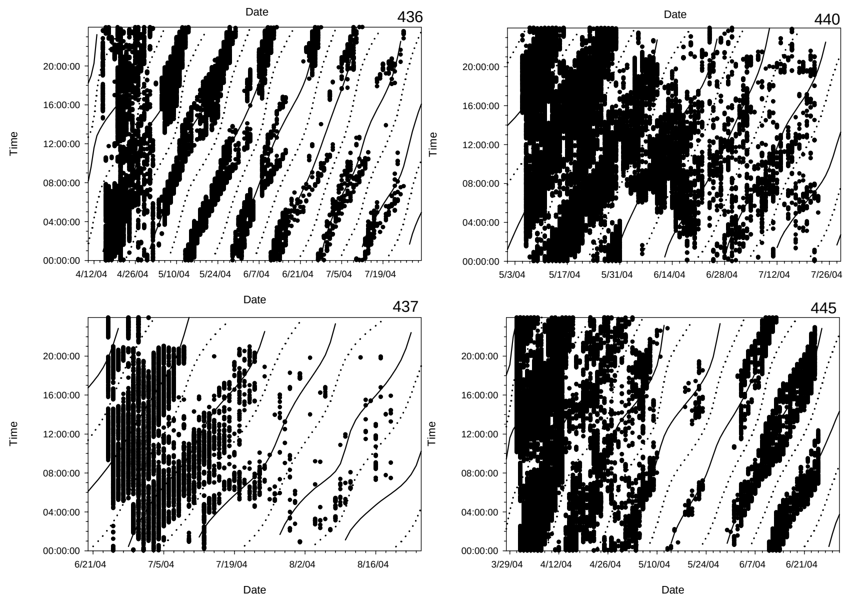
<u>Case study – analyzing residency using VR2 data</u>

There are multiple approaches to examining residency:

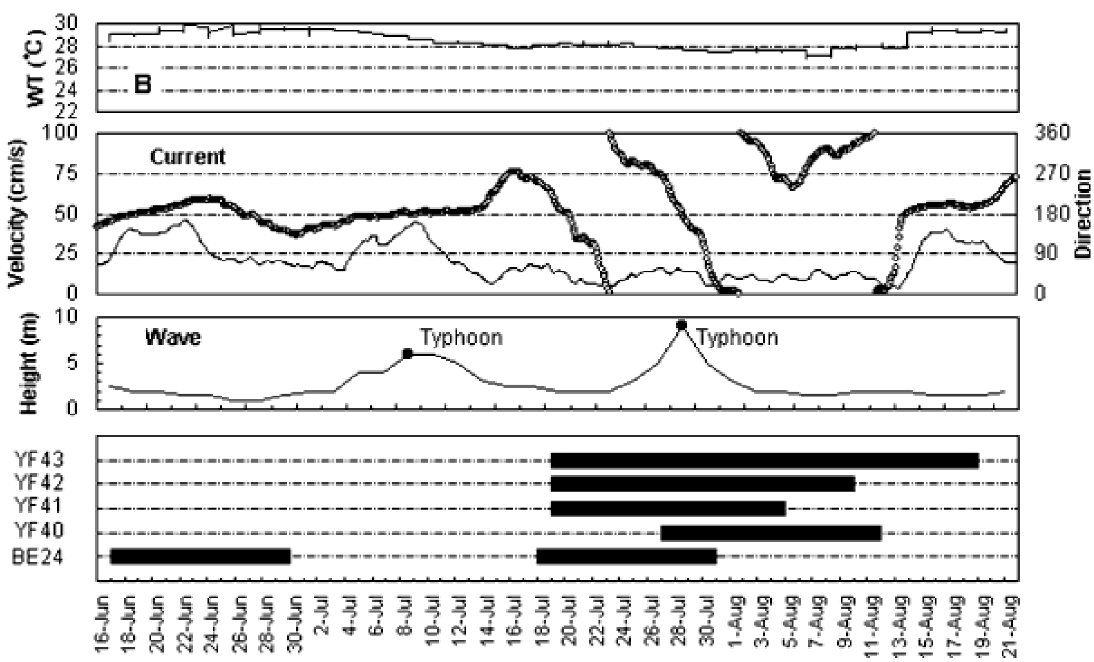
1. Visual. A common graphical approach to display residency data is the "abacas plot." This type of plot shows when individuals are present within a monitored area. The example below is for two types of tuna at FADs from Otha and Kakuma (2004).



Greater complexity can be built into the visual representation by showing the detection data as time-date plots. The plot below shows data from four juvenile sawfish (Simpfendorfer unpubl. data) and how they relate to periods of high (solid lines) and low tide (dashed lines). These plots show that the over time the pattern of occurrence at the receiver changes.



2. Visual and correlative. To help interpret the abacas plot other types of data (e.g. physical data) can be plotted along with the presence data to show correlations between changes in animal behavior and changes in other factors. In the example below the presence of tuna at a FAD is correlated with several physical factors by Otha and Kakuma (2004).



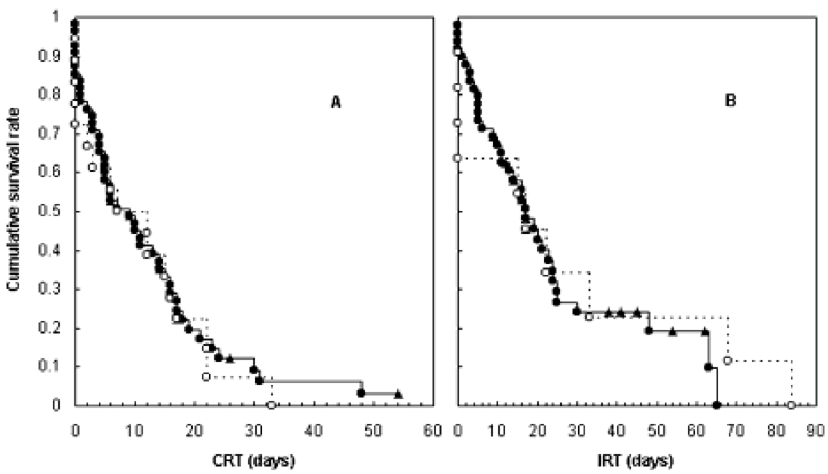
3. Quantitative analyses. The most common approach to quantitative analysis of VR2 data is to bin the hits according to one or more factors. These may include, but are not limited to:

- Time of day (e.g. hits per hour)
- Tidal height (e.g. proportion of hits within 2 hours of high tide)

- Crepuscular pattern (e.g. proportion of hits within 1 hour of sun down)
- Diel pattern (e.g. proportion of hits at night)

Once the data have been binned the proportions between groups can be tested using chi squared tests, G-tests, t-tests or others. These tests can be used for either individuals and/or for groups. For example, Otha and Kakuma (2004) used t-tests to compare the numbers of hits between day and night for individual tuna. Other more detailed analytical approaches can be used. For example, Otha and Kakuma (2004) used Kaplan-Meier survival estimation to examine the pattern of residency at FADs.

Fig. 5A, B *Thunnus albacares*, *T. obesus*. Continuous residence time (*CRT*, A) and intermittent residence time (*IRT*, B) of yellowfin (*closed symbols*) and bigeye (*open symbols*) tuna estimated by the survival analysis of Kaplan–Meier (*triangles* recapture as censored data)



In quantifying residency from VR2 data there are several things to consider:

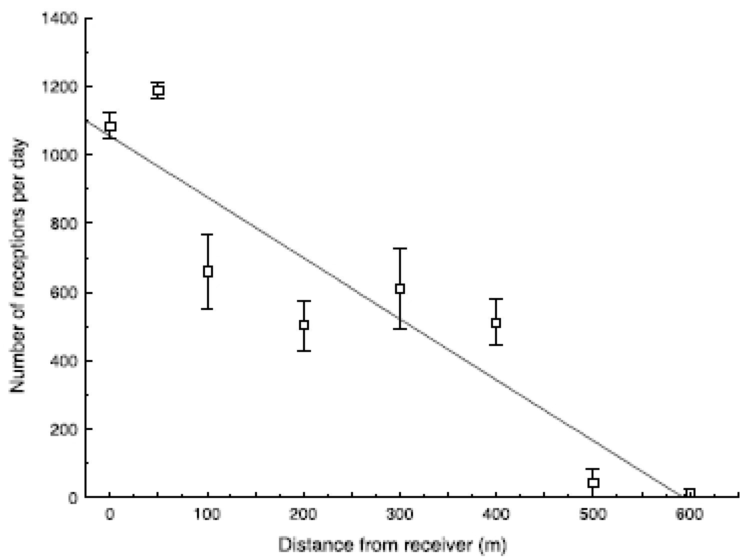
- How do you define residency?
  - Present in the receiver area for one day, one week, etc.
  - Present for a minimum number time (hours, day)
  - Present a minimum amount of each day (e.g. 12 hours per day)
- When does residency end?
  - As soon as residency conditions are not met.
  - After a set amount of time even if an individual is not necessarily present for it all
- When considering a group of individuals how do you define an overall measure of residency time?
  - The mean, median, minimum, maximum, confidence intervals.
  - Use survival analysis (see example above from Otha and Kakuma 2004 for two different measures of residency time).

In any study it will be important to clearly define these types of values based on the biology and behavior of the organism, and behavior of the equipment.

Positioning

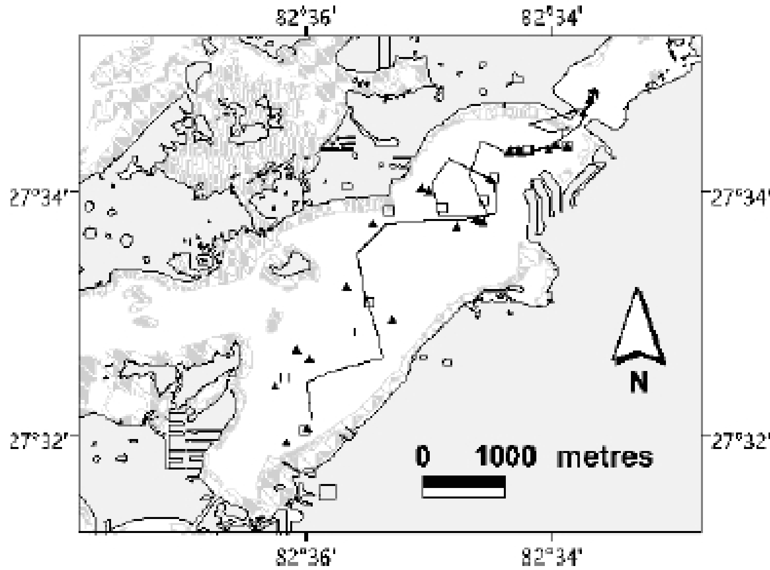
Determining the position of a tag requires that the location of a receiver is known. This simple positioning also requires that the reception distance of a receiver is known. Several authors have taken the approach of taking VR2 data and attempting to obtain information on the location of an individual at a finer scale than that of the coarse range of a receiver. This type of analysis provides the user with information that can be used in graphical and quantitative approaches, including those used more typically by active tracking studies. However, it should be pointed out that positioning will not always be successful (for a variety of reasons) and is not equivalent to active tracking data. This is the case since in doing this type of analysis data on receptions has to be combined for a defined period of time to do the calculations. As such position data more appropriately represent "center of activity" locations that provide a measure of the location during the defined time period. The most commonly used algorithm is that of the mean position described by Simpfendorfer et al. (2002).

The vast majority of studies that have employed positioning approaches to VR2 data rely on being able to determine a decay function to the proportion or number of detections received by distance from the VR2. This type of decay function is determined using range tests that record the number of detections at set distances. As an example the range test on which the positioning algorithm of Simpfendorfer et al. (2002) is based is given below.



Once this relationship is known it is possible to determine the mean distance an animal is from a receiver based on the number of detections per unit of time. This assumes that an individual is not moving a long distance during the unit of time. During the workshop there was a long discussion about range testing and whether the relationships observed using range tests that show decreasing detection rates with increasing distance from a receiver. Another approach to this is that used by Simpfendorfer et al. (2002) is to use a weighted mean position that assumes that if an individual is heard on several receivers then the distance from each of the receivers will be proportional to the inverse of the number of detections. Once these types of positioning algorithms have been implemented it is important that they are ground-truthed. This can be achieved by double tagging fish with tags for passive monitoring and active tracking or by towing a tag or tags with a boat in a manner similar to that which the study species moves (see the example below).

Fig. 6. Mean-position estimates based on Δ_r = 15 min (solid triangles) and Δ_r = 30 min (open squares) from a simulated shark track (solid line). Simulated track data were produced by towing a transmitter behind a small vessel powered by an electric trolling motor. Cross-hatched areas indicate seagrass habitat.



Doug Pincock (Vemco-Amirix) indicated that the declining relationship between signal reception and distance was not consistent with the way the VR2 should work, which should be a consistent rate of detection followed by an almost vertical drop off in detections moving away from the VR2. Several participants discussed their experience with determining these relationships and what the data actually represents. It was pointed out that even though the VR2 did not theoretically work in this way, the reality was that these relationships have been reported with some regularity. However, James Lindholm reported that in high relief areas this type of relationship does not always occur.

Dou Pincock responded by stating that Vemco was not questioning field results obtained and planned to develop a paper which would give users more insight on variability of detection rate with range.

Once positioning data have been calculated and ground-truthed they can be used in a variety of ways, more along the lines of (but not exactly like) active tracking data:

- Site fidelity test
- Home range analysis
- Habitat utilization
- “Behavioral” studies
- MPA research

Long distance movement analysis.

In situations where VR2s are arranged in lines, curtains or gates the purpose of the research is often to demonstrate movements. This type of work has been carried out with out-migrating salmon smolts over varying scales. Work by Lacroix et al. (2004a) and Lacroix et al. (2005) examined the out-migration of Atlantic salmon on a relatively small scale in the Bay of Fundy, while the new POST project (Welch et al 2002) plans to track smolts along most of the west coast of North America. With this type of approach the distances traveled, migration routes, timing of travel (especially for out-migration) and rate of movement can be studied.

Analysis of this type of data can be based heavily on traditional mark-recapture studies as the data form is similar. However, there are a couple of important differences:

- There is no bias caused by non-uniform distribution of recapture efforts that has made traditional tag-recapture data difficult.
- When many lines of receivers are used the data are equivalent to individuals that are recaptured and released alive multiple times, improving the amount of data recovered from individual fish.
- The spatial resolution is a function of the number and spacing of the lines.
- The probability of recapture of individual tags by a line of receivers must be known to correct for those that cross lines but are not detected because of code collisions, gaps in the receiver line or rapid movement across the line.

This type of analysis will often produce fewer lines of data per receiver because individuals are only present near a receiver for a short period of time. Because of this there is a higher probability of false detections occurring and researchers must be cognizant of this fact when determining which data to include in analyses.

The types of analysis in addition to movement that can be carried out with the same type of data include:

- Survival analysis. Data can be used to determine the survival rate during migratory events.
- Exact timing of adult salmon migration into natal rivers. By using long life tags the time, date and location of homing migrations can be examined.
- How environmental factors can influence migratory routes. By comparing routes between years and superimposing them over physical data it is possible to at least qualitatively assess how they can change the pathways used by migratory stocks.

Other used of VR2 data

Data from VR2s has already been used to investigate a wide variety of studies which were not discussed in any detail in the session. These include:

- Mortality/survival
- School fidelity
- Philopatry
- Marine protected area analysis (e.g. proportion of time in or out of a reserve)

The techniques for analyzing VR2 data for these types of approaches have been published.

Future needs for data analysis

In discussions it was pointed out there are few published techniques for analyzing VR2 type data, which makes getting papers published more difficult because reviewers are unfamiliar with the data and how they should be analyzed. It would therefore be prudent for VR2 users to develop a set of standard techniques to assist in this regard.

Section III

Study Registry, Data Management and Databases

Study Registries

Mike Arendt presented data regarding a study registry and commented on the database of telemetry users compiled by Ron O'Dor to define the number and location of VR2 users.

General Info Fields included in these databases are:

- Project Name
- Contact information
- Study species
- Life history stage
- Study location
- Region/state
- Country
- Ocean basin

Specific Information that can be included:

- Equipment manufacturer
- tag/type mode/freq
  - ID and serial number (keeping in mind IDs could be the same within and across companies)
- low and high tag number (ID and serial)
- tags and activate and anticipate expiration
- tag attachment method
- tag comments
- manual tracking
- automated tracking
- publications

Mike's survey of users revealed:

- 24 species with replicate studies (2 -5 replicate studies)
- > 76 pioneer studies with new species

Manufacturer compatibility may be critical in some regions
For example:

- Studies examining the same species in same area (e.g. bull sharks in FL)
- Hindrance of combined efforts: Multiple species in the same area may cause problems (San Diego, NC, ME)
- Advantage: Expansion of coverage (FL, GA, VA CT, ME)

Data Management, Database, Reduction

Data management
What is needed from the database?

- Ability to import raw data from receivers
- Ability to save imported animal data and correlate it with recorded metadata
- Easily query data for individuals, regions, etc.

Questions about data management:

- Is or should there be a standardized database template out there to do this?
- Can/should Vemco provide something like this for users?
- Can users help each other out or is there a need for each group to reinvent the wheel on their own?
- Potential resource webpage? Freeware style site similar to other shareware files for analyzing data (i.e. radio telemetry analysis sites)

There are currently several websites for people who do radio tracking (ecological software/shareware websites), although there is no user support for these programs, they are available for download.

Data Reduction
Need:

- to distill 1000s to millions of lines of data into something that is useful?
- do you have to?

Comments

- this is especially true for studies with large numbers of receivers
- binning of numbers of detections (e.g. number per hour) can be effective
- positioning algorithms can be applied in some situations

Doug Pincock replied that Vemco is in the process of producing improved VRPC software to help expedite importation of raw receiver data into a database. This software will be standard equipment with new receivers once it is developed and can be distributed to existing users. The program will provide users several options for data export format to aid in databasing and data reduction efforts.

Several Access templates will be posted on the Vemco website and Vemco has expressed willingness to support and host a website that will provide a means for users to swap programs and database information.

Users will continue to develop database options and these will continue to require customized approaches to meet the varying goals of the studies utilizing this technology.

Software:

Several groups are currently developing analysis and display software for handling VR2 data. None of these programs are available to users at the time, but within the next year one or more programs are likely to be available for sale or as freeware for users. These programs have a variety of end results and users will have to determine what application is best suited to their data needs and/or if custom software packages must continue to be developed.

Resolution on coded acoustic tags

Whereas long term research utilizing coded passive acoustic telemetry has been growing rapidly in popularity such that it is now occurring throughout coastal and oceanic environments worldwide.

Whereas the results of this research are producing vital information that is being used to improve the management of aquatic resources and understanding of aquatic ecosystems.

Whereas the use of a small number of frequencies enables the cooperation and collaboration of scientists worldwide by allowing them to detect coded tags from other researchers, increasing the geographic range over which coded tags can be detected and logged.

Whereas the validity of the results from individually coded tags relies on there being no uncertainty about the identity of the animals to which tags are attached.

Whereas tag manufacturers must ensure that tag codes provided to researchers will not result in two identical codes ever occurring in the same geographic area, even if only remotely possible, given that many species over the long term may travel large distances even if in the past these types of movements have never before been observed.

Whereas the production of cloned tags by third-party manufacturers will potentially result in the release of animals with the same codes in the same geographic area, thereby invalidating the results of each of these studies.

Whereas researchers must understand that duplicate codes in the same region may reduce or inhibit their ability to draw valid conclusions and produce peer-reviewed publications based on their data.

Therefore let it be resolved that the attendees at the November 2005 passive acoustic telemetry workshop strongly encourage researchers to not utilize cloned acoustic tags that do not ensure the existence of duplicate tag codes such that the results of their research are valid and can be published in peer-reviewed publications. Furthermore, manufacturers of cloned tags should be required to fully disclose the possibilities and implications of duplicate codes to individual researchers and the research community as a whole.

Workshop Participants

Workshop Participants

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Survey Form

VR2 Telemetry workshop at Wrigley Institute of Environmental Science

All participants are asked to complete the following questionnaire. Information from the questionnaire will be used to compile a pdf to be provided to all participants prior to the workshop and will be used in our discussions. All responses and documentation will only be used for the purposes of this workshop and will not be published or distributed beyond meeting participants.

Your name and institution:
Contact information:
Study species:
Study location:
Amount of area monitored:
Length of monitoring period: (i.e. 3 mos, 6 mos, etc.)
Number of receivers deployed:
Number of transmitters deployed:

Description of your method: Independent widespread units to detect presence absence; line, gate or curtain to monitor passage/migration; grid or other array type

Research purpose: (i.e. migration studies, home range analysis, site fidelity, behavior, etc.)

