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REVIEWS

# A review of detection range testing in aquatic passive acoustic telemetry studies

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**Abstract** Passive acoustic telemetry provides an important tool to study the spatial ecology and behaviour of organisms in marine and freshwater systems, but understanding the detection range of acoustic receivers is critical for interpreting acoustic data and establishing receiver spacing to maximize study efficiency. This study presents a comprehensive review of how acoustic detection range has been considered and assessed to date, summarizes important variables to monitor when determining the detection range of a receiver array, and provides recommendations to account for detection range during experimental design, analysis and data interpretation. A total of 378 passive acoustic telemetry studies (1986–2012) were scored against a set of pre-defined criteria to provide a standardized assessment of how well detection range was accounted for, from a maximum possible score of 45. Scores ranged from 0 to 39 (11.1 ± 0.4; mean ± 1 SE). Over the past decade mean scores have been consistently between 6.7 and 12.9 which indicates that detection range has not been adequately considered in most contemporary acoustic telemetry studies. Given the highly variable nature of detection range over space and time, it is necessary to create a culture of detection range testing among the scientific community. For robust telemetry studies it is recommended that consideration of detection range should be given a greater focus within study design, execution and data analysis. To aid array design in new systems, short-term detection range tests should be conducted in the most representative area of the study system prior to deployment. As well, fixed distance

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sentinel tags should ideally be deployed at a representative receiver site within the array to provide a continuous assessment of detection range and influential environmental parameters should be monitored to facilitate modeling of detection range variability over time. When warranted, data analysis should incorporate modeled variation in detection ranges.

**Keywords** Acoustic telemetry · Ultrasonic telemetry · Passive telemetry · Range test · Detection range · Animal movement

## Introduction

Acoustic telemetry[1] has expanded our ability to study the spatial ecology and behaviour of aquatic organisms in marine and freshwater systems, providing insights into species well beyond what can be directly observed (e.g. with SCUBA or underwater video). Acoustic telemetry was first undertaken in the 1970s (Kanwisher et al. 1974; Ireland and Barlow 1978) and was predominantly based upon active tracking, whereby the target organism is equipped with an acoustic tag and then followed in real time by a boat with a directional hydrophone and above-water acoustic receiver. The location of the target animal is estimated in relation to the tracking vessel, based upon a compass bearing and perceived signal strength. This technique is extremely labour intensive, but provided one of the only methods to track real time movements of aquatic animals, especially in large deep lakes or oceans. Passive acoustic telemetry evolved in the late 1980s (McKibben and Nelson 1986; Klimley and Butler 1988; Klimley et al. 1988), where the hydrophone/receiver setup is combined into a stand-alone archival battery powered underwater receiving unit, or as a series of hydrophones that relay information to a central receiver through underwater cables or wirelessly via radio signals (Heupel and Webber 2012). Detections of acoustically tagged animals are then recorded and archived on the receiver unit for later processing. Units can be deployed independently or as part of a receiver array for prolonged periods, and serviced (e.g. downloaded, battery change if not powered independently, cleaned of fouling) at intervals based on technical or logistic constraints.

The advent of passive acoustic telemetry offers several major benefits over active acoustic telemetry (Heupel et al. 2006). Firstly, passive telemetry is less labour intensive, as once the animals are tagged and the array established, data collection operates autonomously until data download and/or monitor maintenance is required. Secondly, data is collected 24 h a day, seven days a week for the period the receivers are deployed and the battery life of the acoustic tags. This is in contrast to active tracking where the period of data collection is dependent on the longevity of the tracking crew and can be interrupted or delayed by poor weather conditions. Passive telemetry also poses far less disturbance than active tracking, which involves a vessel and crew physically following the animal. Thirdly, passive telemetry can track multiple individuals, either of the same or of several different species, simultaneously within a single receiver array (Clements et al. 2005). This has enabled the investigation of far more complex ecological questions (Payne et al. 2010) such as abundance distribution/habitat utilization and predator prey distribution and interactions at an ecosystem level (Heupel and Webber 2012). Lastly, multiple receiver arrays over broad spatial scales (e.g. ocean basins or entire coast lines) can provide an international network that serves as a communal resource for tracking animals over vast distances, including national and international political boundaries (Welch et al. 2002; Cooke et al. 2011).