What is your data management strategy? (i.e. Access database file, etc.)

What data analysis techniques have you applied to your VR2 data? What approaches would you like to employ in the future?

What software do you use to analyze your data?

Do you visualize your data and if so how? (i.e. ArcView, mapping software, animation programs, etc.)

What do you see as the limitations of the current technology? What problems are you/have you had with the current technology?

Where would you like to see the technology go/what additional options would you like to have?

On a scale of 1 to 5, how satisfied are you with current VR2 technology and methodology (5 = extremely satisfied)?

Finally we would like to request an abstract (paragraph) about your VR2 projects. Please feel free to include up to 2 figures per project.

Pre-workshop survey summary

Workshop Vital Statistics:

Number of meeting participants: 20 + 2 Amirix/Vemco staff

Number of survey forms returned: 20

Species fitted with transmitter based on survey results:
- Over 50 species of teleost, 21 species of elasmobranch and 2 cephalopods
- most common: elasmobranchs, salmon, rockfish, lingcod, sturgeon, cod

Locations of study: West coast of North America, Washington estuaries, Puget Sound, San Francisco Bay, Central California coast, Southern California Bight, Channel Islands, San Diego, Hawaiian Islands, Belize, northern Gulf of Mexico, central Gulf coast of Florida, Florida Everglades, Florida Keys, Gulf of Maine, Bay of Fundy, the Indian Ocean (Seychelles), Tasmania and the Northern Territory (Australia)

Area monitored by acoustic systems: 1 – 1610 km^2 and a linear array covering 2600 km; POST program covering 1550 kms with 150 km lines

Length of monitoring period: 4 months to 4 years

Number of receivers deployed:
- Total currently or previously deployed by the group = 1,318, projected to be over 1,400 by 2007
- Range: 6 – 200
- Most studies use 50 - 100

Numbers of transmitters deployed:
- Total currently or previously deployed by the group = 7,415, projected number by 2007 c. 13,700+
- Range: 12 – 3,750
- Most studies deploy c. 100 per year

How satisfied are you with the current technology: most users rated the current technology at 4 out of 5 but felt that the methodology lagged behind somewhat

Deployment types and project objectives:

Methods of deployment:

Gate	8
Grid	5
Grouped	3
Independent units	9
Lines	12

Purpose of research:

Assess stock enhancement efforts	1
Behavior	9
Contaminant exposure	1
Critical habitat identification	2
Habitat use	8
Homing	2
Home range	10
Marine reserve	4
Migration	10
Movement between FADs	1
Movement patterns	4
Presence-absence	2
Residency	3
Response to environmental change	2
School fidelity	1
Site fidelity	14
Species interaction	1
Survival	5
Timing of use	4
Technological advancement	1
Vertical movements	1

Data Management:

Data management is completed via:

Access	11
Excel	10
Oracle	4
Standard stats package	2
No method	2

Data analysis techniques applied by users:

Analysis techniques applied include but are not limited to:

Mortality analysis	Distribution analysis	Circular analysis
Time series analysis	Time of detection	Nearest neighbor analysis
Spatial analyses	Detection in relation to water quality	Position averaging
Linear regression	Fourier analysis	Fate models (Program MARK)
Multivariate statistics	Chi-square	Random walk models
ANOVA	t-test	Home range (kernel, etc)
GLM	G-test	

Comments:
We want to fit the data into a database framework that will allow direct extraction using standard SQL queries (through a user friendly front end) and application of standard mark-recapture software and statistical packages (MARK, R or S-Plus, SAS)

Need more sophisticated approach to analyze distribution data along lines of monitoring receivers to test against various distribution models; need to develop theoretical distribution models that incorporate environmental data (e.g., currents, temperature). Need models that can overlay distribution data and environmental data to facilitate analysis. There is a need to incorporate receiver efficiency into the error of data analyses or in the error associated with estimates (e.g., survival).

More geostatistical analyses to determine movement and flux rates for input into spatial dynamic multispecies models.

Software:

Software programs used for analysis:

21 different programs or types of program have been identified by users.

ACON (private)	1
EASy (to be released)	1
Excel	10
GIS	2
LabView	1
MapInfo	1
MathCad	1
MatLab	4
Minitab	1
MVSP	1
RATTRAP (private)	1
S-Plus	2
SPSS	1
SAS	4
SigmaStat	1
Statistica	3
SURVIV	1
Systat	3
Unidentified database	1
Unidentified stats package	3
Zippi	1
None	1

Software used for visualization: most users reported using ArcView (or ArcGIS), but other programs (including custom software) are being used such as: ACON, ArcMap, DART, EASy, Interactive Data Language (IDL), MapInfo, Mapsource (Garmin), MatLab, RATTRAP

Limitations of current technology:

- Code overlap across studies (5 users)
- Variation in signal range over time and conditions (4 users)
- False detections (4 users)
- Difficulty in data retrieval/receiver recovery (3 users)
- Signal collision (2 users)
- Biofouling (2 users)
- Transmitter size (too large) (2 users)
- Code management across studies (2 users)
- Inability to adjust gain to increase/decrease detection range (2 users)
- Only works on a single frequency (2 users)
- Lack of standardized data management and analysis software/methods (2 users)
- Data retrieval (2 users)
- Code pulse duration for higher code schemes
- Too many hits from sedentary individuals (would like a disregard time programming ability)
- Unit failure, flooding
- Transmitter detection in stratified conditions
- Range of transmitter detection
- Number of unique tag codes available
- Drift in time stamp
- Effects of noise sources on detection
- Conflict with fisheries and the public (gear destruction, loss)
- Need to carry a laptop on board
- Inability to hear other transmitters (e.g. Lotek) and vice versa
- Deployment/recovery costs - technology needs to improve for receivers to provide consistent results; the costs of deployment/recovery often far exceed the cost of receivers.
- Inaccurate operational information - parameters often appear to be calculated rather than empirically derived. For instance, I and my colleagues have regularly recorded more than 4 times the estimated battery life for acoustic transmitters (including V8s, V16s, and V32s). One batch of V8SCs sat on the shelf for 3 years and were predicted to be dead, but in-fact have provided more than 2 months of data and are still transmitting. I recognize the need for VEMCO to be conservative in their estimates, but a more realistic estimate of battery life would make planning for studies easier. Another example is the phenomenon of code collisions. I have deployed multiple tags within the range of particular VR2 receiver and do not appear to be losing data at anything close to the rate estimated by VEMCO.
- Limited range of detection - requires a high density of monitoring receivers in open marine habitat. The large number of receivers needed in marine studies requires a large-scale and expensive effort for data and receiver recovery, especially in marine situations with severe conditions.
- Lack of standardized testing of receiver and array efficacy - (e.g., efficiency of a line of receiver in a certain habitat based on deployment method, location, depth, etc…).
- Battery failure

What users would like to see added to current technology or developed in the future:

- Smaller CHAT tags that can communicate with VR3 (6 users)
- Ability to monitor and include environmental data (temperature salinity) (3 users)
- Truly unique id codes (without very extended pulse codes) (3 users)
- Integrated passive transponder within the receiver to aid receiver recovery in low visibility or if loose from mooring (3 users)
- Ability to provide positional data (so larger area can be monitored than with VRAP) (3 users)
- Ability to download in harsh conditions (rough seas, salt spray, open boat) (e.g. PDA rather than a laptop) (2 users)
- Ability to download without retrieving the receiver (2 users)
- Wireless communication with the receiver (2 users)
- Smaller, more powerful transmitters (2users)
- Transmitters that can report whether an individual is alive or inside a predator (2 users)
- Ability to change batteries in harsh conditions (redesigned battery pack)
- Different housing options for deployment options (e.g. a flatter unit for use in shallow conditions)
- More sensor options on transmitters (e.g. smaller pressure tag)
- Ability to "save files as" or "export files" from VR software to make it easier to analyze and handle data
- Gain control of the receiver to allow the ability to tune to obtain better spatial resolution
- Cheaper deployment options (e.g. cheap acoustic releases)
- Record of total time a receiver is deployed to help assess when batteries need to be changed
- Deployment and retrieval options for high energy environments and better methods of attachment
- Single seamless telecommunications network with VR2 as one key sensor within an observation array and used to provide an essentially perfect monitoring network of fish movement and survival
- A VRAP system that can cover more area - downloading large array is time consuming. Cable connection to a base station would be very useful and would allow real-time data collection.
- Long cables connected to monitoring nodes for use on open seas, surface node that can collect data from multiple units at regular intervals and transmit back
- Remote access to data
- Information on distance of an individual from the receiver
- The ability to detect and record transmitters made by other manufacturers and vice versa
- Remote warning of battery usage, impending failure
- Wet/dry sensor switch to initialize unit when deployed in remote locations.

Table of study species

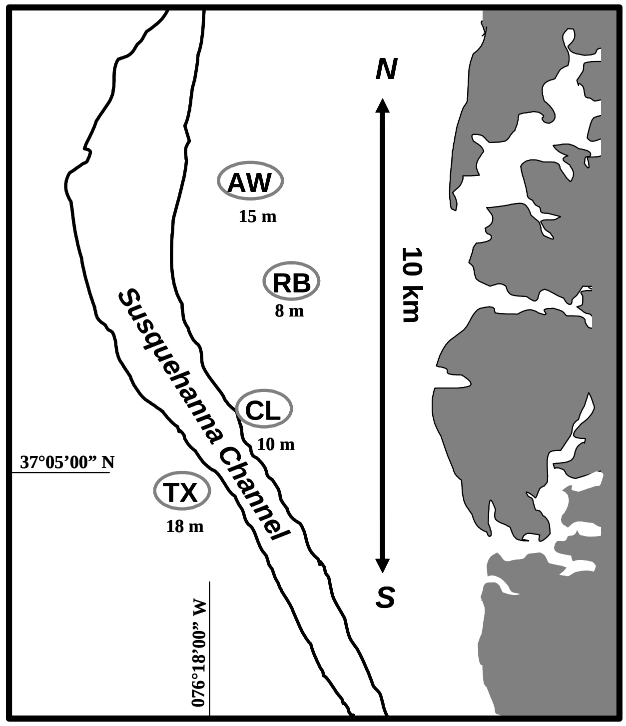
Species	Investigator	Region
Acadian redfish	James Lindholm	Gulf of Maine
American eel	Dewayne Fox	Delaware Bay and River
Atlantic cod	James Lindholm	Gulf of Maine
	Gilles Lacroix	Bay of Fundy/northern Gulf of Maine
Atlantic salmon	Gilles Lacroix	Bay of Fundy/northern Gulf of Maine
Atlantic sharpnose shark	Michelle Heupel	Florida panhandle
Atlantic sturgeon	Gilles Lacroix	Bay of Fundy/northern Gulf of Maine
	Dewayne Fox	Delaware Bay and River
Barred sandbass	Chris Lowe	Southern California Bight
Bigeye tuna	Laurent Dagorn	Indian Ocean and Hawaii
Black bream	Jayson Semmens	NT, Australia
Black grouper	James Lindholm	FL Keys
	Jerald Ault	South Florida and FL Keys
Black jewfish	Jayson Semmens	NT, Australia
Blacktip shark	Michelle Heupel	Terra Ceia Bay, FL
Blacktip reef shark	Chris Lowe	Palmyra Atoll
Bonefish	Chris Lowe	Palmyra Atoll
	Jerald Ault	South Florida and FL Keys
Bonnethead shark	Michelle Heupel	Charlotte Harbor, FL
Blue parrotfish	James Lindholm	FL Keys
Blue rockfish	Chris Lowe	Southern California Bight
Bococcio	Chris Lowe	Southern California Bight
Bull shark	Michelle Heupel	Charlotte Harbor, FL
Bull trout	Fred Goetz	Puget Sound
California sheephead	James Lindholm	Channel Islands, CA
	Chris Lowe	Southern California Bight
California halibut (cultured)	Mike Shane	San Diego
Cabezon	Rick Starr	Central California
	Chris Lowe	Southern California Bight
Copper rockfish	Chris Lowe	Southern California Bight
Chinook salmon	Tom Keegan	San Francisco Bay
	Fred Goetz	Puget Sound
Coho salmon	Fred Goetz	Puget Sound
Coral reef species	Carl Meyer	Hawiian Islands
Cutthroat trout	Fred Goetz	Puget Sound
Cownose ray	Michelle Heupel	Charlotte Harbor, FL
Draftboard shark	Cynthia Awruch/Jayson Semmens	Tasmania
English sole	Mary Moser	Puget Sound
Galapagos shark	Chris Lowe	Hawaii
Giant trevally	Chris Lowe	Hawaii

Gray reef shark	Chris Lowe	Bikini Atoll
Green sturgeon	Mary Moser	Willapa Bay, WA
Greenspotted rockfish	Chris Lowe	Southern California Bight
Grey Nurse shark	Barry Bruce et al.	Southern Australia
Grouper	Rick Starr	Belize
Hogfish	James Lindholm	FL Keys
Kelp bass	James Lindholm	Channel Islands, CA
	Chris Lowe	Southern California Bight
Lemon shark	Michelle Heupel	Charlotte Harbor, FL
Leopard shark	Chris Lowe	Southern California Bight
Lingcod	Stephen Katz	WA/Puget Sound
	Rick Starr	Central California
	Chris Lowe	Southern California Bight
Mahi mahi	Laurent Dagorn	Indian Ocean and Hawaii
Mexican rockfish	Chris Lowe	Southern California Bight
Ocean whitefish	Chris Lowe	Southern California Bight
Octopus	Jayson Semmens	Tasmania
Princess parrotfish	James Lindholm	FL Keys
Rainbow trout	Fred Goetz	Puget Sound
Red grouper	Jerald Ault	South Florida and FL Keys
Red snapper	Steve Szedlmayer	Northern Gulf of Mexico
Rockfish	Stephen Katz	WA/Puget Sound
	Rick Starr	Central California
Round stingray	Chris Lowe	Southern California Bight
Salmon	David Welch	West coast of North America
Sandbar shark	Dewayne Fox	Delaware Bay
Sevengill shark	Stephen Katz	Willapa Bay, WA
Silky shark	Laurent Dagorn	Indian Ocean and Hawaii
Sixgill shark	Stephen Katz	Puget Sound
Smalltooth sawfish	Colin Simpfendorfer	Florida Everglades
Skipjack tuna	Laurent Dagorn	Indian Ocean and Hawaii
Southern bluefin tuna	Alistair Hobday	Southern Australia
Southern stingray	Michelle Heupel	Charlotte Harbor, FL
Squid	Jayson Semmens	Tasmania
Steelhead	Tom Keegan	San Francisco Bay
Tautog	Mike Arendt	Chesapeake Bay
Tiger shark	Chris Lowe	Hawaii
Vermillion rockfish	Chris Lowe	Southern California Bight
Wahoo	Laurent Dagorn	Indian Ocean and Hawaii
White seabass (cultured)	Mike Shane	San Diego
White shark	Barry Bruce et al.	Southern Australia
Widow rockfish	Chris Lowe	Southern California Bight
Yellowtail snapper	James Lindholm	FL Keys
Yellowfin tuna	Laurent Dagorn	Indian Ocean and Hawaii

Participant Abstracts

Michael Arendt, South Carolina Department of Natural Resources

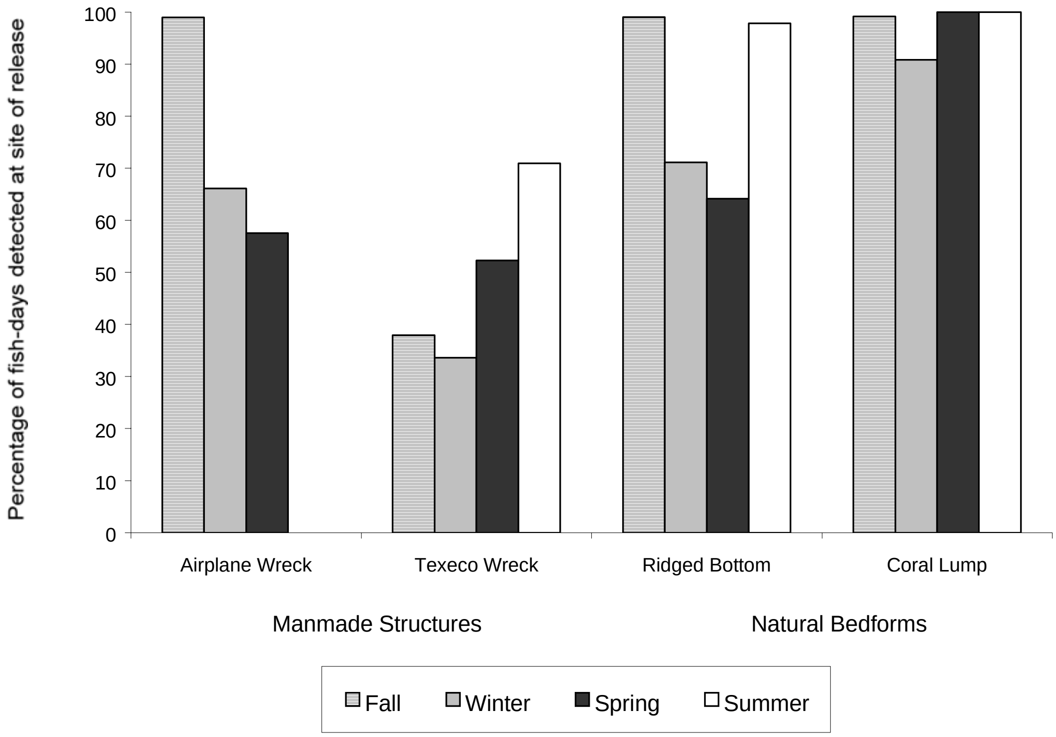
Tautog (*Tautoga onitis*) is a highly prized game fish targeted by anglers fishing at natural and manmade structure (Briggs 1977, Lucy & Barr 1994) between Massachusetts and Virginia. Capture and recapture data suggest regional differences in seasonal distribution and activity patterns of adult tautog within this species' geographic distribution. North of New York, adult tautog are rarely encountered inshore in winter, and most tag return data indicate a seasonal inshore-offshore movement of adults in the spring and fall, respectively (Cooper 1966, Briggs 1977; Lynch 1995). Conversely, in Virginia and Maryland tautog are caught year round (Hostetter & Munroe 1993; Eklund & Targett 1991; White et al., 1997).



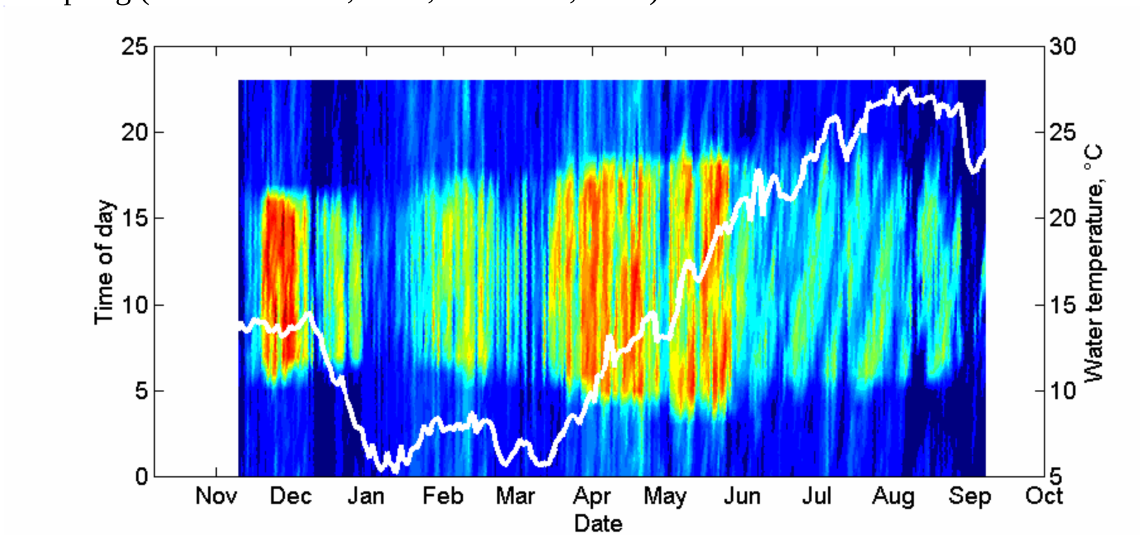
To better understand the seasonal distribution and activity patterns of adult tautog in Virginia waters, an ultrasonic tagging and monitoring study conducted from Nov 1998 to Sep 1999. Two manmade (TX, AW) and two natural habitats (CL, RB) known to support tautog, were selected for this study. Two automated acoustic receivers (VR1; Vemco, Ltd.) were deployed at each of the four sites to ensure continuous monitoring within a 400m radius of each site. Coded acoustic transmitters (V16-1H-R256) were surgically implanted into tautog (400-514 mm TL) in two batch efforts in the fall (n=16) and spring (n=11), such that the total number of tagged animals per site was 4 to 8.

Ninety-three percent (n=25 of 27) of tautog remained inshore within the Chesapeake Bay throughout the entire study, including winter and summer, when studies conducted from more northern waters have documented inshore-offshore migrations (Cooper 1966, Briggs 1977; Lynch 1993). Over-wintering in Chesapeake Bay could not be documented for one tautog released in the fall; however, this fish was recaptured the following spring within 10 km of where tagged and released. One tautog released in the spring traveled south and exited the study area within a week of release and was not detected again.

Overall residence (i.e., percent of days detected at release site) at natural sites was greater than residence at manmade sites. Seasonal differences in detections at the largest natural site (CL) were only noted during the winter. Seasonal detections for the smaller natural site (RB) were considerably less in winter and spring; however, it was unclear as to whether fish left this site or transmitters failed prematurely. Seasonal residence at both manmade sites was highly variable among seasons and, conversely to tautog tagged at natural sites, several tautog tagged at manmade sites were detected elsewhere.



Diel activity patterns were noted for tautog at all study sites, with occurrence of detections closely associated with sunrise and sunset times. Seasonal changes in activity were also inferred from changes in the absolute number of hourly detections each day. Overall detections were greatest during the late fall/early winter and again in April-May. Increased detections may have been related to increased use of the water column (and therefore improved detection capability) associated with preparation for over-wintering in the fall and spawning in the spring (Olla and Samet, 1977; Olla et al., 1980).



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Jerald Ault, University of Miami

Study 1A.- We used an acoustic telemetry system to test the hypothesis that the bonefish *Albula vulpes* exhibits site fidelity in selection of foraging areas in the northern Florida Keys. Stationary hydrophone receivers with data-logging units were deployed surrounding a discrete bonefish foraging area. Individuals were captured, fitted with acoustic transmitters, and then released within the study area. The reception ranges of receiver stations within the array were evaluated by moving a transmitter within the array. These data were used to assess spatial coverage of monitoring and decipher fine-scale movement patterns from recorded presence–absence data: 64% of tagged fish were detected by receivers for multiple days following release. Tagged fish frequented the experimental area for periods ranging from 3 to 61 d. Only 2 individuals, tracked for 48 and 61 d, demonstrated site fidelity characterized by daily movements into the study area. Our observations contradict earlier studies that concluded that bonefish range widely throughout available habitats, and suggest that bonefish utilize shallow habitats most, although deep channels may provide refuge from the rapid temperature changes that occur on the shallow flats.

Study 1B.- We are using advanced acoustic telemetry (AT) tagging methods to determine high-resolution movements (i.e., site fidelity, longshore and offshore spawning migrations) and habitat utilization patterns of bonefish. The AT tagging study has provided new and unique insights into bonefish movements tracked at relatively fine time (minutes) and space (50 m) scales for periods of time ranging up to 3 months. To date 42 bonefish have been AT tagged in an expanded large-scale study and these have provided a plethora of information on bonefish movements and responses to environmental conditions. Several bonefish have been detected to move offshore from the barrier islands for distances up to 6 miles east out to the barrier coral reef during periods corresponding to drops in atmospheric pressure. A number of bonefish seem to exhibit high degrees of site fidelity by returning the same locations on several occasions over many weeks. Substantial long-shore movements of up to 9 miles have occurred in relatively short periods of time (e.g., < 12 hours).

Study 2.- A recent decision by the Florida Governor and Cabinet gave unanimous approval to implementation of a management plan that creates a 46 mi^2 no-take marine reserve (RNA – or 'research natural area') in Dry Tortugas National Park (DTNP). The Park's RNA was designed by the Park to protect precious coral reefs, fishery and cultural resources, and to ensure sustainability of intensely exploited regional fisheries resources, a central role of marine reserves. As fish biomass in the RNA builds because of reduced exploitation, it is exported to areas proximal by directed movement, and by advection of larvae by ocean currents. However, the reserve concept has met with considerable skepticism by recreational fishing lobbyists whose constituencies' available fishing area will be reduced by RNA implementation. A principal concern raised was that RNAs may instead be biological sinks, reducing further the availability of fish. Because of the complexity and sensitivity of this issue, from the outset of RNA establishment in DTNP, it is critical to quantify flux rates across reserve boundaries for key exploited reef fish species (i.e., groupers and snappers). This project will use state-of-the art acoustic telemetry technology to track real-time movements of groupers in key habitats of DTNP to precisely estimate population flux rates in fully-protected areas free from exploitation.

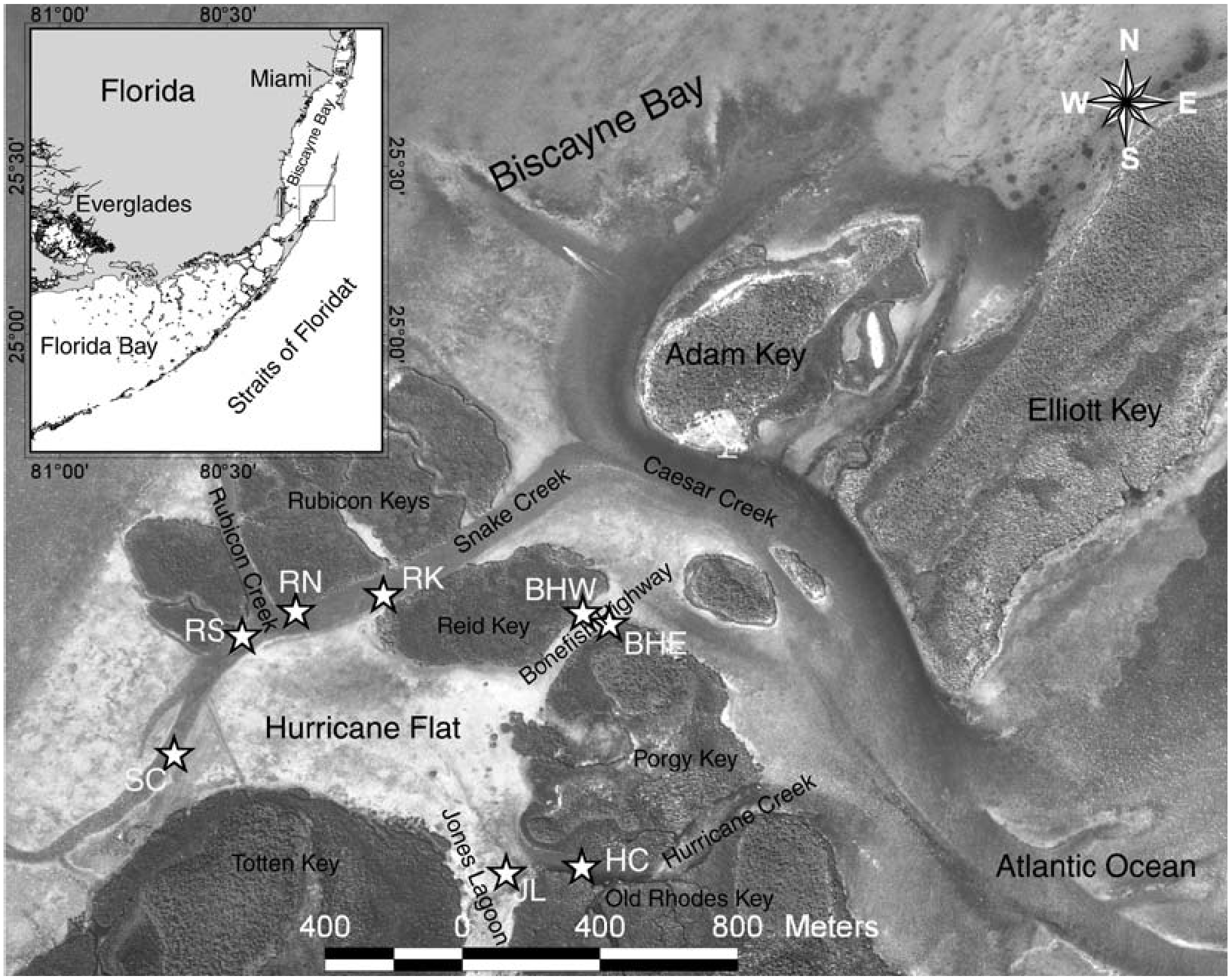


Figure 1A. Study area showing details of shallow flats, channels, mangrove islands, and other surrounding features. Individual hydrophone receiver locations are indicated by stars; BHE, BHW: east and west of Bonefish Highway, respectively; HC: Hurricane Creek; JL: Jones Lagoon; RK: Reid Key; RN, RS: Rubicon north and south, respectively; SC: Snake Creek

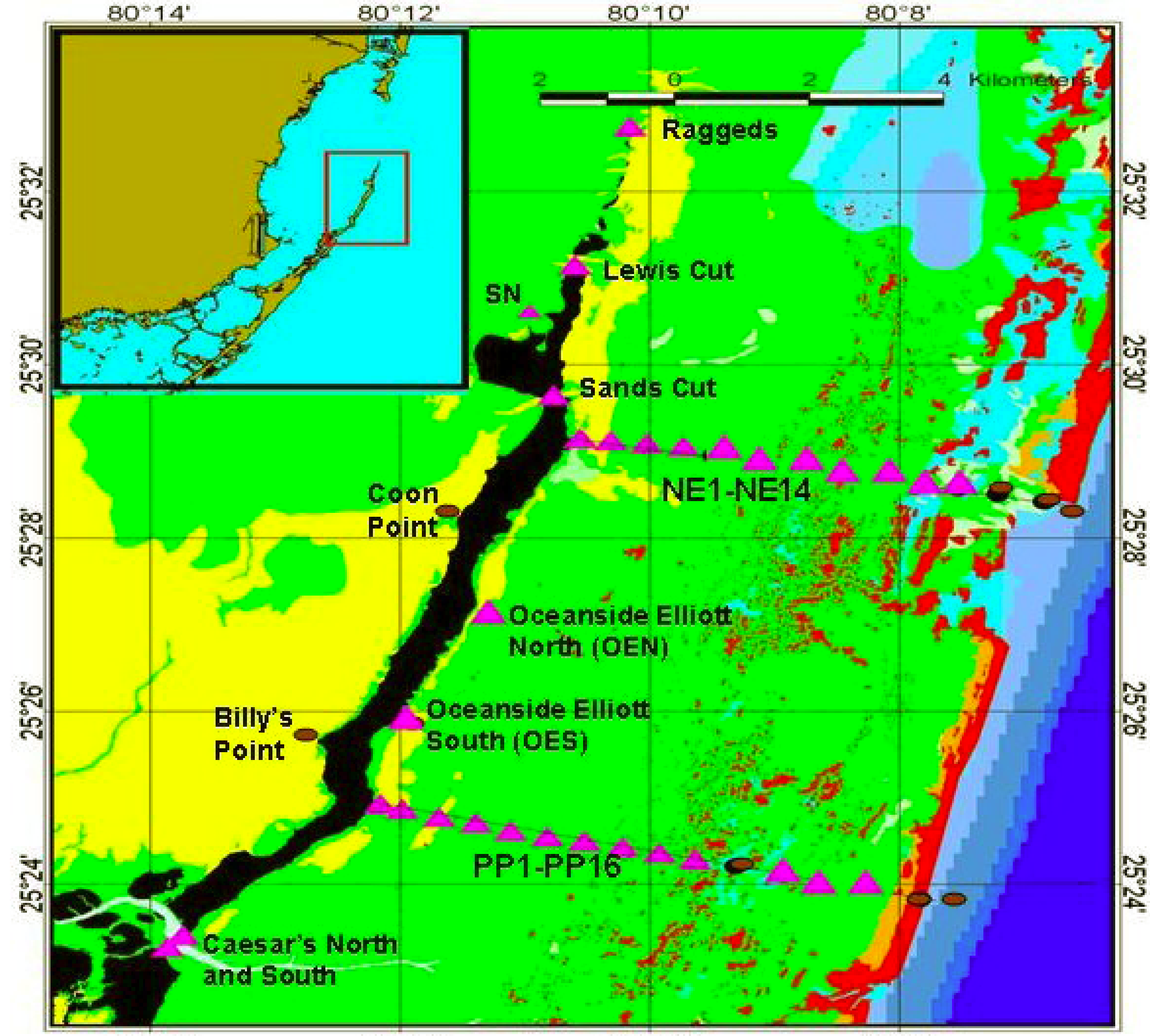
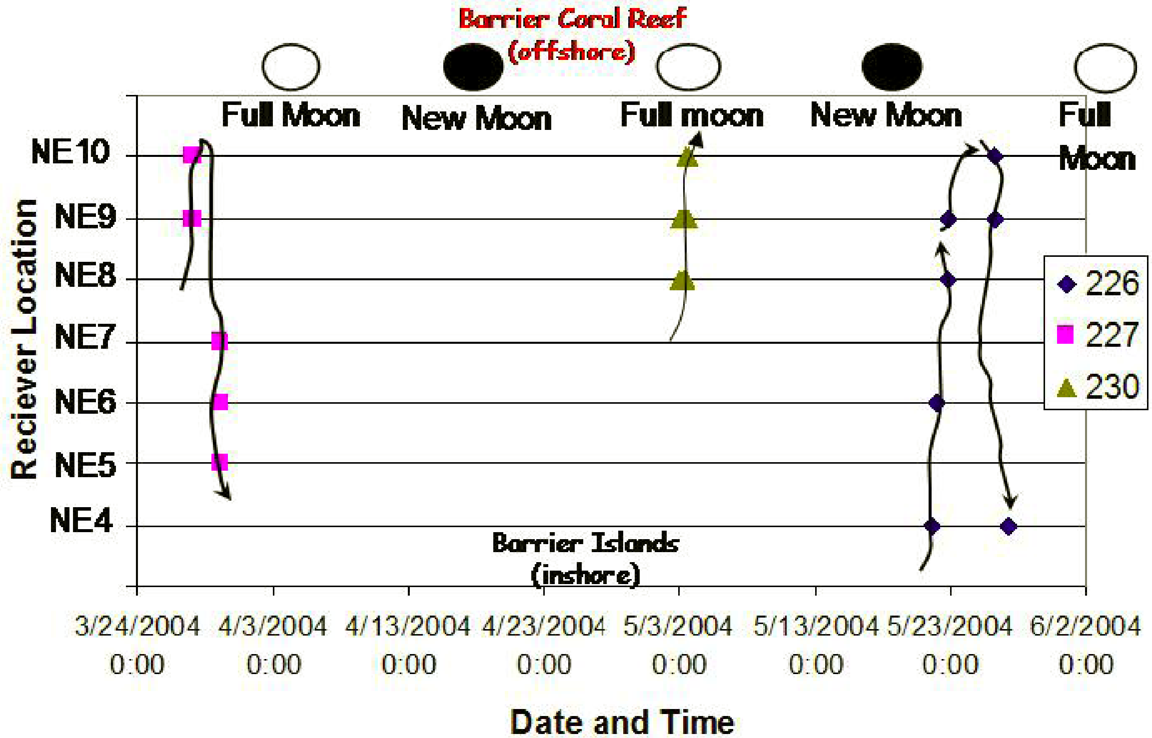


Figure 1B1.- Locations of the forty receivers used in the bonefish acoustic telemetry study located in the northern Florida Keys. Cross-shelf and barrier island pass deployments of VR2 hydrophone receivers are shown as triangles and ellipses. Each triangle represents a receiver that has picked up at least one tag transmission. Every brown ellipse represents a receiver that has never obtained a tag transmission.



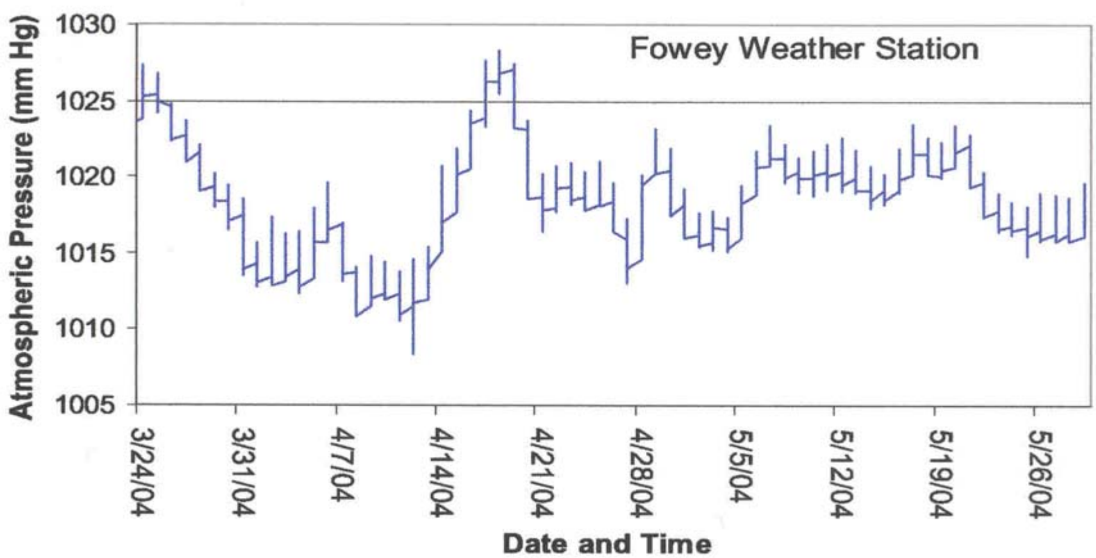


Figure 1B2.- Time of acoustic tag transmissions received by offshore hydrophones for bonefish #226, #227, #230 and the atmospheric pressure recorded at Fowey Light weather station during the same period.

Cynthia Awruch, University of Tasmania

MOVEMENT PATTERNS OF THE DRAUGHTBOARD SHARK (C*EPHALOSCYLLIUM LATICEPS*) COMBINING ACOUSTIC TELEMETRY AND CONVENTIONAL TAGGING INFORMATION.

Awruch, C. A. [a,b,✉]; Frusher, S. [a]; Stevens, J. [b] and Semmens, J. [a]

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The draughtboard shark *Cephaloscyllium laticeps* (Duméril, 1853) is the most common catshark in the coastal areas of southern Australia. We have been using a combination of acoustic and conventional tagging technology to give us a greater insight into the behavior of this species. The conventional tags have provided valuable information on long-term movement. Between January 2000 and February 2004, 375 tagged sharks were released in Crayfish Point Reserve, Tasmania, Australia. To date, 121 sharks have been recaptured with 36% recaptured more than once. A high proportion of sharks remained within the reserve; others moved to the south-west and east coast of Tasmania. The longest period between tagging and recaptures was 39 months. The acoustic data have provided information on site fidelity, residency periods and behavior. Between January-July 2003, 25 sharks were fitted with Vemco V8SC acoustic tags. Vemco VR2 automatic acoustic receivers were deployed in the Crayfish Reserve, in the Derwent River and Storm Bay. Acoustic data showed that most sharks stayed within the reserve, supporting the finding from conventional tagging. Sharks were more active during night time. Stationary behavior (lack of movement) of up to 4 days was also observed.

CSIRO Pelagic Fisheries and Ecosystems, Tasmania

Acoustic monitoring work within CSIRO's Pelagic Fisheries & Ecosystems group concentrates on examining spatial dynamics, site fidelity, residency patterns and behaviour of a range of species including tuna, sharks and (in the near future) swordfish. It is often done in conjunction with other forms of either conventional or electronic tagging (eg satellite tracking PSAT tags).

Examples of projects include:

<u>Designing protected areas for grey nurse sharks</u>
B. Bruce, J. Stevens, R. Bradford (CSIRO)
N. Otway (NSW Fisheries)

Grey nurse sharks (= sand tiger = raggies) are listed as critically endangered on the east coast of Australia. They seasonally aggregate at specific sites where they are vulnerable to various fishing interactions. We have been using a combination of bottom moored VR2 acoustic receivers and active tracking to determine the movements of sharks between sites in eastern Australia; the amount of time individuals spend at monitored sites; their behaviour and spatial use patterns at these sites and when (temporarily) resident at a site, how big an area do they use. These data will help establish how 'critical' these areas are for grey nurse and how large protected areas need to be in order to be effective for this species.