As a result of the above benefits, the recent technological advancement of the receivers and increasing financial accessibility of the equipment, there has been a sharp increase in the number of passive telemetry based studies over the past three decades (Heupel and Webber 2012; Fig. 1). Passive telemetry, as with all ecological tools, however has certain limitations including: (1) the need for several receivers to define movements, as opposed to just one for active tracking, requiring greater capital investment in equipment; (2) challenges with deploying receivers in some habitats, for example deep water (Domeier 2005); (3) array design and receiver placement is dependent upon either a precursory knowledge or educated prediction of the target species movements/habitat utilization (Heupel et al. 2006; Heupel and Webber 2012); (4) with non-positional array designs, a detection reveals that the study animal is within the detection range of that receiver but the exact location of this animal remains unknown; and importantly (5) an investigator only knows where the study

[1] Has alternatively been referred to as 'ultrasonic telemetry'.

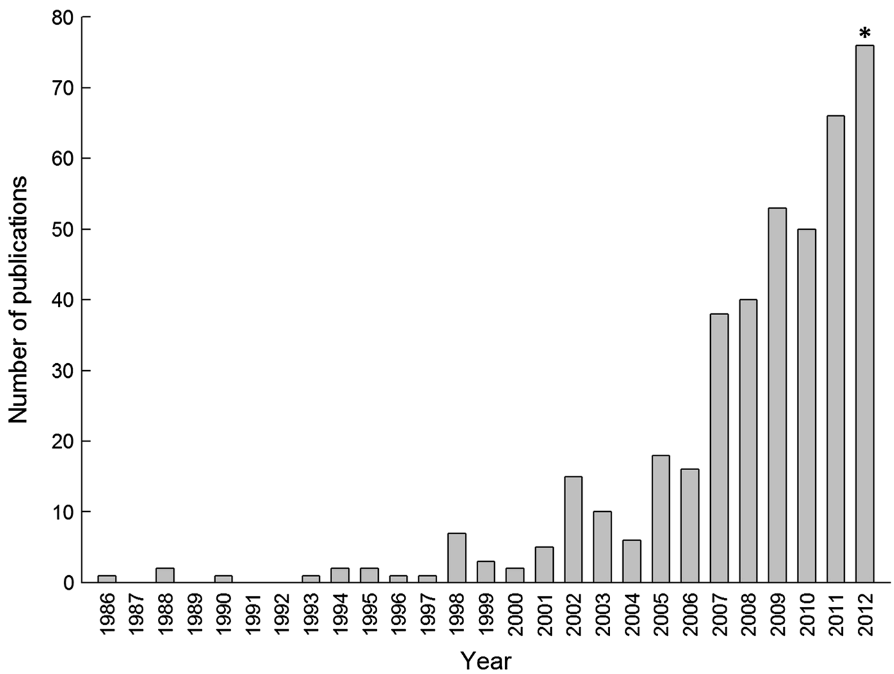


**Fig. 1** Number of passive acoustic telemetry publications by year; *projected total based on first 6 months of 2012

animals are when they are within detection range of at least one acoustic receiver. When animals are not detected it is not possible to state where the animals are or what they are doing. In circumstances where range is greatly reduced a tagged animal may even be in close proximity to the receiver without being detected (Udyawer et al. 2013). In certain systems it is possible to state with a high level of confidence that an organism is upstream or downstream of a line of receivers, or between two receiver lines, but the specific location remains unknown. Consequently, knowledge of the acoustic detection range of receivers during any passive telemetry based study is critical to its successful application and for accurately interpreting the movement and behavior of tagged animals. In addition, this information is required for establishing array spacing and geometry, for example if tracking animals using receiver lines or grids of receivers. Moreover, failure to understand detection range limits and associated detection efficiencies could lead to erroneous conclusions on animal movements that could misinform management (Payne et al. 2010).

With the rapid growth of passive acoustic telemetry, receivers are now being deployed in diverse systems such as rivers and coral reefs, at times associated with human activities and infrastructure (e.g. shipping channels, hydropower facilities), and under various environmental conditions including kelp forests, under ice and in deep-water, further complicating detection range limits and data interpretation. This paper reviews how acoustic detection range has been considered and assessed in the literature to date, considers which variables are most important to consider and monitor to determine the acoustic detection range of a receiver setup, and finally provides recommendations to account for detection range during experimental design, analysis and data interpretation.

## Importance of considering detection range in passive telemetry studies

The basic passive telemetry system employs battery powered acoustic tags[2] and receivers. An acoustic signal is produced by converting electrical energy stored in the battery into acoustic energy, which is transmitted into the aquatic environment through a transducer (Cooke et al. 2012). A receiver, consisting of a hydrophone and receiver unit detects the

[2] Are alternatively referred to as ‘acoustic transmitters’.

propagated signal and reconverts the acoustic energy into electrical energy. This electrical signal is then interpreted by the receiver's processing unit and stored with a time/date stamp on an internal storage device. Detection range exists in passive telemetry studies because the acoustic energy emitted through the tag's transducer is affected by spreading losses, refraction and attenuation as it travels through the water body to the receiver (Singh et al. 2009). In addition, these factors are influenced by the specific properties of the water body, such as salinity, temperature, suspended particles and substrate, which can vary spatially and temporally (Medwin and Clay 1997).

To date, there has been no standardized definition of detection range in the literature, with varying definitions presented by different authors. This has in part been driven by the varying nature of study designs that require different levels of confidence in detection range in order to effectively address research questions (Heupel et al. 2006). Commonly detection range has been defined as the maximum distance receivers within the array are able to detect a tag. Variations on this definition have included a mean maximum detection range, either between receivers or a series of detection range tests (e.g. Field et al. 2011; Andrews et al. 2007; Girard et al. 2007; Speed et al. 2011), a range of maximum detection ranges (e.g. Humston et al. 2005; Bansemer and Bennett 2009; Dagorn et al. 2007; Kerwath et al. 2009), or an absolute maximum detection range (e.g. Lino et al. 2011; Kerwath et al. 2007; Fairchild et al. 2009). Others have defined detection range as a conservative distance relative to the maximum detection range, usually to justify a specific spacing distance between receivers (e.g. Topping and Szedlmayer 2011a; Lacroix and McCurdy 1996; Adams et al. 2009; Serrano et al. 2009). Detection range has also been defined as the distance at which a certain proportion of transmissions are detected, including 100 % (Arendt et al. 2001), 95 % (Whitty et al. 2009), 92 % (Olsen and Moland 2011), 85 % (Espinoza et al. 2011a, b), 80 % (Starr et al. 2000; Lindholm et al. 2007), 50 % (Bessudo et al. 2011; Bertelsen and Hornbeck 2009) and 35 % (Kawabata et al. 2010). Finally, detection range has been defined and presented as the relationship between detection probability and the distance between the receiver and tag (Claisse et al. 2011; Topping and Szedlmayer 2011b). Defining what is meant by 'detection range' within the context of the study is essential and should be outlined and justified relative to the study design and questions being investigated. We propose that to unify the definition, detection range be defined as *the relationship between detection probability and the distance between the receiver and tag*. This can be presented graphically in the form of a logistic curve of detection probability (Fig. 2), derived from the results of detection range testing in the field.

Given environmental heterogeneity, acoustic detection range is unlikely to be constant over the period of a study resulting in variable detection range occurring over time at a set distance between transmitter and receiver (Fig. 3). Aside from positional array designs such as the Vemco Positioning System (VPS; Espinoza et al. 2011b), Lotek MAP System (Cooke et al. 2005; Niezgoda et al. 2002) or the HTI high resolution 3D positioning system (Rillahan et al. 2009), the exact location of a study animal relative to a given receiver is unknown. Therefore, without an understanding of the detection range of the receiver and its variability, it is impossible to interpret what any given detection represents (Payne et al. 2010). With passive acoustic telemetry, it is possible to say, with a high level of confidence, that a particular animal was present within a certain volume of water. However, it is difficult to establish with certainty that a study animal is not within a given volume. In fact, it is not possible to state that an animal is not in a defined volume of water without a proper understanding of the acoustic properties of that water body at the time of the detection. A thorough understanding of a receiver or array's detection range increases the confidence of statements relative to the absence of a study animal from the study system (Udyawer et al. 2013). Through the use of fixed tags, often referred to as 'sentinel tags', Payne et al. (2010) demonstrated that apparent diel behaviour patterns in cuttlefish could be explained by diel variation in tag detection efficiency. Thus, assessing and monitoring the dynamic nature of detection range within a given study array is an essential prerequisite to be able to make reliable behavioural inferences from acoustic detections.