<u>Site fidelity, residency times and home range patterns of white sharks around pinniped colonies</u>
B. Bruce, J. Stevens, R. Bradford (CSIRO)

This study has (since 2001) used VR2 acoustic receivers to provide information on site fidelity, residence times and home range patterns around pinniped colonies in South Australia; determine movement patterns of white sharks between different sites used to monitor white shark population status in South Australia; examine the effects of repeat chumming at particular sites on the frequency at which white sharks visit those sites, their periods of residency and their behaviour; and to examine seasonal movement patterns of white sharks in relation to pinniped pupping events in order to assess interactions between white sharks and pinnipeds and how these interactions may be influenced by changes in white shark numbers or behaviour.

<u>Movements of juvenile southern bluefin tuna in southern Western Australia: lines and hotspots.</u>
Alistair Hobday (CSIRO)
Ryo Kawabe (Nagasaki University)
Yoshi Takao (NRIFSE)
Kazu Miyashita (Hokkaido University)

The primary goals of the acoustic monitoring experiment is to determine the time and spatial pattern of movement paths and residency time of juvenile (age 1) southern bluefn tuna (SBT) in the acoustic survey region of southern Western Australia. Specifically objectives are to:

- Examine the west-to-east movement rate of age-1 SBT across the acoustic survey area, and the latitudinal range of movements (includes residence times),
- Determine short-term school integrity from the pattern of acoustic detections
- Determine the areas on the southern coast of WA in which fish are most likely to be resident over the summer acoustic survey period.

These factors influence the detection of tuna in the survey region and the may enable correction of abundance indices derived from the survey. The experimental array consisted of 70 VR2 acoustic receivers deployed in three lines crossing the shelf and at three hotspots between the lines. The listening stations were deployed for approximately 100 days between December 2004 and March 2005 to evaluate the long-shelf movements of juvenile SBT. A total of 79 fish were tagged with acoustic tags; 13 were also tagged with temperature-depth dataloggers, while 16 were tagged only with dataloggers. A total of 55 (70%) acoustic tagged fish were detected at the stations, the most in any year of this experiment. Fish were present within the area covered by the lines for the majority of the experimental period and detailed tracks were obtained.

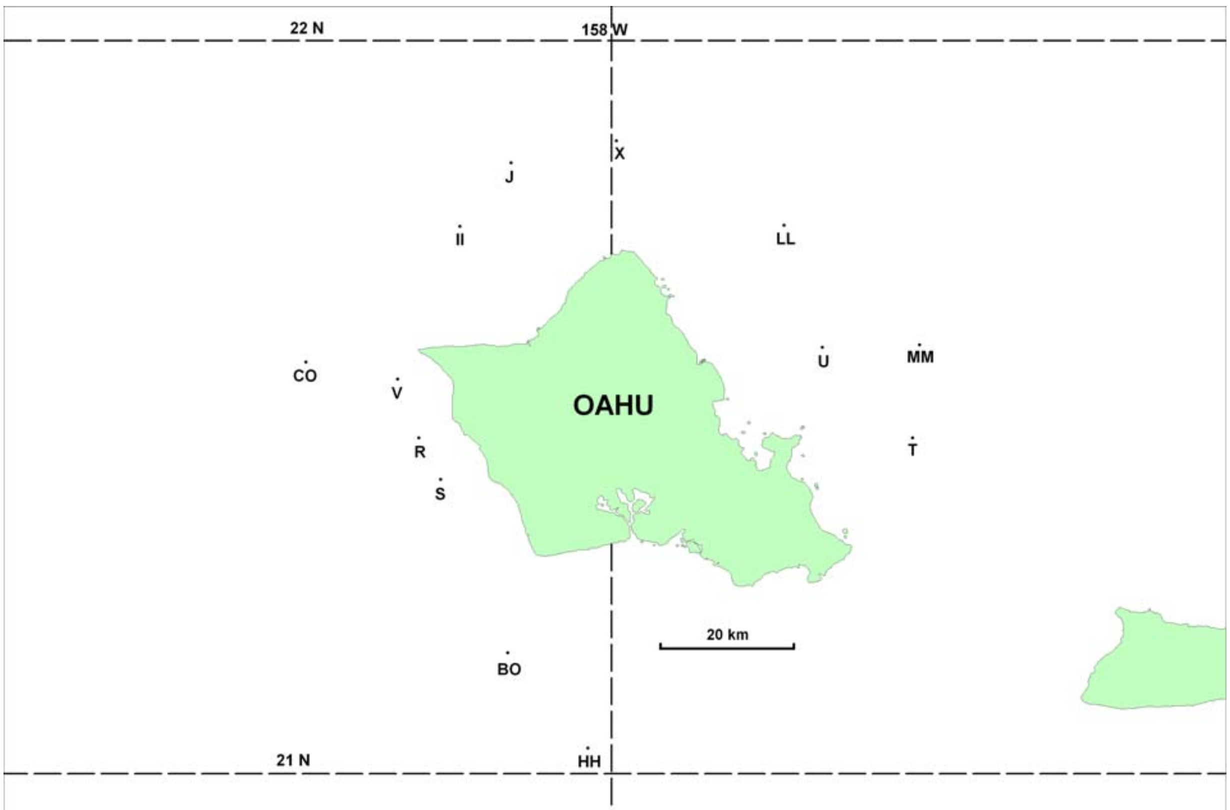
Additional deployments of acoustic receivers will be used to examine the spatial dynamics of SBT at specific hotspots in the eastern Great Australian Bight. Specific objectives of this work will be to:

- Examine persistence of SBT at one topographic features in southern Australia
- Determine the depth preference of SBT at one topographic feature in the GAB.
- Determine visibility of SBT from planes participating in the aerial survey
- Determine short-term school integrity from the pattern of acoustic detections
- Influence on environmental conditions on residence

Deployments of VR2 receivers around specific features and using 256 sensor tags (temp + depth)

Laurent Dagorn, IRD

We use VR2s mainly to measure the time residency of pelagic fish at FADs, and movements of fish between FADs. We also deploy some depth tags in order to study the vertical behavior of fish around FADs, mainly in a comparative approach (different sizes, different species).
Hawaii: the 13 anchored FADs around Oahu have been equipped with VR2s in 2002 and maintained since that time.
Seychelles: VR2s (and ARGOS VR3s) have been deployed on single drifting FADs in the Indian Ocean, for short term deployments.

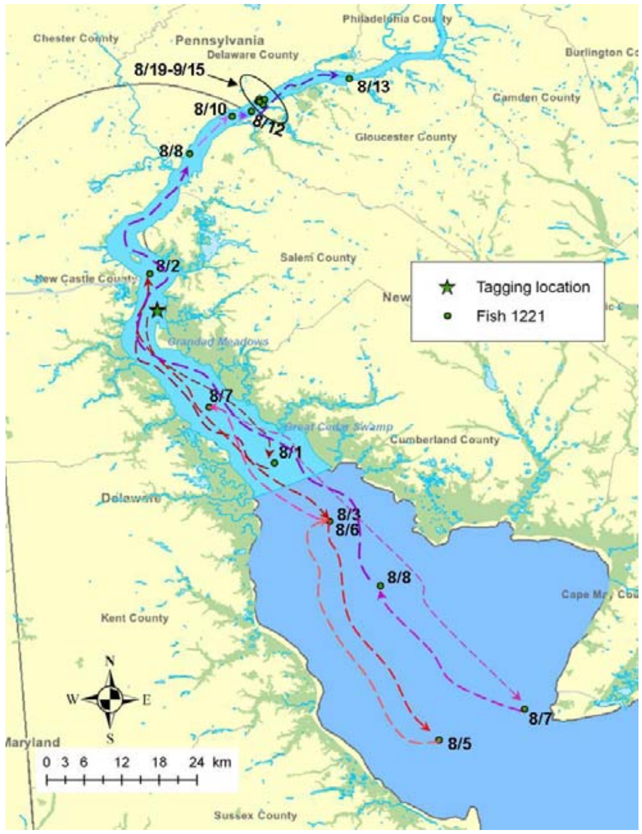


Dewayne Fox, Delaware State University

Sandbar sharks are one of the most abundant sharks on the U.S. east coast and form a large component of the US shark fishery. In an attempt to recover stocks of sandbar and other harvested sharks, NMFS implemented a FMP for many Atlantic species. Managers have illustrated the importance of adequate nursery areas for rebuilding depleted stocks. One of the most important shark nursery areas for sandbar sharks is Delaware Bay. Previous studies have identified core areas that are heavily utilized by young sandbar sharks. This study is aimed at quantification of fine-scale spatial and temporal use of these core areas by sandbar sharks. Movements of telemetered sandbar sharks will be monitored throughout their entire summer residence with an array of automated receivers. Data collected in this study will enable us to precisely identify essential habitat for YOY and juvenile sandbar sharks on a long-term basis.

The worldwide distribution of Atlantic sturgeon at one time was centered in the Delaware River. Unfortunately, this harvest was not sustainable and quickly led to the collapse of the Atlantic sturgeon population. Present day status of this historically important fish is unknown in the Delaware River and has lead to the species being listed as either threatened or endangered in surrounding states (DE-NJ-PA). I plan to utilize a combination of gillnetting and telemetry to assess the status of adult Atlantic sturgeon in the Delaware River. Additionally, telemetry results and egg sampling will be used to identify the location of Atlantic sturgeon spawning sites. I will provide state and federal agencies with needed information on the status of the Delaware River Atlantic sturgeon. This information will include insights on the present day status of adults, duration of river residency, and both the temporal and spatial distribution of spawning locations which will form the basis of critical habitat designations.

Current and proposed receiver placement for tracking sturgeon and sharks in Delaware Bay.



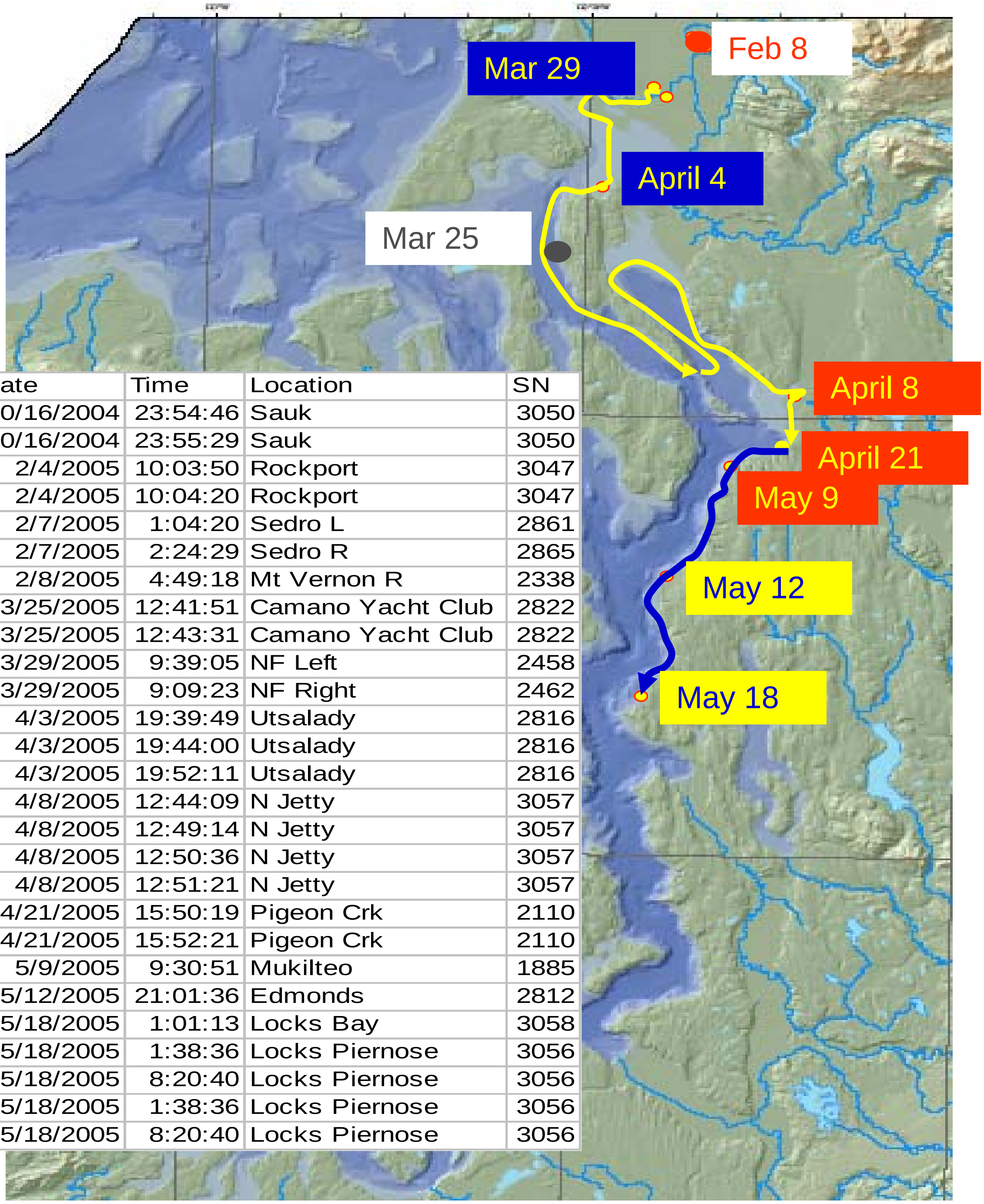
Example tracks for fish monitored within Delaware Bay. Dashed lines are inferred movement patterns based on detections.

Frederick Goetz, US Army Core of Engineers and University of Washington

Puget Sound Biotelemetry Project

Puget Sound includes 4000 km of estuary and marine shoreline dispersed among five major sub-basins, eleven major river deltas, and hundreds of smaller estuaries. A consortium of federal (Army Corps, NOAA, US Fish and Wildlife Service), university (University of Washington), tribal (Squaxin Island, Northwest Indian Fisheries Commission), and local agencies (City of Seattle, King County) have combined efforts, over the past four years, to develop a regional acoustic monitoring network (> 140 VR2s) that is being used to salmon and trout, and now covers over 1000 km of shoreline including POST arrays at the major constrictions all salmonids must migrate through enroute to the Straits and ultimately the Pacific Ocean. This system will allow development of survival estimates, identification of migratory pathways, and details of habitat use in a number of sub-basins. We have conducted four years of study of estuary and nearshore marine habits and habitat use by bull trout a member of the charr family, two years on marine migration of coho smolts, a pilot year testing capture and tagging methods for post-smolt chinook salmon, and one year of study on sea-run cutthroat trout. Future plans include a four year study of marine migration and habitat use of resident Puget Sound Chinook salmon and sea-run cutthroat trout, a 2-3 year study of smolt migration and survival of steelhead, 1-2 years of coho salmon smolt behavior and marine migration. We plan to increase our tag release from 300 fish in 2005 to up to 1500 tags in 2006. Our system is providing information on other species from other independent researchers studying six-gill shark, Pacific cod, squid, adult Chinook salmon, and green-sturgeon among others.

Our bull trout study, 220 fish tagged to date, provides a reference of habits and habitat use within the Puget Sound basin upon which we plan on developing a conceptual model of fish behavior for a suite of resident and ocean-bound salmon and trout. We have identified marine migration pathways for sub-adult and adult bull trout moving between rivers, estuaries and marine shorelines in Puget Sound. Figure 1 provides an example of one fish migrating over 250 km from freshwater (Skagit River) along marine and estuary shorelines to a spring estuary foraging site in Shilshole Bay in downtown Seattle: this fish passed by 14 separate receivers. In habitat use we have identified site range or feeding territory size (Figure 2 top) and possible explanations for the timing of fish movement out of marine waters in relation to environmental conditions (Figure 2 bottom).



Tag	Date	Time	Location	SN
648	10/16/2004	23:54:46	Sauk	3050
648	10/16/2004	23:55:29	Sauk	3050
648	2/4/2005	10:03:50	Rockport	3047
648	2/4/2005	10:04:20	Rockport	3047
648	2/7/2005	1:04:20	Sedro L	2861
648	2/7/2005	2:24:29	Sedro R	2865
648	2/8/2005	4:49:18	Mt Vernon R	2338
648	3/25/2005	12:41:51	Camano Yacht Club	2822
648	3/25/2005	12:43:31	Camano Yacht Club	2822
648	3/29/2005	9:39:05	NF Left	2458
648	3/29/2005	9:09:23	NF Right	2462
648	4/3/2005	19:39:49	Utsalady	2816
648	4/3/2005	19:44:00	Utsalady	2816
648	4/3/2005	19:52:11	Utsalady	2816
648	4/8/2005	12:44:09	N Jetty	3057
648	4/8/2005	12:49:14	N Jetty	3057
648	4/8/2005	12:50:36	N Jetty	3057
648	4/8/2005	12:51:21	N Jetty	3057
648	4/21/2005	15:50:19	Pigeon Crk	2110
648	4/21/2005	15:52:21	Pigeon Crk	2110
648	5/9/2005	9:30:51	Mukilteo	1885
648	5/12/2005	21:01:36	Edmonds	2812
648	5/18/2005	1:01:13	Locks Bay	3058
648	5/18/2005	1:38:36	Locks Piernose	3056
648	5/18/2005	8:20:40	Locks Piernose	3056
648	5/18/2005	1:38:36	Locks Piernose	3056
648	5/18/2005	8:20:40	Locks Piernose	3056

Figure 1. Marine migration pathway for one fish moving from Skagit River to Shilshole Bay estuary in downtown Seattle.

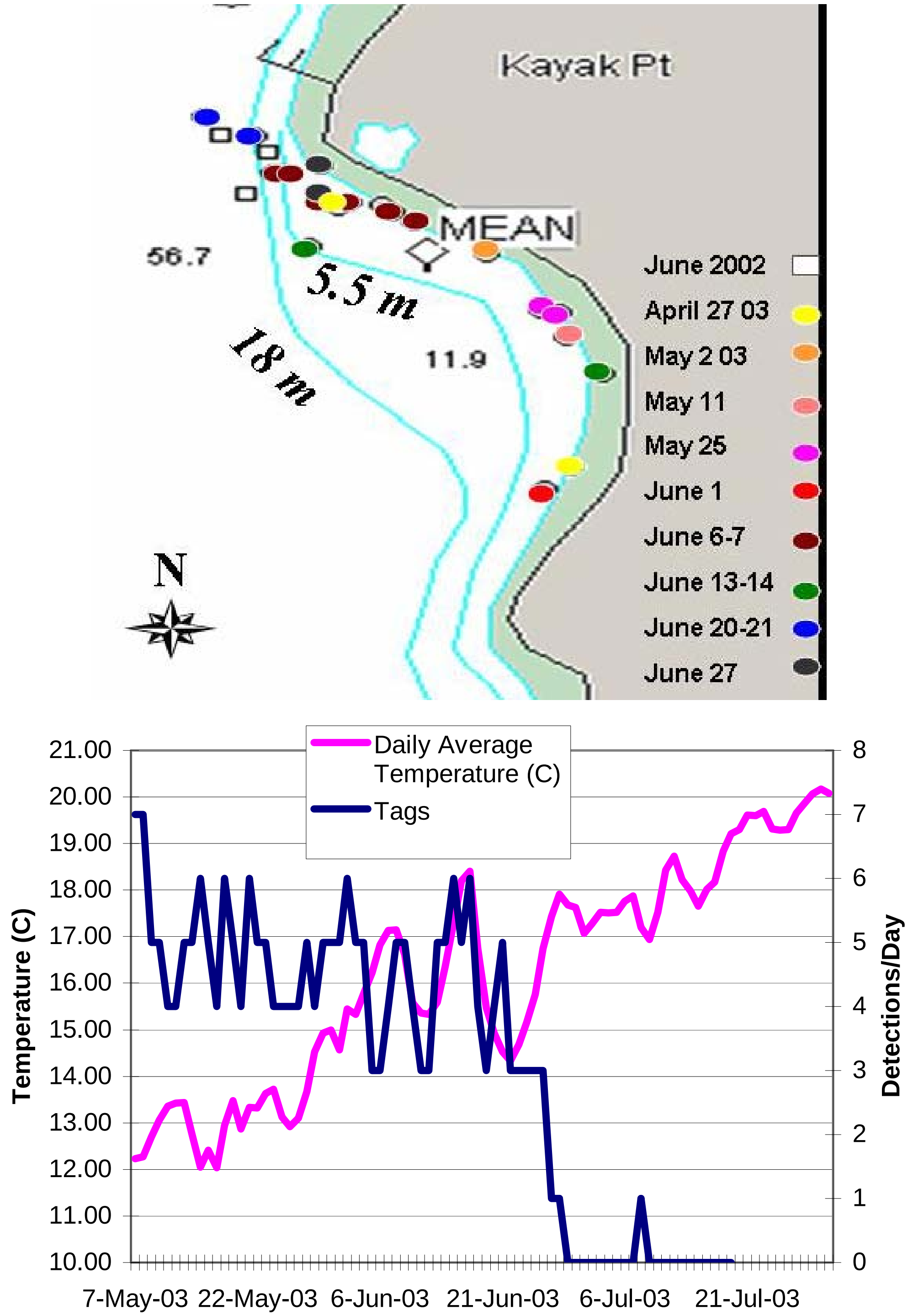


Figure 2. **Top figure** shows site range or feeding territory size for one fish over two seasons at a marine shoreline area - shoreline length of approximately 900 m. Within one 24-hour period this fish moved 300 m. This fish returned to the same site two years in a row. **Bottom figure** shows the number of detections per day and water temperature at an estuarine location at the edge of a large river. The number of detections per day dramatically declined once the water temperature reached approximately 18 C on a continuing. This timing occurred as these fish entered freshwater on their upstream migration to upriver spawning or feeding grounds.