The importance of understanding the acoustic detection range of the receivers within an array can vary dependent on the array design and the question/s being investigated (Heupel et al. 2006). Studies examining the timing, scale and survival of individuals that undertake large scale movements/migrations

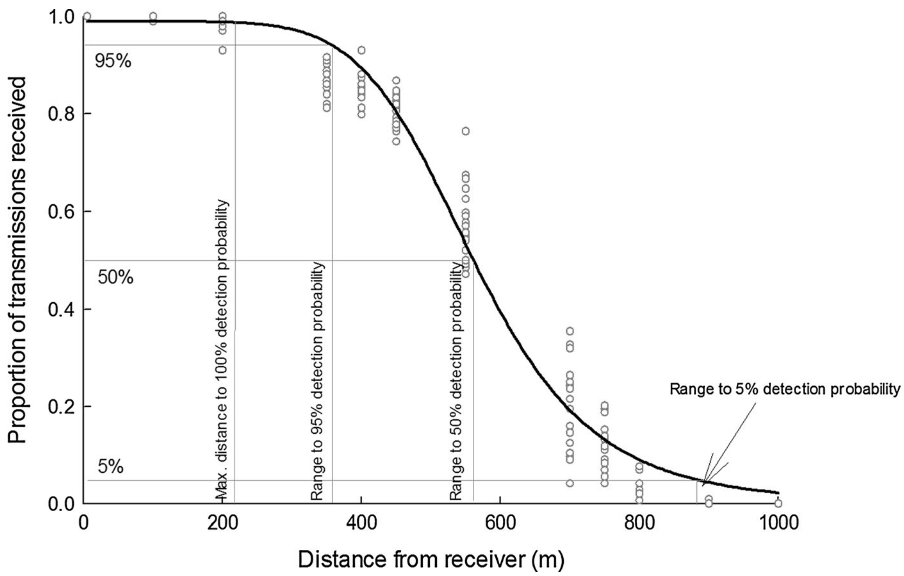


**Fig. 2** Range metrics for acoustic receiver data. *Grey circles* represent daily proportions of detection received (hypothetical), *black line* is a logistic regression through data points and *grey lines* represent the range metrics (labeled)

commonly use acoustic ‘gates’ or ‘curtains’ (e.g. Aarestrup et al. 2010; Balfry et al. 2011; Davidsen et al. 2009; Welch et al. 2009). These are linear deployments of consecutive receivers, that are positioned so the detection range of neighbouring receivers overlap and all tagged animals will be detected, preferably providing 100 % detection coverage (Heupel et al. 2006; How and de Lestang 2012). If the animal is not detected, this can have considerable influence on the interpretation of the detection data, particularly relating to survival rates. Such studies are often assessed for ‘detection efficiency’, which essentially describes the likelihood that an acoustically tagged animal will be detected as it crosses the line of receivers (Welch et al. 2008). Estimating detection efficiency can be aided by the monitoring of detection range, as changes in detection range could render the gate or curtain ineffective at detecting passing study animals under certain conditions (Heupel et al. 2006). As the term ‘detection efficiency’ has become widely used in recent literature, the quantitative frameworks for assessing it have become better developed (e.g. Melnychuk 2009; Melnychuk and Christensen 2009; Melnychuk and Walters 2010; Welch et al. 2008; Balfry et al. 2011; Chittenden et al. 2009; Manel-la et al. 2011; Moore et al. 2010; Roscoe et al. 2011), however, the specifics of detection range assessment as a function of efficiency are commonly not provided.

Studies that are focused on less mobile species, home-ranges or the seasonal habitat use of a particular area (e.g. Bellquist et al. 2008; Comeau et al. 2012; Hannah and Rankin 2011; Jorgensen et al. 2006; Lowe et al. 2009; MacArthur et al. 2008; Topping et al. 2006), adopt alternative array designs. These designs vary but generally aim to gain maximum coverage of a study area with the number of available receivers, with receiver locations based on existing information on animal movements and habitat use (Heupel et al. 2006; How and de Lestang 2012). For such a design, understanding the detection range of the array is also crucial for data interpretation. Recent use of positional grid arrays, to allow more exact positioning of tagged animals, has reduced positional uncertainty and given greater location relevance to acoustic detections (e.g. Espinoza et al. 2011b; Cooke et al. 2005; Niezgoda et al. 2002). Within these systems, detection range is in many respects less important, however, in order for the grids to function, neighbouring receivers must have completely overlapping ranges; i.e. a tag must always remain within the range of at least three receivers for a location to be calculated. Thus, for positional grid arrays, comprehensive modeling and detection range testing at the study site is also necessary during the design phase and during the deployment of the gridded array (Espinoza et al. 2011a; Cooke et al. 2005; Niezgoda et al. 2002).

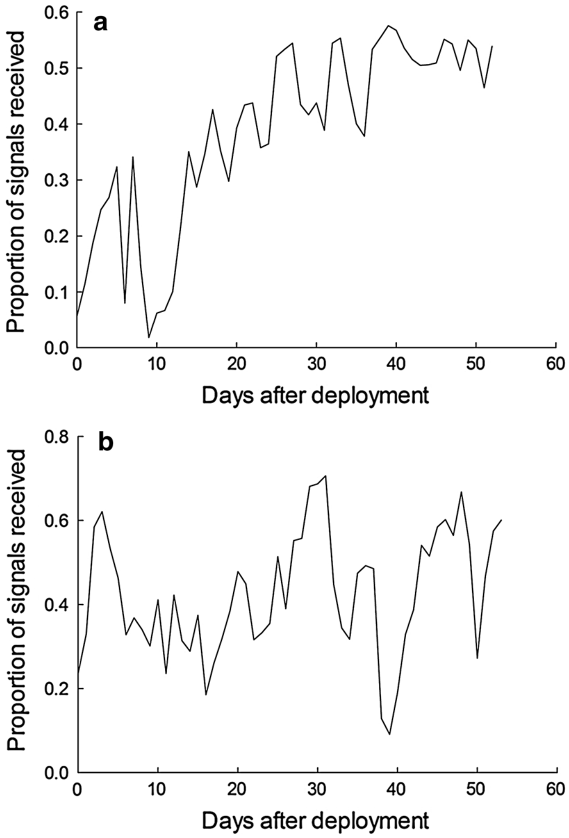


**Fig. 3** Temporal variation in the detection of fixed location sentinel tags moored **a** 100 m and **b** 200 m from an acoustic receiver during the same time period in Cleveland Bay, Queensland, Australia

## Methods

To assess how effectively passive telemetry studies have considered and monitored detection range, 378 passive acoustic telemetry papers, published from 1986 to July 30th 2012, were reviewed (for full list of reviewed references see Online Resource 1). Using an ISI Web of Science search, papers were identified with the search terms ‘acoustic’, ‘ultrasonic’, and ‘sonic’ proceeded by each of the words ‘telemetry’ and ‘tracking’. In addition, papers cited within these publications, and not present in the original searches, were included. To undertake an overall assessment, papers were scored against a set of predefined criteria (Table 1) to determine how comprehensively the study had considered and investigated detection range from a total available score of 45. Where studies had referenced their acoustic detection range information from a previously published study, parameters 3–8 scores (Table 1) were obtained from the referenced paper. The validity of the reference was then assessed against additional criteria (Table 2) and the percent of the total score (from parameters 3–8) from the referenced paper awarded. Where multiple papers were referenced, a mean score was assigned. For eight studies the referenced study was either not available or not published in English (Walsh et al. 2012; D’Anna et al. 2011; Hubley et al. 2008; Willis and Hobday 2007; Mitsunaga et al. 2012; Conrath and Musick 2010; Fujioka et al. 2010a) consequently these studies were excluded from the scoring process. The final scoring results were considered by year of publication to investigate trends over time.