Michelle Heupel, Mote Marine Laboratory

<u>Terra Ceia Bay blacktip shark studies</u>

I have been using VR1 and VR2 technology to monitor the presence and movement of sharks in coastal regions since 1999. Initial studies began to define how young sharks used a confined nursery (residence time, home range size, document philopatric behaviors). A population of blacktip sharks within Terra Ceia Bay Florida was monitored for four years for this project using a series of 25 receivers (Figure 1). Approximately 30-40 sharks were monitored per year in this site. The receiver array was designed with overlapping detection ranges to ensure continuous contact with sharks. High volumes of data necessitated the use of data summary techniques such as position averaging. Based on the data from position estimates numerous analysis techniques have been applied including calculation of mortality rate, home range size through time, habitat use in relation to prey density, movement patterns in relation to temperature and day length (emigration and immigration studies), examination of population dynamics (e.g. nearest neighbor analysis) and response to extreme weather events.

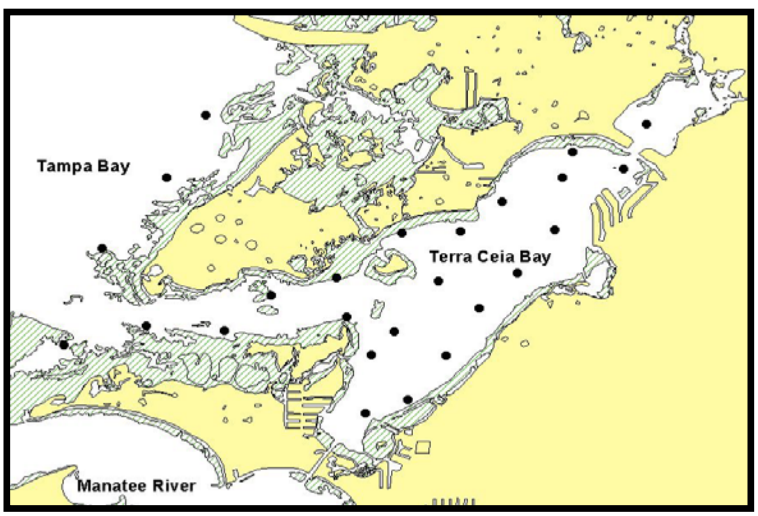


Figure 1. Terra Ceia Bay Florida (adjacent to Tampa Bay) showing the location of acoustic hydrophones.

Pine Island Sound shark studies

Research in Pine Island Sound, Charlotte Harbor was aimed at defining the movement patterns of numerous shark species using the same habitat to define intra-specific interaction and overlap of habitat use. Over 60 sharks of 5 species were monitored within the sound during each of the three years of this study. Bonnethead sharks were the most common residents within the sound with individuals remaining within the area for over 100 days and several individuals returning to use the site in subsequent years. Home ranges of bonnethead sharks were consistently small, but shifted location within the sound to display use of the available habitat. Juvenile bull and lemon sharks (c. 200 cm TL) were also monitored within this site and appeared to use the same regions as bonnethead sharks often moving into shallow waters. Both lemon and bull sharks are known to prey on elasmobranchs and may have been actively feeding on bonnethead sharks which are much smaller (c. 70 cm TL). Future analyses of these data will examine whether bull and lemon sharks were using shallow regions at the same time bonnethead sharks were or whether temporal variation in habitat use meant that these species rarely interact. In addition to species interactions and individual population home range and residency analysis this site also experienced a hurricane in 2004. Hurricane Charley crossed directly over this study site and for the third time to date the receivers recorded the movement of sharks out of the study site as the storm approached (Figure 2).

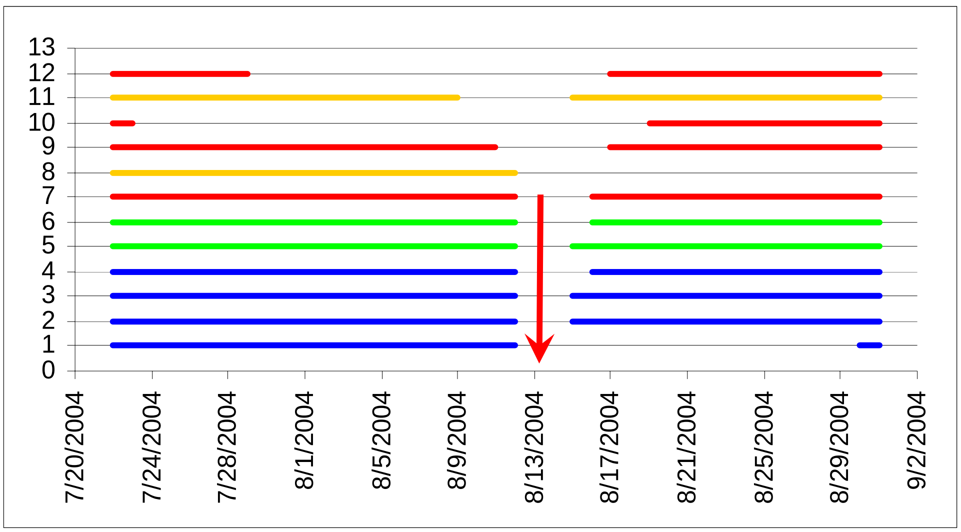


Figure 2. Presence of sharks in Pine Island Sound as Hurricane Charley passed. Arrow indicates storm landfall. Red lines = bull sharks, yellow = lemon sharks, green = blacktip sharks and blue = bonnethead sharks.

Caloosahatchee River bull sharks studies

Most recently I have applied VR2 technology to examine the use of the Caloosahatchee River by juvenile bull sharks. The Caloosahatchee River is a heavily altered environment with an artificial link to Lake Okeechobee. The lower 32 km of the river are considered to be estuarine with highest salinities near the mouth where the river is tidally influenced. However, water levels within Lake Okeechobee are currently managed by draining water through the Caloosahatchee and St. Lucie rivers. This water management strategy means that flow and salinity are heavily impacted within the river and vary dramatically. In the dry winter season the dam is typically closed and the river is in a well mixed, more estuarine state. During the wet summer months the dam is open to varying degrees and the estuarine portion of the river is fresh all the way to the river mouth. This project uses 23 VR2s to examine the movement patterns of bull sharks to define how much of the river they use, how long they remain within the river and how they respond to salinity variations. Based on current data it appears that sharks are following a salinity gradient. When the river is well mixed sharks use the entire monitored portion of the river, but when the river is fresh sharks are only located near the mouth of the river (Figure 3). Examination of salinity data from monitors deployed by the South Florida Water Management District reveal a distinct pattern between salinity level and the distance sharks move up the river (Figure 4). This project is ongoing and may incorporate additional species in the near future.

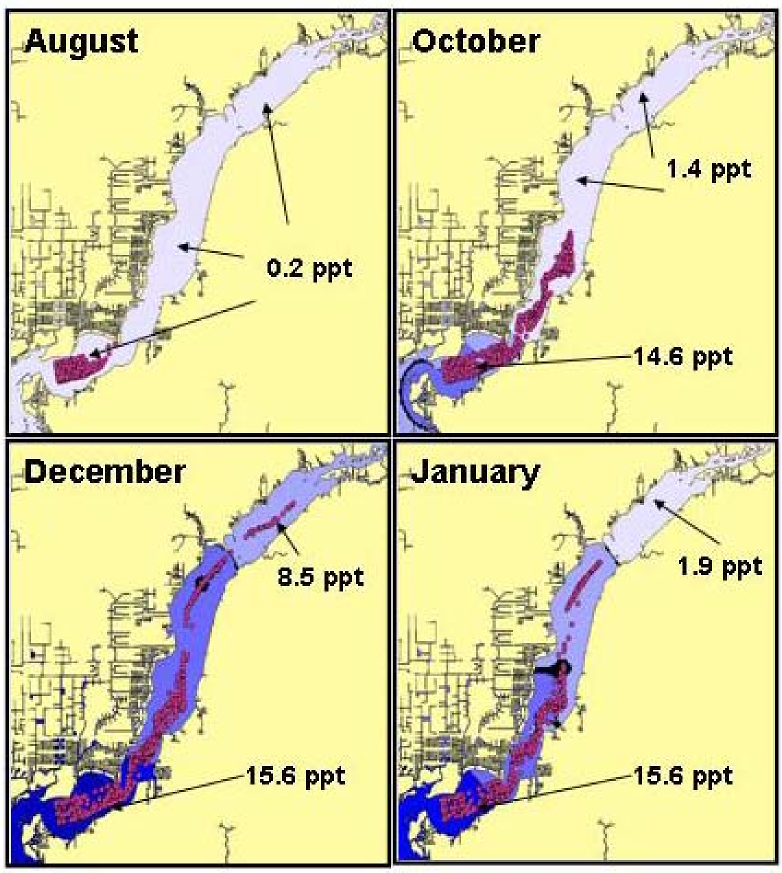


Figure 3. Map of *C. leucas* locations within the Caloosahatchee River in relation to salinity levels through time. Points indicate shark locations and increasing salinity is represented by darker coloration.

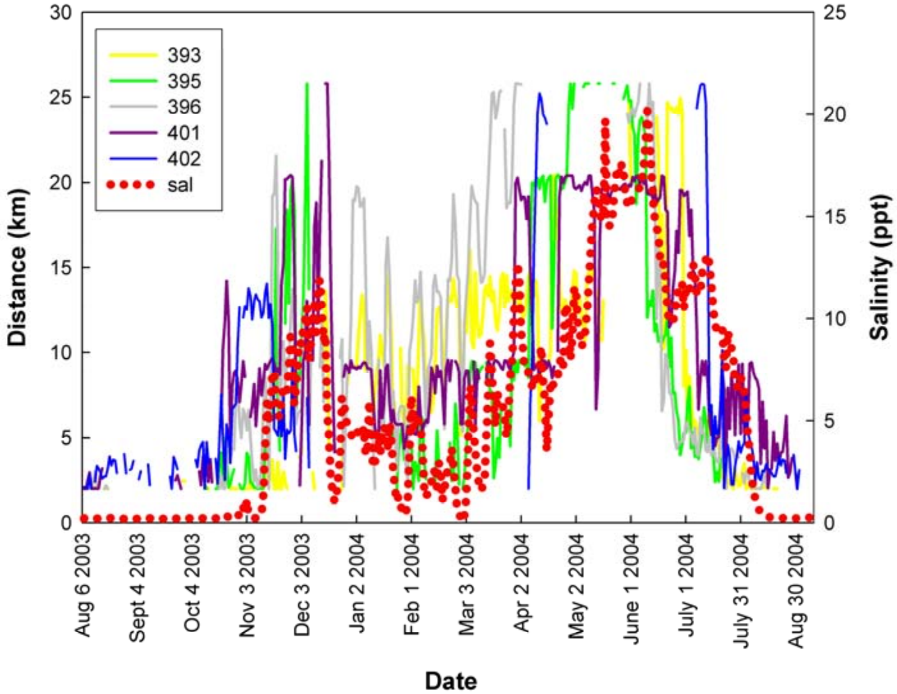
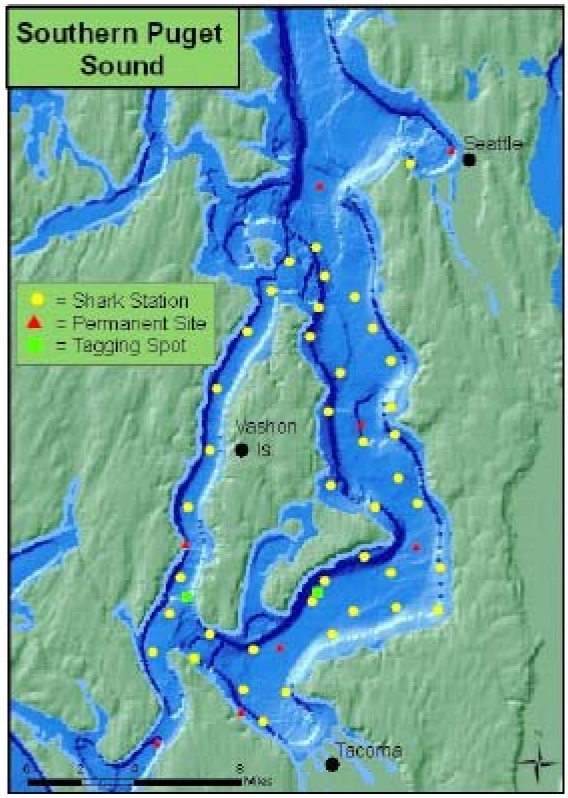


Figure 4. Distance young bull sharks traveled up river in relation to salinity level. Salinity is indicated by red dotted line.

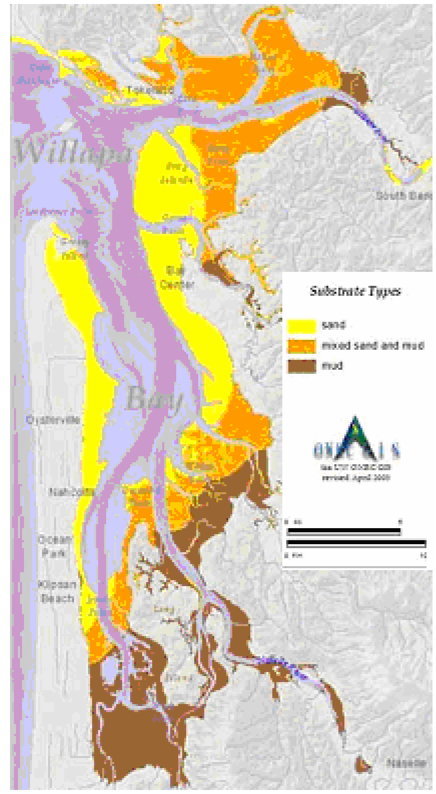
Stephen Katz, Northwest Fisheries Science Center NOAA-Fisheries

Current research revolves around two questions:

1) What are the daily, seasonal, annual movement patterns of 6-gill sharks in southern Puget Sound, Wa., USA? The temporal and spatial patterns of movement will inform inferences about fish-habitat associations, home ranges, the interactions of the fish with human impacts and structures in the Sound. Currently this is a collaborative project with NOAA-Fisheries, Wa. Dept. of Fish and Wildlife and the Seattle Aquarium. There are currently 22 6-gilled sharks tagged with internally placed, coded acoustic transmitters. The fish range from 45 to 207 kg and are of both sexes. We are using uncorrelated random walks as null models for the observed patterns of movement. From these models it is possible to extract characteristic scales of movement of individuals. Findings include that some fish move a lot and some not so much. Individuals have been observed covering 16km in 18 hours. Smaller individuals move more than larger sharks. Average daily movements are larger in the spring and summer, and are less in the winter. There appear to be groups of sharks that cover large parts of the sound (domains with long dimensions of 15-20km), and whose domains are in close proximity (<0.5km), but who don't cross into adjacent domains. We are currently looking into the role that bathymetric features play in this segregation. This study is also being supplemented with stable isotope assays to evaluate the trophic role of these fish and how the scale of their movements impacts an otherwise spatially complex food web in Puget Sound.



2) What are the daily, seasonal and annual movement patterns of 7-gill sharks in Willapa Bay, WA. USA. Willapa bay is a large estuary of four coastal streams with significant oyster, crab and salmon fisheries. This study is just being initiated, but anticipated inferences are similar to the 6-gill shark study with the added components that 7-gill sharks may be impacting the harbor seal and Dungeness crab in Willapa Bay. Unfortunately there is no monitoring of 7-gill abundance. However, the ranges and characteristic movements of these sharks in the estuary will be an important factor in determining their overall ability to impact the crab or seal populations. So far there are 20 7-gill sharks tagged with coded acoustic transmitters. There are 14 VR2 receivers deployed. First steps include documenting how far into the estuary these large (47-147kg) sharks go and what associations are there between the patterns of movement and the habitat—which consequent to the commercial impact of oyster farming is unusually well mapped.



Tom Keegan, ECORP Consulting, Inc.

The need for information on the distribution of federally listed Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in San Francisco Bay has been recognized by the Long Term Management Strategies Science Assessment and Data Gaps Work Group (LTMS Science Group). This information is necessary for evaluating effectiveness and efficiency of the use of environmental windows for managing and protecting fish stocks of concern (e.g., special status species, as well as commercially important species), especially relative to dredging and dredge material disposal operations. This information is also important to federal and state resource agencies in an effort to aid the recovery of federally listed Chinook salmon and steelhead ESUs.

The LTMS Science Group received funding for purchasing 50 stationary receivers (Vemco model VR2-500), a mobile tracking system (Vemco Model VR100, with both omni and directional hydrophones), 100 coded transmitter (i.e., acoustic) fish tags (Vemco Model V7-XL), and a shock/water resistant laptop for shipboard data downloading and processing.

Our current objective is to develop a detailed pilot study design to refine study objectives and methodologies for determining location and timing of juvenile Chinook salmon and steelhead in San Francisco Bay, and 2) to conduct a pilot study to begin monitoring the migration and distribution of juvenile Chinook and steelhead in San Francisco Bay. Placement of receivers should be related to the likely migration routes of the population(s) being studied, areas of the Bay where dredging and/or disposal occurs, and/or habitat considerations (e.g., bathymetry, biological habitats, etc.). Similar considerations would apply to application of mobile tracking. Main areas of interest for deployment of receiver arrays are:

- Areas of constriction, including bridge abutments (or just off abutments) such as Richmond-San Rafael Bridge, I-80 Bay Bridge, Dumbarton Bridge, and Carquinez Straits Bridge,
- Piers and wharves in the bay, including the refinery wharves and fishing wharves,
- Other structures in the bay, including pilings, islands (Red Rock, Marin Island),
- Marina entrances and Port entrances/harbors
- Marsh system inlets, including Napa River Marsh, Petaluma Creek, Sonoma Creek, Montezuma Slough, South Bay Salt Ponds.

Gilles Lacroix, Fisheries and Oceans Canada

In some initial research in the Bay of Fundy, the concept of using arrays or lines of closely-spaced monitoring receivers in marine habitat was tested and developed first using VR20 and then VR1 receivers (Lacroix and Voegeli 2000; Lacroix et al. 2004; Lacroix et al. 2005). The Bay of Fundy is 320 km long and 50 km wide at the narrowest point, has extreme tides (7-9 m), and flows into the Gulf of Maine. The success of these studies in determining the survival and migratory behaviour of Atlantic salmon smolts and post-smolts in coastal habitat lead to a recent large-scale two-year study in the Bay of Fundy where >550 salmon smolts were tagged and monitored over 4-6 months each year. Smolts from 13 groups (6 rivers, wild and hatchery origin, various release times) were monitored through estuaries, and their progress through the Bay of Fundy and their success in leaving the bay was automatically monitored using several long lines of 50-80 closely-spaced VR2 receivers deployed from shore to shore across the bay (see Fig. 1). The migration success or survival leaving the estuaries, the inner and then the outer Bay of Fundy was determined with a high accuracy. Specific areas where losses occurred were identified and potential causes of mortality were examined. The distribution of post-smolts along the monitoring lines revealed the use of specific migration corridors and the effect of surface circulation within the bay on migration. A rather unique behaviour where many post-smolts curtailed their migration to the Atlantic Ocean, returned to the bay during the first summer at sea, and showed an extended period of residency within the Bay of Fundy and northern Gulf of Maine was documented. This behaviour was explored in relation to fish origin and timing of migration, tidal flow, surface circulation, and sea surface temperature.

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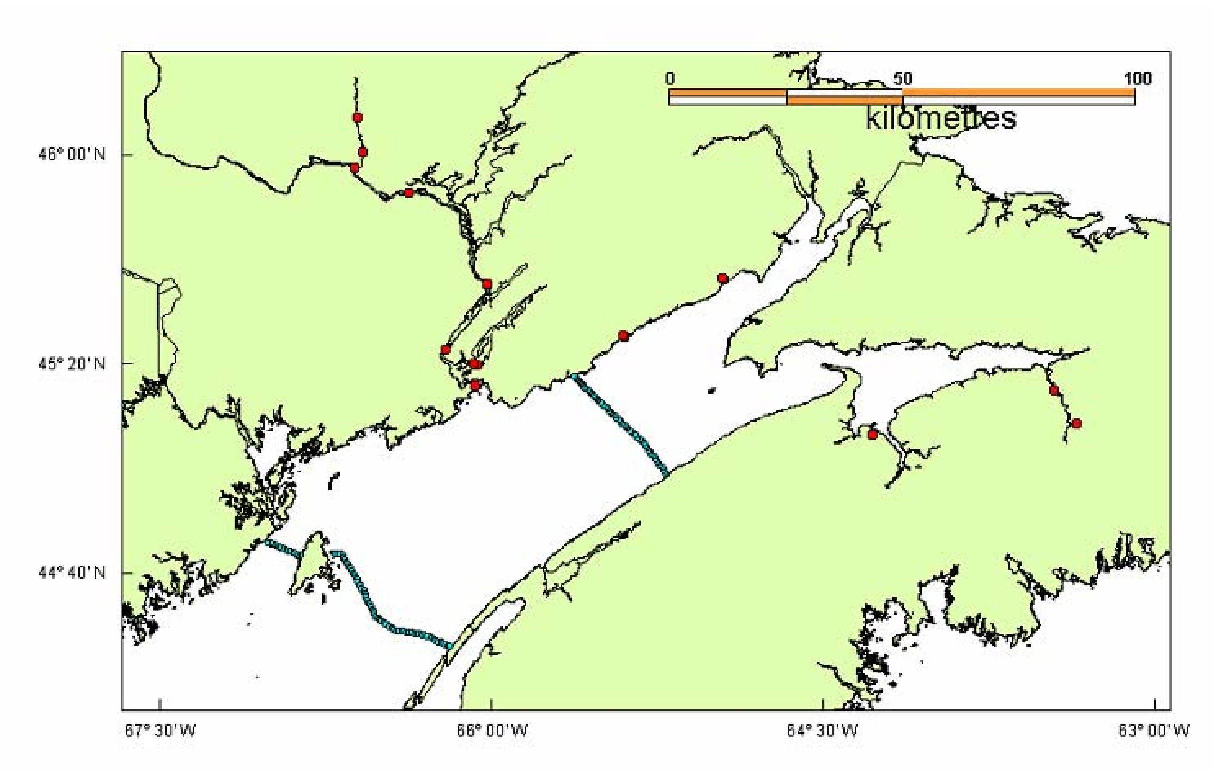

Fig. 1. Position of VR2 monitoring receivers in estuaries (red dots) and within the Bay of Fundy (lines of green dots) in one of the years where Atlantic salmon were monitored.

James Lindholm, Pfleger Institute of Environmental Research

Site Fidelity and Movement of Fishes in California's Channel Islands

In June of 2000 scientists at the Pfleger Institute of Environmental Research (PIER) initiated a multi-year project to monitor the behavior, movement, and habitat use of giant sea bass (*Stereolepis gigas*) tagged with acoustic transmitters at Anacapa Island. In 2003, the project was expanded to include monitoring of tagged white sea bass (*Atractoscion nobilis*). The monitoring area of both of these species was expanded to include not only Anacapa Island, but also Santa Cruz Island, Santa Rosa Island, Catalina Island, and Santa Barbara Island, as well as 3 locations on the mainland (Figure 1). In 2004, the program was expanded further to include the study of site fidelity and movement of kelp bass (*Paralabrax clathratus*) and California sheephead (*Semicossyphus pulcher*) inside and out of the new State Marine Reserves at Anacapa and Santa Barbara Islands. Results to-date have shown movements of tagged giant sea bass from Catalina Island north to Santa Rosa Island, including seasonal use of Santa Cruz Island. Tagged white sea bass have also been recorded moving from Santa Rosa Island to Catalina Island, as well as to the sites along the mainland at Pt. Dume and Pt. Vicente. Sheephead and kelp bass, as expected, have shown greater site fidelity to location of their release. However a variety of movement behaviors have been recorded among individuals, including an apparent shift in territories by a terminal male sheephead during spawning season (Figure 2). Ultimately, the goal of this research is to characterize the landscape ecology of fishes in the Channel Islands while also providing data at a scale that is meaningful for management.

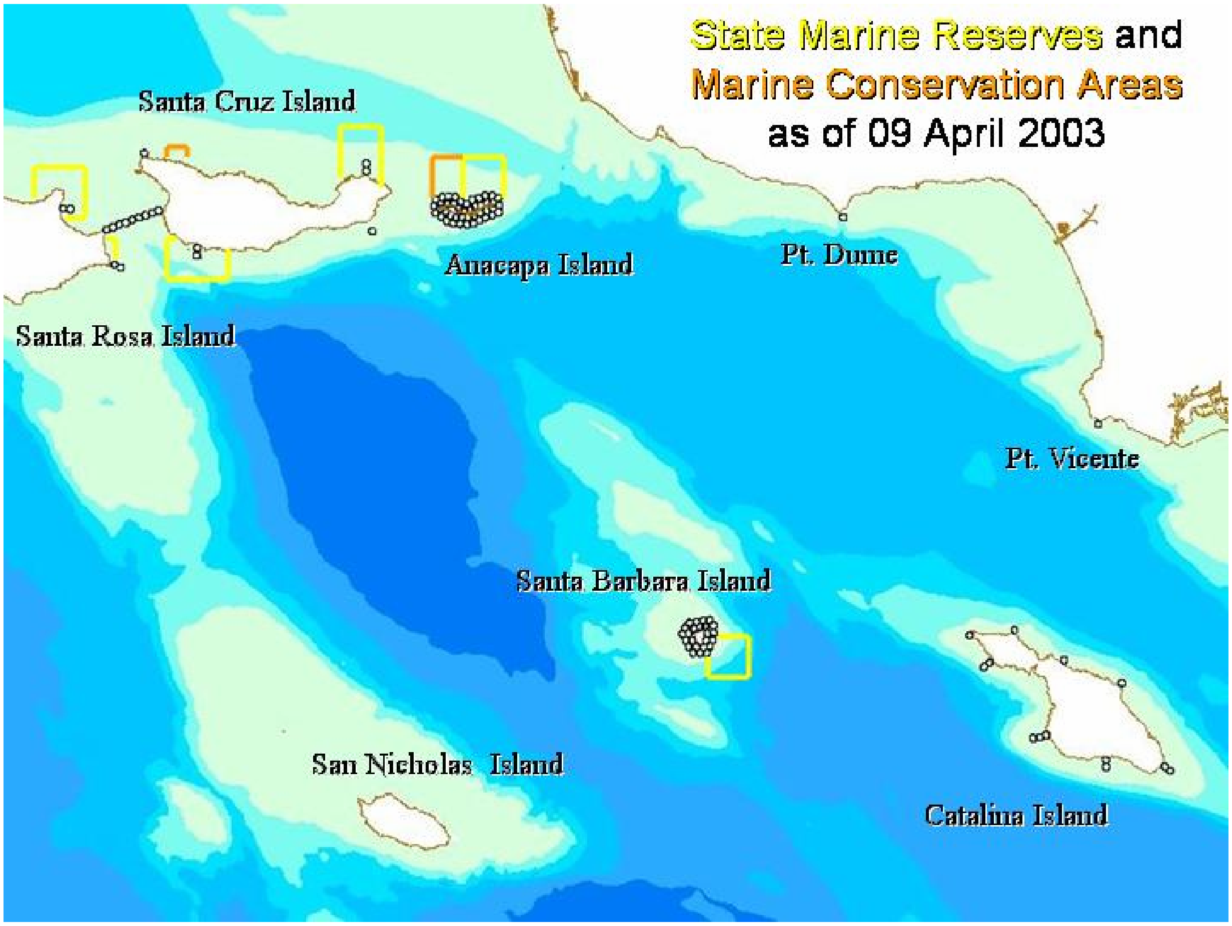

Figure 1. Map of PIER's VR2 acoustic receiver array in the Channel Islands and along the mainland. Each black circle (94 total) represents a single VR2 receiver with an estimated radius of detection of 500 m. The State Marine Reserves (no-take reserves) and the State Conservation Areas are also shown.

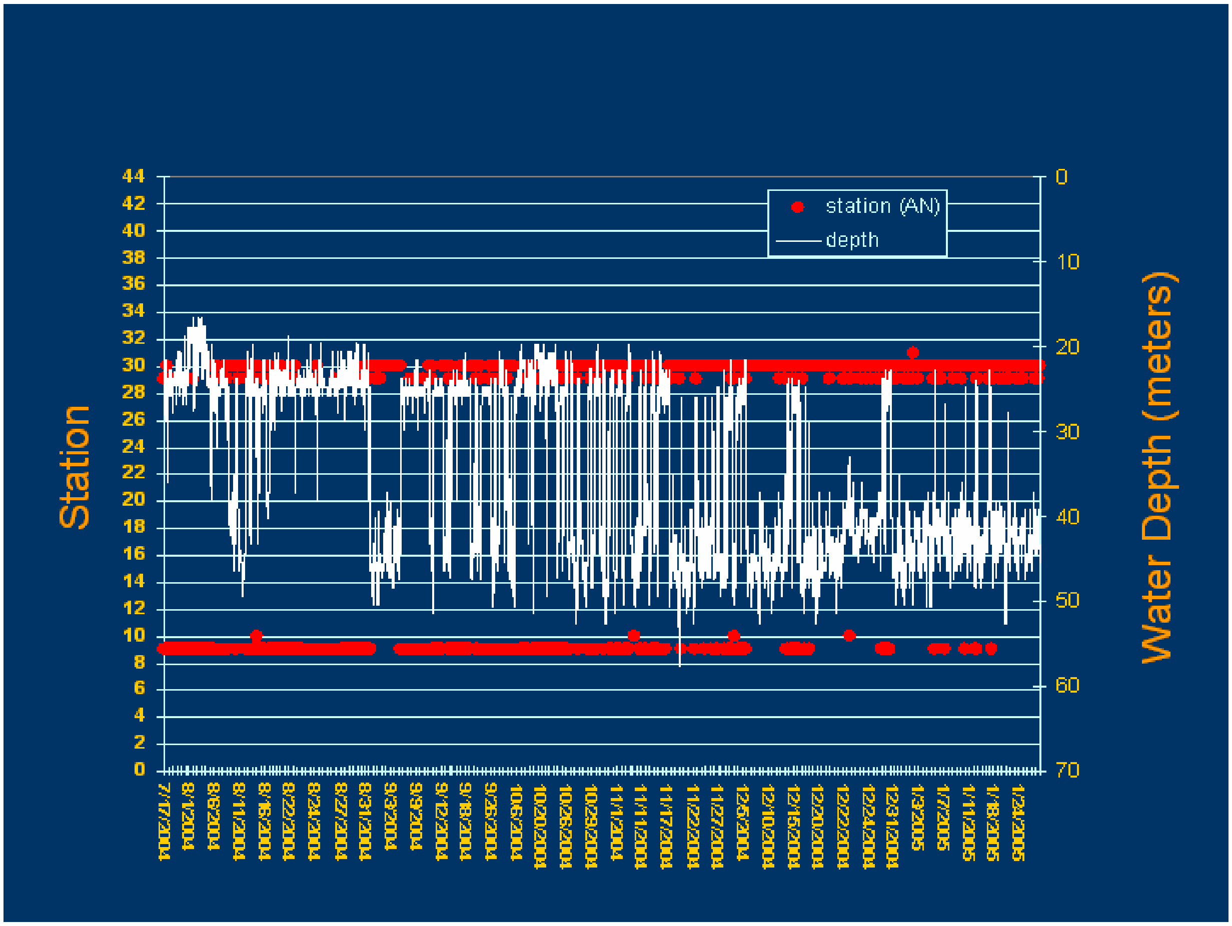

Figure 2. Data are shown for a single terminal male California sheephead tagged at station #9 inside the State Marine Reserve at Anacapa Island in July 2004. Each red circle represents a single 24 hour period during which the fish was detected at a given receiver. Stations 1-20 form the inner-ring of receivers, while 21-44 form the outer-ring. As such, stations 29, 30, 31 are actually adjacent to stations 9 and 10 in deeper water. The white line depicts the depths at which the fish was recorded through January 2005.

Habitat-Mediated Movement of Atlantic Cod in the Southern Gulf of Maine

Atlantic cod (*Gadus morhua*) is a demersal, omnivorous fish once found throughout the north Atlantic, from the surface to a depth of 600 meters. The fact that cod swim in the ocean is well understood. Precisely how cod move relative to different features of the undersea landscape is much less understood. Since 2001, this project has used acoustic telemetry to quantify cod movement over different features of the landscape to inform management. Preliminary movement studies on cod occurred in the gravel habitat of northeastern Stellwagen Bank in 2001. Cod were caught and tagged with coded-acoustic transmitters then released within the overlap of the Stellwagen Bank National Marine Sanctuary (SBNMS) and the Western Gulf of Maine Closed Area (WGoMCA). Beginning in 2002, movements of tagged cod were recorded by an array of four acoustic receivers deployed on the seafloor at deep boulder reefs (Figure 1). From May 2002 through October 2002 and from September 2004 through March 2005 (Figure 2), cod movement was investigated at each of the four boulder reef sites. The same piled boulder reefs were used in both periods in order to quantify any influence of seasonality on cod movement behavior. To-date, three broad categories of movement behavior were identified at each of the four piled boulder reefs, across years and across seasons. Multiple cod showed high site fidelity (present > 90% of the study) to the boulder reef where they were caught and released. A second set of cod were recorded moving among the four piled boulder reefs included in the study (including movements as far as 24 km). A third group of cod were recorded only briefly at the boulder reef where they were caught and released before leaving the study area. In each case, cod size (Total Length) was not a factor in the recorded movement behavior.

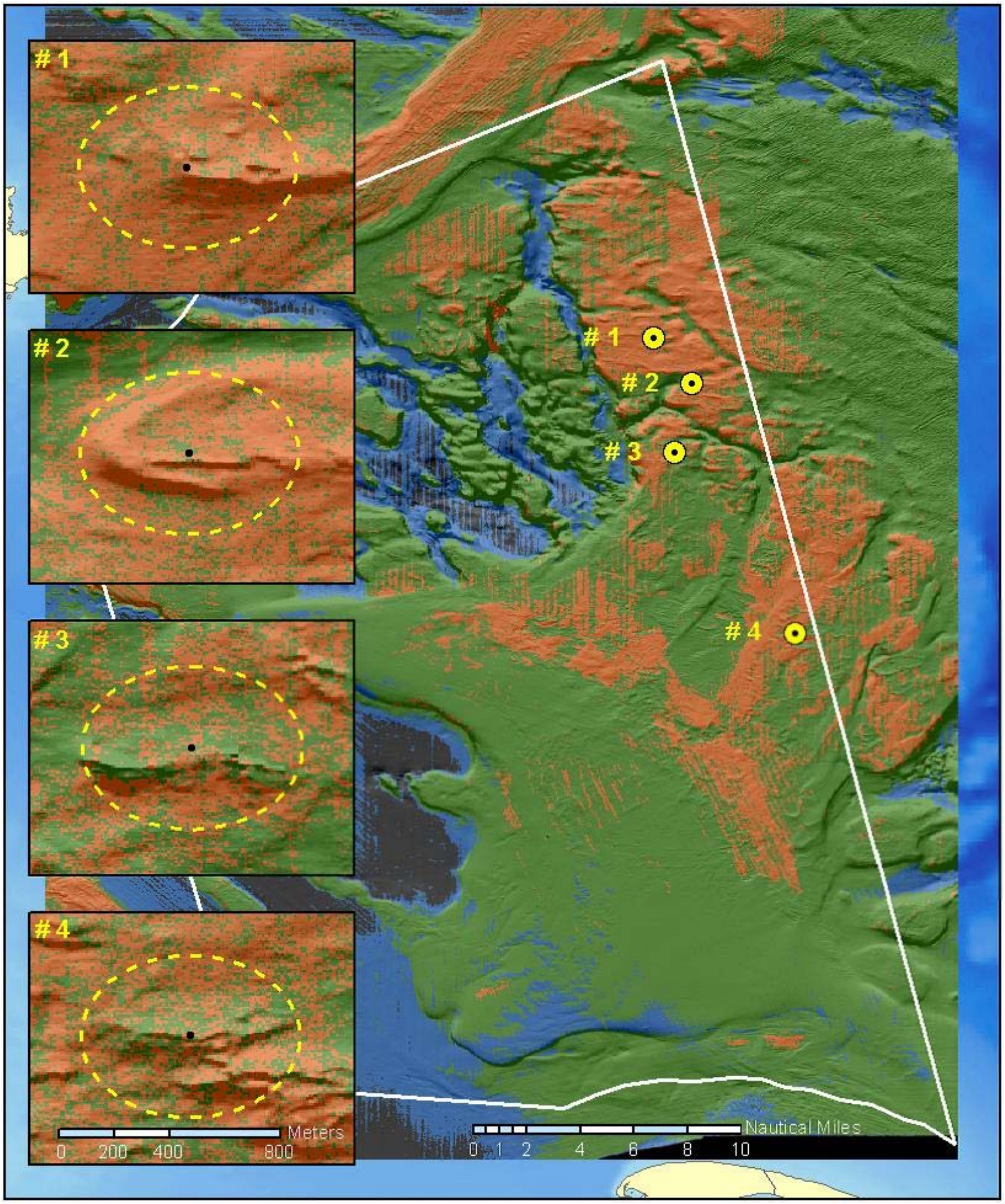

Figure 1. Combined sun-illuminated topography and acoustic backscatter map of VR2 receiver sites at piled boulder reefs in the SBNMS. Each receiver is shown with an estimated radius of detection of 400m.

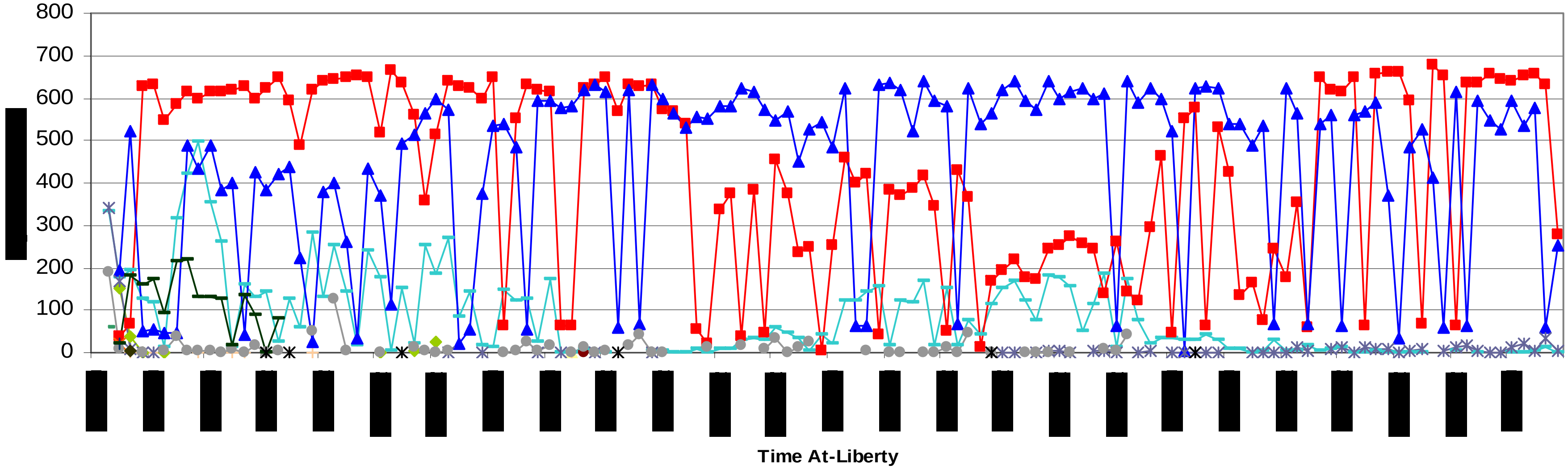

Figure 2. The number of transmitter signal detections per day is shown for multiple Atlantic cod tagged at one of the four deep boulder reef sites in 2002. Each symbol represents a different fish.

Movement of Coral Reef Fishes: The Role of Scale and No-Take Protection in the Conch Reef SPA/RO

The largely sedentary behavior of many fishes on coral reefs is well established. However, information on the movement behavior of individual fish, over fine temporal and spatial scales, continues to be limited. It is precisely this information that will be vital for conservation and management where spatial management measures (such as marine reserves) are under consideration. From 2001 through 2003, a total of 120 fish—including black grouper, yellowtail snapper, blue and princess parrotfish, and hogfish—were tagged in the vicinity of Conch Reef in the northern Florida Keys. Multiple VR2 receivers were deployed at each named reefs from Alligator Reef to Carysfort Reef. Though some movement was recorded to the north and south of Conch Reef, the majority of fish showed strong site fidelity to the reef. Movements within the Conch Reef complex were extensive, but the limited number of receivers located there did not allow for precise quantification of movement behavior. During the November 2005 *Aquarius* mission, the receiver array (26 receivers) will be collapsed to cover the SPA/RO at Conch Reef and the surrounding fished areas. A total of 100 fish, including black and red groupers, yellowtail snapper, blue parrotfish, and hogfish, will be collected, surgically-tagged, released and subsequently tracked by saturation divers during the 10-day mission, while the VR2 array will record movements at a larger spatial and temporal scale. The placement of the receivers will allow us to 1) track movements of tagged fishes within the reserve, 2) record any spillover of tagged fish from the reserve into surrounding fished areas, and 3) record any movement away from Conch Reef to the north or south, for up to 1 year following the *Aquarius* mission.

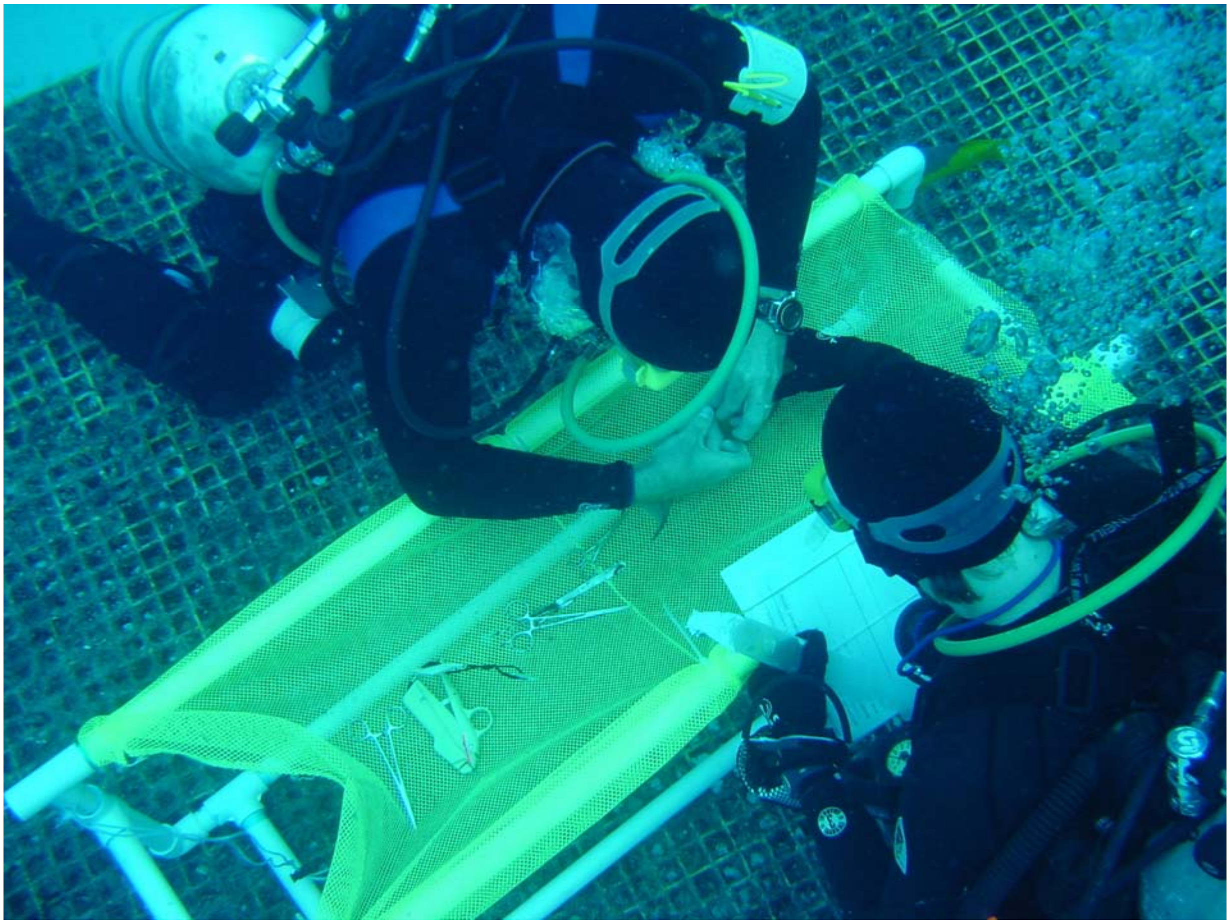

Figure 1. Saturation divers surgically implant a coded-acoustic transmitter in a hogfish (*Lachnolaimus maximus*) on a platform adjacent to the *Aquarius* Undersea Laboratory (From Lindholm et al. 2005).

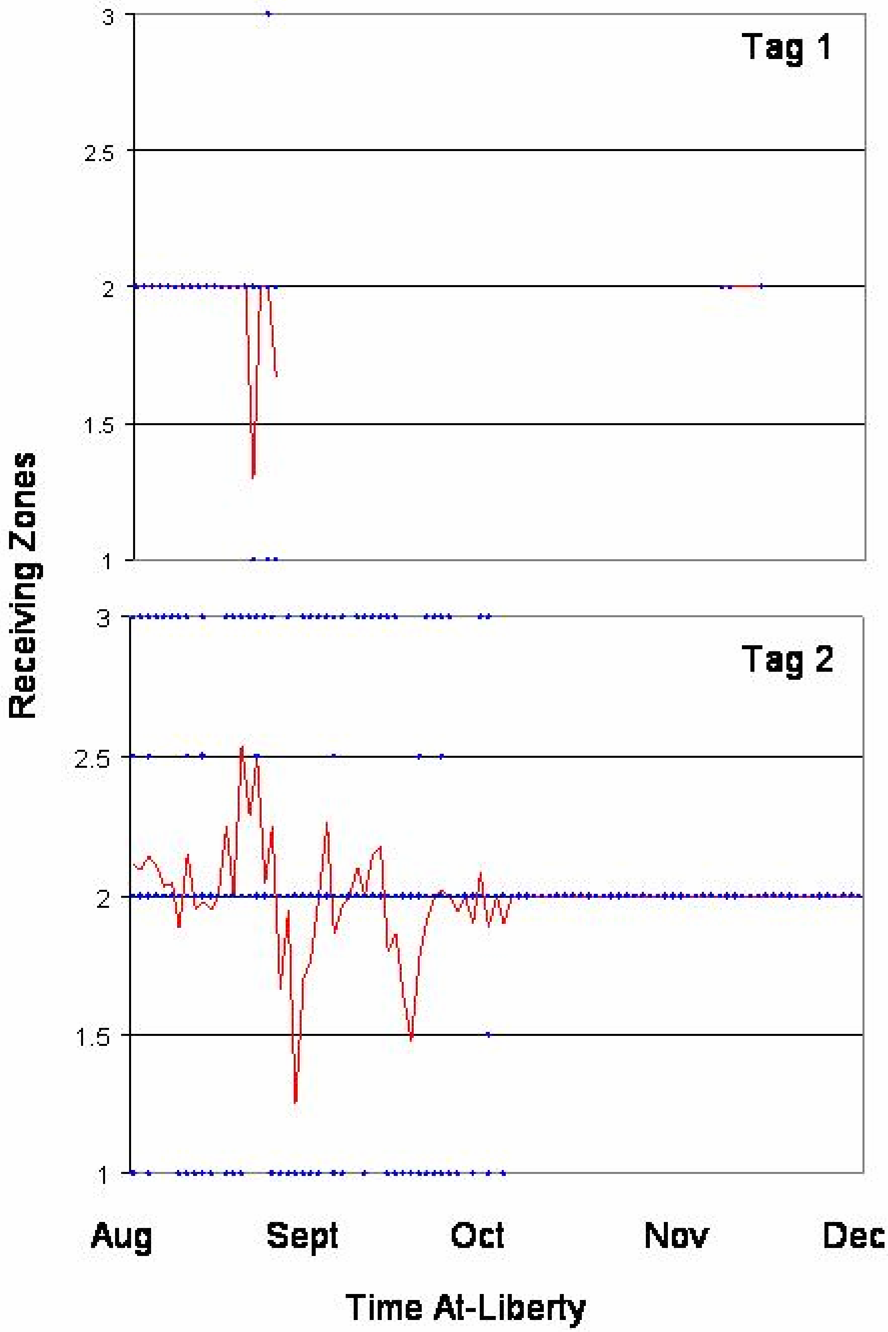

Figure 2. Movement data for two tagged hogfish among five receiving zones at Conch Reef in the northern Florida Keys from August 29th through December 2nd, 2002. Blue circles represent days for which a given transmitter was detected at a particular zone. The average behavior of the tagged fish over time is depicted by the red line. (From Lindholm et al. In Review)

Christopher Lowe, University of California at Long Beach

We have been using VR1-2's since 1998 and have used them on a variety of projects and to answer a variety of questions. In most cases, we have used them in concert with manual tracking and standard tag and recapture methods to define home ranges of nearshore fishes over varying spatial and temporal scales. In some cases, we have used VR technology to address questions of site fidelity at remote locations where manual tracking was not logistically feasible. The following provides some examples of how we have used VR technology on various projects over the last 6 years.

Increased shark-related mortalities on endangered monk seal pups in the Northwestern Hawaiian Islands, raised questions as to whether large sharks such as tiger and Galapagos sharks were routinely patrolling small islets that seals use as nurseries at French Frigate Shoals. To test this hypothesis, we placed VR1s around all the major islets at FFS and tagged 12 tiger sharks and 3 Galapagos sharks with V16-R256 tags (batt. life ~ 4 years) from 1999-2002. All sharks were detected at islets around the atoll; however, tiger sharks were detected significantly more often at East Isl. (where most of the blackfooted albatross chicks are fledged) during summer month and during morning hours. Galapagos sharks were most often detected at Trig Isl. (where most of the monk seal pup). Using VR1 technology at this remote, hard to access field site, we were able to conclude that Galapagos sharks only occasionally patrol Trig Isl, and based on visual observations are responsible for a majority of the monk seal pup deaths. Tiger sharks, however, focus on East Isl. during morning hours in summer months to take advantage of fledging albatrosses. Some of the results of this study and a description of the methods are currently being published as part of a symposium proceedings (3rd Symposium on the Northwestern Hawaiian Islands – Atoll Research Bulletin). Another manuscript is currently in prep describing how some large sharks focus activity around these islands because they offer concentrated sources of semi-terrestrial prey.

We have also used VR technology to describe the home ranges and site fidelity of nearshore gamefishes in no-take marine reserves. This research has occurred in both tropical (Hawaii and Palmyra Atoll) and temperate settings (southern California). Over the last 6 years we have been acoustically monitoring the site fidelity of kelp bass, sheephead, ocean whitefish, barred sand bass, and leopard sharks in a small no-take MPA (0.13 km^2) at Catalina Island, California. Results from acoustic monitoring coupled with manual tracking have indicated that kelp bass and sheephead exhibit relatively small home ranges and show long term fidelity to these home ranges (at least 1 year) (Lowe et al. 2003, Topping et al. 2005); however, sheephead exhibit seasonal increases in area use that were only detectable using acoustic monitoring (VR technology) (Topping et al. accepted). Similar work has been done in Hawaii quantifying the movements of giant trevally at Midway Atoll, part of the National Wildlife Sanctuary (Lowe et al. in press). We are also currently using VR2s to quantify lagoon fidelity of bonefish, blacktip reef sharks, whitetip reef sharks, and giant trevally at Palmyra Atoll (Friedlander et al. in review).

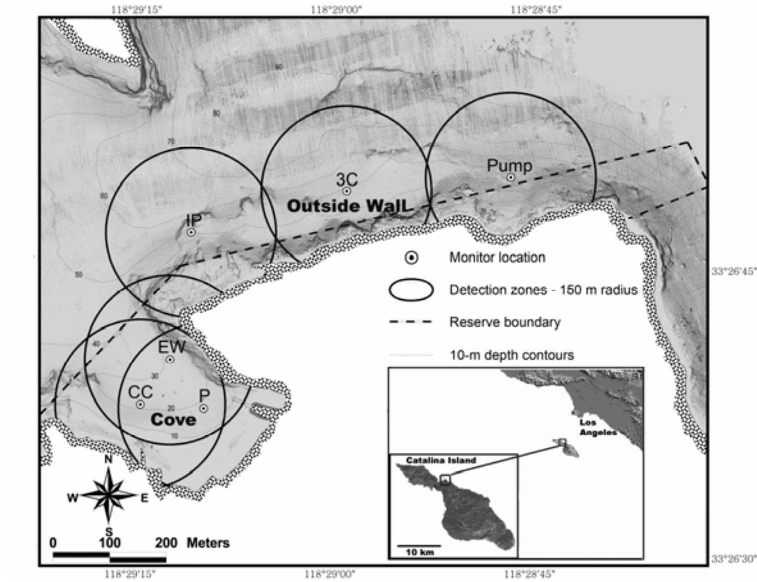

Fig. 1. Location of VR1 receivers throughout the Catalina Island Marine Science Center Refuge (Topping et al. accepted).

We have also been using VR technology to monitor the site fidelity of reef associated fishes to offshore petroleum platforms off the coast of southern California. Debate over decommissioning of these platforms along with evidence that these platforms may be the last vestige of some rockfish species in southern California has raise concerns over the ecological importance of these platforms. We have tagged 100 fish of 17 different species at 3 platforms in the Santa Barbara Channel and have monitored their site fidelity over the last 1.5 years. VR receivers enabled us to determine post-release survivorship and emigration away from one platform towards others over this time span. We have also been able to document intra-platform movements by placing VR receivers at different locations on the platform. This work is ongoing and a 2nd phase of the research will commence in 2006, when we will translocate reef fish from platforms in the channel to neighboring natural reefs to see whether fish will "home" back to their original capture location.

We have used VR2 receivers to document longshore movements of round stingrays along an open coastal beach in southern California. Tag detection range was found to vary considerably in the shallow, surf zone (range: 40-400m). Twenty five round stingrays were tagged at Seal Beach, Calif. and their fidelity to the San Gabriel River mouth was monitored using V8SC-R4k tags. Rays were found to show season fidelity to Seal Beach and were recaptured as far away as 50 km (Vaudo & Lowe, in press).

Topping, D.T., **C.G. Lowe**, and J.E. Caselle. (accepted). Site fidelity and seasonal movement patterns of adult California sheephead, *Semicossyphus pulcher* (Labridae), ascertained via long-term acoustic monitoring. Marine Ecology Progress Series.

Vaudo, J.J. and **C.G. Lowe**. (*in press*). Movement patterns of round stingrays (*Urobatis halleri*) near a thermal outfall. Journal of Fish Biology.

Lowe, C.G., B.M. Wetherbee, and C.G. Meyer. (*in press*). Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and giant trevally around French Frigate Shoals and Midway Atoll. Atoll Research Bulletin.

Topping, D.T., **C.G. Lowe**, and J. Caselle. 2005. Home range and habitat utilization of adult California sheephead, *Semicossyphus pulcher* (Labridae), in a temperate no-take marine reserve. Marine Biology 147:301-311.

Lowe, C.G., D.T. Topping, D.P. Cartamil, and Y.P. Papastamatiou. 2003. Movement patterns, home range and habitat utilization of adult kelp bass (*Paralabrax clathratus*) in a temperate no-take marine reserve. Marine Ecology Progress Series 256:205-216.

Carl Meyer, University of Hawaii

The overarching feature of our VR2 use in Hawaii is the creation of an ’informal’ Archipelago-wide array. This allows us to investigate animal movements across a broad range of spatial scales. Thus we can detect very long distance movements (up to 2,600km) of tagged animals, and also address questions of site fidelity and relatively fine-scale habitat use. The array is modular, being made up of VR2 clusters that have been deployed by 8 researchers at intervals along the Hawaiian Chain. Each cluster has been deployed to answer specific, relatively fine-scale questions at a particular site. Collectively Hawaii researchers are quantifying movements of 21 species including fish, sharks and sea turtles. In addition to collecting large volumes of fine-scale movement data, the array has detected long distance (>50km) movements of 4 species and inter-island movements by 2 species. The number of researchers & species under investigation continues to grow. This presents us with both challenge & opportunity. The challenges include transmitter code management and continued willingness to share VR2 data files among independent researchers. The major opportunity is the ability to detect long-distance movements of target species using an extensive monitoring array that would be beyond the scope of resources of most individual researchers.

Mary Moser, Northwest Fisheries Science Center NOAA-Fisheries

Use of acoustic telemetry to document English sole (*Parophrys vetulus*) movements: application to management of contaminated sediments.

Mary L. Moser[1], Mark S. Myers[1], Sandra M. O'Neill[2], Steve L. Katz[1], Stephen R. Quinnell[2], and James E. West[2]

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Assessments of estuarine and marine fish exposure to contaminated sites have traditionally relied on indirect evidence, such as the capture of sentinel species in these areas and/or the presence of high contaminant levels in various fish tissues. Along the Pacific Coast of North America, English sole (*Parophrys vetulus*) are used as a sentinel species because they are broadly distributed in benthic habitats where they would contact contaminated sediment. English sole are also an effective sentinel species because they seem to show high fidelity to feeding areas, migrating only in winter for spawning (Day 1976). Strong correlations between sediment polycyclic aromatic hydrocarbons (PAHs) and the prevalence of neoplastic and preneoplastic liver diseases in English sole collected from contaminated areas also suggests high site fidelity (Myers et al. 1999). However, the amount of time adult English sole spend in contaminated areas and the spatial extent of their summer feeding movements have never been assessed directly.

We tested the use of acoustic telemetry to document the time individual English sole spent in contaminated areas and whether they showed inter-annual fidelity to these sites. This work was conducted in Eagle Harbor, a small, PAH-contaminated embayment of Puget Sound, Washington (Figure 1). This site was selected because it has been the subject of an ongoing study of sediment contamination and its effects on fish health (Myers et al. 2003). In 1994, a contaminated subtidal area of Eagle Harbor was covered with a cap of clean sediment (Figure 1). Subsequent testing for toxicopathic lesions and several direct measures of PAH exposure in English sole trawled from this embayment was used to determine whether remediation was successful (Myers et al. 2003). Now estimates of English sole home range are needed to more precisely link the degree of contaminant exposure with fish health. Acoustic telemetry in this small study area seemed to be a logical tool for documentation of English sole movements in and around contaminated sites.

Methods

Initial laboratory experiments in 2003 verified that acoustic transmitters could be surgically implanted into adult English sole without tag expulsion or negative effects on survival or feeding within the first month of tagging (Moser et al. In Press). In the summers of 2003 and 2004, we trawled adult English sole from Eagle Harbor and surgically implanted uniquely-coded acoustic transmitters in 39 of the largest (> 27 cm) fish. The transmitters (Vemco V8 series) were 9 × 30 mm cylinders weighing 5 g. We tested both high (147 dB) and low (139 dB) power transmitters set at a variety of pulse intervals (20-60 s, 40-120 s, and 180-360 s).

After their release near the capture site, the sole were detected during periodic scans of set listening posts with a portable receiver (Vemco VR60) and/or by a continuously scanning array of underwater receivers (Vemco VR2) (Figure 1). We also tested use of a three-dimensional positioning system (Vemco VRAP) to document small scale (on the order of meters) sole movements. The positioning system was deployed in Eagle Harbor near the known locations of two English sole and two stationary transmitting beacons were also deployed nearby. Position information for the four targets was taken over a 24 hr period, with the hope of observing diel patterns of fish movement.

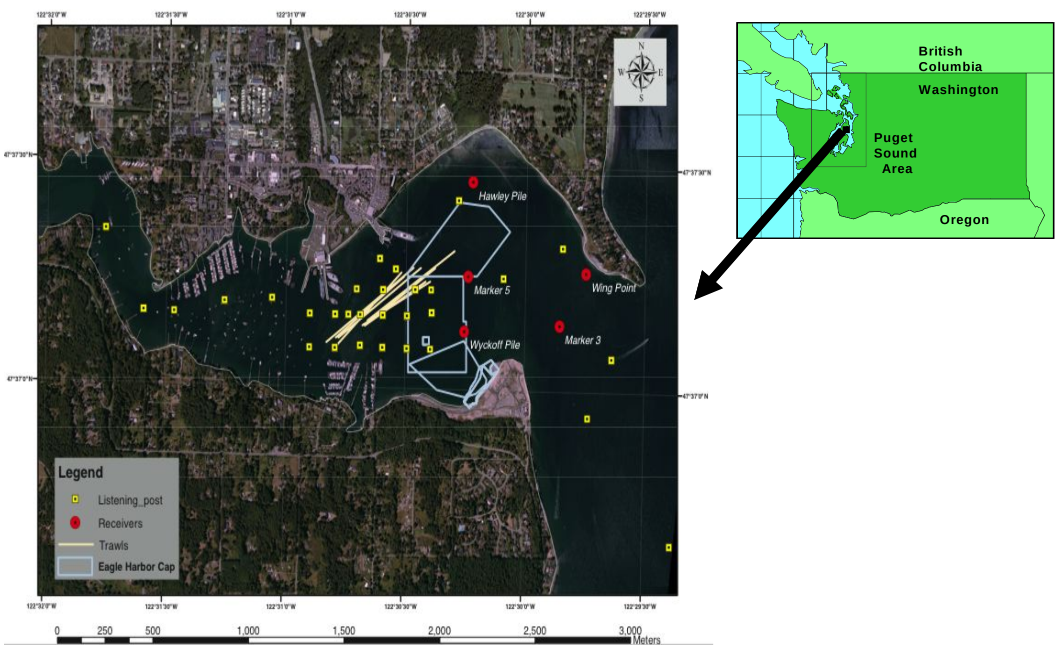

Figure 1. Aerial photograph of Eagle Harbor with fixed receiver locations (red), mobile listening posts (yellow), trawl lines (white) and location of the sediment cap (blue) denoted.

What Worked

Surgical implantation of the transmitters seemed to work well, particularly in the second year when fish were allowed to recover from surgery in a submerged cage for several days prior to release. The fixed receiver arrays detected all but one of the English sole that exited Eagle Harbor and provided valuable information on the diel and seasonal patterns of fish movement. The low power transmitters set at a 20-60 s pulse interval proved most useful. The low power reduced transmission collisions (which result in the inability to identify fish codes) and improved spatial resolution, while the shorter burst interval reduced the time needed to scan listening posts. In addition, these transmitters had an extended battery life, which allowed us to document the return of English sole to Eagle Harbor in the second and third summers of the project.

What Did Not Work and Recommendations

Our study was limited by the inability to develop accurate, high resolution (< 100 m) maps of English sole home range from mobile tracking. The time intensive process of scanning listening posts would have been easier with a receiver that automatically triangulates fish position (expensive). We needed daily, or even hourly, calibration of transmission range, due to the effects of passing algal blooms and ferry traffic in this acoustically-challenging study area (time-consuming). An automated system to conduct and incorporate these calibrations would result in more accurate home range delineation. Tag miniaturization would also allow study of a greater size range of English sole.

Downloading receiver arrays, which in some cases required dive operations, would have been eased by the addition of wireless communication with the receivers. Cell phone links would allow downloading from the laboratory and reduce the need for expensive boat and dive operations. The usefulness of data obtained from the fixed receiver arrays was constrained by the large (over one second per day), and unpredictable amount of drift in receiver time stamps. This is a common problem among logging receivers and should be remedied.

Finally, we were disappointed with the results from the VRAP positioning system. In addition to the high cost of this equipment and the expertise needed to set it up, we found that its application was very restricted. The system was most accurate (± 1.5 m) when stationary targets were inside the relatively small envelope of system reception (a triangle of 450 m on a side). Precision of stationary target location outside of this envelope was unsatisfactory (± 60 m). Thus, the system was strongly dependant on position of the fish, which move relative to the hydrophone array. Dynamic position referencing, via on-board GPS or referencing stationary pingers perhaps, would greatly improve the performance of systems like VRAP. While this technology shows great promise, we did not pursue its use further due to results of this trial.

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Gretta Pecl, University of Tasmania

ADDRESSING SPATIAL MANAGEMENT ISSUES OF MOBILE SPECIES WITH ACOUSTIC TELEMETRY

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Management concerns about escalating catch and effort levels for southern calamary in Tasmania, Australia, led to the introduction of a three-month block closure of the two main regions, separated by 25-35km, where calamary aggregate to spawn and are therefore targeted by the fishery. As calamary are a predatory and highly mobile species, questions have been raised concerning the relationship between populations within the adjacent areas of Great Oyster Bay and Mercury Passage, and the degree of protection that closing these areas may be providing to spawning animals. Eighty-three VR2 receiver stations moored throughout the east coast were used to detect detailed movements of 46 acoustically tagged squid, where each receiver could detect and record the date, time and unique ID number of an acoustically tagged squid every time it swam within 300-500m of the receiver. The receivers were placed along the boundaries of Great Oyster Bay and Mercury Passage, across smaller bays within these areas, and on individual seagrass beds. Over 118,000 ‘hits’ were obtained on the VR2’s with the data clearly demonstrating that calamary are very active during the spawning season, with many squid easily travelling a minimum of 100’s of km within a few weeks. Although most squid were travelling distances much greater than the 25-35km gap between Great Oyster Bay and Mercury Passage, movement of squid between these two areas was not detected. The placement of the receivers also allowed an estimate of the percentage of time that squid were staying within the closed area, and therefore protected from commercial fishing. Squid were detected on the boundaries of the closed areas, however, most squid were detected again on other receivers within the closed area, indicating that although squid had moved within the vicinity of the boundary they had not actually left the closed, and therefore protected area.

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Utilizing passive and real-time telemetry to examine the movement of *Octopus maorum* in relation to a unique fishery

Examining movement and migration patterns of cephalopods is essential for understanding population dynamics and managing their stocks. Large numbers of *Octopus maorum* move into the dead-end bottleneck of Eaglehawk Neck, Tasmania throughout the year and are easily captured by fishers. Understanding why *O. maorum* aggregate in this narrow embayment is important for ensuring sustainable harvesting. Broad-scale movement of *O. maorum* was examined using curtain-arrays of passive acoustic 'listening stations', such that individually tagged octopus were identified and recorded if they moved in or out of Eaglehawk Neck. A real-time acoustic positioning system tracked octopus on a finer scale within the neck. Tagged octopus did not enter or leave the bay during the study, with most animals remaining near the tagging site. Some animals, however, did undergo large movements of up to 4km. Both real-time and passive monitoring demonstrating that O. maorum were night active. Some tagged octopus were caught by fishers, while others remained mobile within the fishery. All octopus captured by the fishery were mature, with 60% female. This research demonstrated that not all octopus in the region move into Eaglehawk Neck, but those that do may do so to mate and/or spawn, creating the potential for recruitment over-fishing.

WHY WON'T MY OCTOPUS COME BACK: UTILIZING PASSIVE TELEMETRY TO UNDERSTAND THE DYNAMICS OF AN OCTOPUS POPULATION

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Traditional tag-recapture studies have long been used to examine movement of marine animals and provide an understanding of population dynamics. However, the disadvantage of these types of studies is the animals have to be recaptured to provide information. A tag-recapture program was undertaken to examine the movement and population structure/dynamics of the maori octopus *Octopus maorum* on an inshore temperate reef in Tasmania, Australia. During monthly sampling over the period of a year 49 octopus were captured in baited lobster traps and tagged with PIT tags and released. Of these tagged animals, however, only 7 were recaptured, with 6 recaptured within a few days of their initial capture and 1 in the following month. This posed the question: Why were there no long-term recaptures? To help answer this question, a complex-array of passive acoustic 'listening stations' was established on the reef, such that individually tagged octopus could be identified and recorded as they moved around the reef. 20 octopus were tagged with uniquely coded acoustic tags and tracked passively. This talk presents preliminary data from this study, which suggests that *Octopus maorum* may only be a short-term resident on reefs, explaining the low recapture rate in the initial tag-recapture study.

Mike Shane, Hubbs-SeaWorld Research Institute

Since 1986 over 1.1 million cultured white seabass have been released into the marine waters of southern California as part of California's Ocean Resources Enhancement and Hatchery Program. To date we have recovered over 1,400 of these fish which have provided limited information in regards to their growth, survival, and movement. Furthermore we have little understanding of their short term survival and movement after their release. For the past 6 years we have employed VEMCO's acoustic telemetry technology to gain clearer insights into these processes. With this methodology we have observed emigration rates from embayments, short term survivorship, and predation by octopods, birds, and marine mammals. In 2004 about 48% of cultured white seabass emigrated from their emabyment within the first week (Fig. 1). For those that stayed in the embayments, only on one occasion did a fish permanently emigrate after the first week. The rest either had their tags recovered from the bottom (39%), or were not heard from after 4 days (35%) or between 14 to 79 days (22%). Additionally we need to improve our knowledge of their survivorship and movement patterns along the nearshore coast after these fish emigrate from their release embayments.

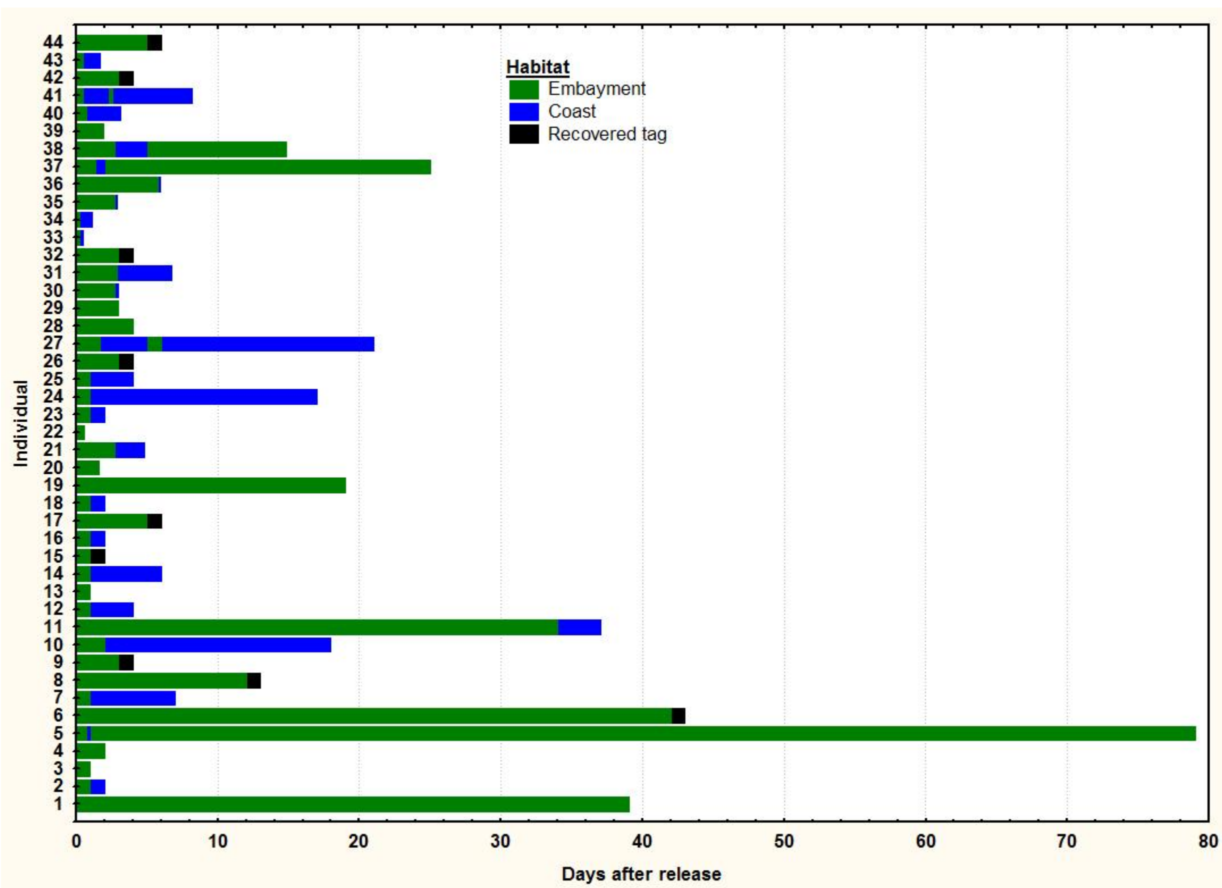


Figure 1. Results of cultured white seabass released into embayments in 2004.

Colin Simpfendorfer, Mote Marine Laboratory

Site fidelity of juvenile smalltooth sawfish in southwest Florida nursery habitats.

The site fidelity of juvenile smalltooth sawfish to nursery habitats at two sites in southwest Florida are being assessed using acoustic monitoring. Nursery habitats were identified using scientific surveys and sightings reports from the public. Three VemcoVR2 receivers were moored in each of two sites (Mud Bay and Faka Union Bay) and downloaded every 1-3 months. Each site is very shallow, with maximum water depths of 1.0 m. Juvenile sawfish ranging in size from 78 cm to 170 cm were externally fitted with Vemco V8SC or V9P acoustic tags to investigate residence time and site fidelity. Data were analyzed graphically to investigate residence time. Small juveniles (<100 cm) showed short residence times (mostly <14 days) in individual sites, while larger juveniles (>130 cm) showed extended residence times. Further data analysis is underway, focusing mostly on parameterizing the presence/absence data for use with multivariate statistics. It is hoped that this approach will enable changes in habitat use patterns within the nursery habitats to be elucidated. The results of this research are being used to aid in development of a recovery plan for this newly endangered species.

Rick Starr, UC Sea Grant Program and Moss Landing Marine Labs

Sonic tagging and automated tracking of Pacific fishes, lingcod, and tropical groupers.

As populations of marine fishes have declined in many of the world's coastal oceans, there has been increasing interest in regional fishery management and especially in the use of marine protected areas. We have used acoustic tagging and tracking technologies to gather information about both short and long-term movements, natural mortality, and behavior of a variety of coastal fishes. In California in 1997 and 1998, we tagged bocaccio and greenspotted rockfishes underwater using SCUBA, and tracked tagged fish for a four-month period by using an array of receivers moored along the edge of a submarine canyon. In 1999 and 2000, we tagged 83 lingcod in an area closed to fishing in Alaska. An array of acoustic monitors moored around the perimeter of the closed area continuously recorded signals transmitted from tagged fish for an 18-month period. From 2001 – 2004, we tagged and tracked Nassau groupers at Glover's Reef, Belize, as they migrated to and from a spawning site. In 2003, we tagged Mediterranean groupers to evaluate site fidelity in the Medes Islands marine reserves in Spain. Currently we are tagging and tracking a total of about 100 black rockfish, lingcod, cabezon, grass rockfish, and other nearshore fishes in Central California to provide information about movements in and around kelp beds. We have about 18 receivers placed with overlapping receiving ranges in Carmel Bay, California. Two of our Moss Landing Marine Labs students are also tracking leopard and prickly sharks.

Steve Szedlmayer, Auburn University

Schroepfer R.L. and S.T. Szedlmayer. In press. Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico. Bull. Mar. Sci.

Questions remain concerning long-term residence and site fidelity of red snapper *Lutjanus campechanus* (Poey, 1860) on artificial reefs in the northeastern Gulf of Mexico. We used event analysis to estimate long-term residency of ultrasonic tagged red snapper, and arrays of 4 to 5 remote receivers to further define site fidelity associated with artificial reefs. Using event analysis, we estimated a median residence time of 373 d, almost double previous estimates. Based upon data from the remote receiver arrays, for the most part (99 % of total time) fish (87%, 13 of 15) stayed within a 200 m radius of their original release site. Exceptions included one fish that frequented both the center reef site and an area to the south of the release site, and another fish that quickly left the center reef site after tagging. These estimates of long-term residence and site fidelity further suggest that artificial reefs provide suitable habitat for *L. campechanus*.

Other published telemetry papers: TAFS 134:315-325, Copeia 1997(4):846-850, JFB 65:973-986, Copeia 1993(3):728-736

POST
PACIFIC OCEAN SHELF TRACKING PROJECT

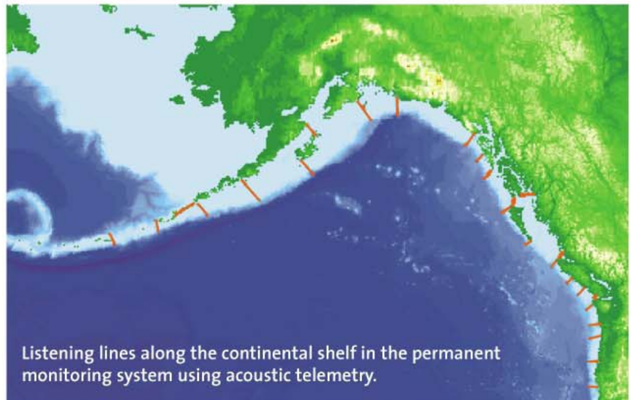
Solving Ocean Mysteries

POST is solving the mystery of where salmon go once they leave the rivers. The acoustic tracking technology is also useful for monitoring the movements and survivals of other marine animals.

POST, managed by the Vancouver Aquarium Marine Science Centre, is one of 13 projects around the world contributing to the Census of Marine Life – a ten-year initiative, launched in 2000, to assess and explain the diversity, distribution and abundance of marine life in the oceans – past, present and future.

Participating organisations include:

- B.C. Ministry of Water, Land and Air Protection
- Fisheries and Oceans Canada
- Pacific Salmon Foundation
- University of British Columbia
- University of Washington
- Malaspina University-College
- Bonneville Power Administration
- US National Oceanographic and Atmospheric Administration



Listening lines along the continental shelf in the permanent monitoring system using acoustic telemetry.

1: Two sizes of acoustic tags used on salmon smolts as small as 12 cm.

2: Receiver to be lowered onto seabed to make up the nodes on the listening line.

Funded by: CENSUS OF MARINE LIFE; Gordon and Betty MOORE FOUNDATION

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POST

PACIFIC OCEAN SHELF TRACKING PROJECT

Acoustic Tracking Technology

Acoustic tags (measuring 7-9 mm in diameter; 20-27 mm in length) are surgically inserted into the abdomen of fish such as salmon smolts as small as 12 cm. The tags emit high-pitched pings that uniquely identify each individual. Listening stations are placed on the seabed along the continental shelf to record the time the fish pass over them. To extend battery life, tags can be programmed to turn off after the fish leave the continental shelf and turn on again when they return. For larger fish, weighing 2-5 kg or greater, tags with life spans of 10-20+ years are potentially feasible.

The Permanent Coastal Array

Work is underway to prepare for the deployment of a permanent system, capable of tracking over 250,000 tagged animals simultaneously, including sea turtles, sharks and marine mammals. The modular receiver units, which will have life spans of 5-10 years, can also host sensors for measuring temperature, salinity and other oceanographic information. Small boats with hydrophones will periodically pass over the lines to retrieve the data from the receivers and transmit the information back to land and subsequently to participating scientists.

2004 Field Trials

In 2004 the POST team tagged over 1000 smolts from eight river systems. These included the Coldwater (Thompson River) coho, and Cultus Lake and Sakinaw Lake sockeye, three key Canadian salmon stocks with major conservation concerns. With the help of local fishermen, we put down 137 receivers to form six major listening lines, each about 20 km long. We achieved detection rates of over 90% for each line. We recorded some fish moving at 2-3 body lengths per second over many weeks. The data showed that smolt survival after entering the ocean was high, contradicting common assumption that smolts have trouble adjusting to seawater and fall prey to predators. Mortality appears to occur throughout the freshwater and marine system with a steady attrition in numbers at all monitored locations. We also saw differences in survival and migration patterns between species and sometimes between stocks of the same species.

The 2004 lines also detected green sturgeon tagged in the United States. One of these fish swam the 480 km distance from the Brooks Peninsula off NW Vancouver Island to Grays Harbor, Washington, in four days! The success in tracking these enigmatic animals (which are potentially endangered in the US) points to the importance of a permanent system that can track many species at once.

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