Of all 378 studies, all those that acknowledged acoustic detection range were then isolated based on description in text or figure captions. These studies were then assessed to see if they considered the detection range to be fixed or variable. Papers were deemed to have assumed acoustic detection range to be fixed if they presented a single value for acoustic detection range for the complete study, and variable if they (1) gave minimum and maximum ranges, (2) stated that the presented range was an average, and/or (3) discussed or acknowledged the variability of acoustic range relative to influencing factors. Finally the above studies were assessed to determine whether they had conducted some form of field based acoustic detection range testing as part of their study. Detection range testing was considered to have been conducted if it was explicitly stated in the text, regardless of whether or not methods or results were presented. Studies that were focused solely on acoustic detection range testing, i.e. did not conduct a focused study on one or more organisms, were not included in this final assessment. However, information from such focused studies of detection range is summarized in later sections of the paper.

## Results and discussion

### Overall results

The detection range scores were highly variable among studies (n = 370) ranging from 0 to 39

**Table 1** Scoring criteria for assessing how comprehensively published studies, based on passive acoustic telemetry, have accounted for detection range

| Scoring parameters | Scoring criteria |
|---|---|
| 1. Did the paper acknowledge the existence of detection range? | Yes = 5, No = 0. If the paper did not acknowledge the existence of range in any way then the overall score for the paper is 0 |
| 2. Was detection range considered as fixed or variable? | Fixed = 0, variable = 2; |
| 3. What was the source of the detection range presented? | Stated with no justification = 0, sourced from manufacturer = 1, stated as estimated = 1, un-described range tests = 2, unpublished data = 2, described range tests = 3, detailed range tests = 4, referenced from another paper = additional marking scheme applies (see methods section) |
| 4. How many methods were employed to assess detection range? | One = 1, multiple = 2 |
| 5. What method/s were employed to assess detection range (if more than one, scores are cumulative)? | Boat based = 3, diver based = 2, fixed sentinel tags = 5, fixed tag with receivers at set distances = 4, post analysis = 1, single tag at different distance intervals for given periods of time = 3, un-described range tests = 0 |
| 6. What was the duration of the detection range assessment? | Temporary <1 day = 1, temporary >1 day = 2, temporary with replicates = +1, Study duration = 5. If duration is undefined or only vaguely indicated a score of 1 will be assigned |
| 7. How many receiver sites were assessed? | One = 1, multiple = 2, all = 4, if receivers tested not within the study system a score of 1 is assigned, if undefined, a score of 1 was assigned |
| 8. Are the transmitters/tags used to assess detection range consistent with those used in the study animals? | Same = 4, different = 1, multiple tags used in study animals and not all tested = 2, multiple tags used in study animals and all tested = 4, multiple tags used in study animals, one tested and other detection ranges calculated from tag properties = 3. If tag type was not listed then a score of 0 will be assigned |
| 9. What variables were considered to influence acoustic detection range? | None = 0, one = 1, multiple = 2, influence of variables investigated = 5 |

Justification for criteria and values can be found in Sect. 4.2 of this review

**Table 2** Criteria for assessing how relevant referenced sources of detection range are to the study that referenced them

| Validity parameters | Validity criteria | Percentage subtracted if criteria not met |
|---|---|---|
| 1. Consistency | The detection range presented is consistent with that presented in the source paper | 100 |
| 2. Source | The referenced study is from a peer reviewed journal | 25 |
| 3. Location | The referenced study is from the same study system (if this criteria is not met, parameter iv is rendered irrelevant and therefore not considered) | 50 |
| 4. Time frame | The referenced study was conducted during the same period | 25 |
| 5. Tag type | The tags used for the study animals in the referenced study are consistent with those used in the current study, or the difference in detection range between the tags has been analytically accounted for | 25 |

Percentages subtracted from the total score of parameters 3–8 of the source paper

(11.1 ± 0.4; mean ± 1 SE; Fig. 4). If studies that sourced detection range through referencing another study were excluded, the remaining studies (n = 345) scores ranged from 0 to 39 (11.3 ± 0.5). For studies that conducted some form of detection range test (n = 170) scores ranged from 9 to 39, with a predictably higher mean score of 18.4 ± 0.5. Considering only studies that sourced detection range information through referencing another study (n = 25) scores ranged from 5 to 28 (10.6 ± 1.2). There were

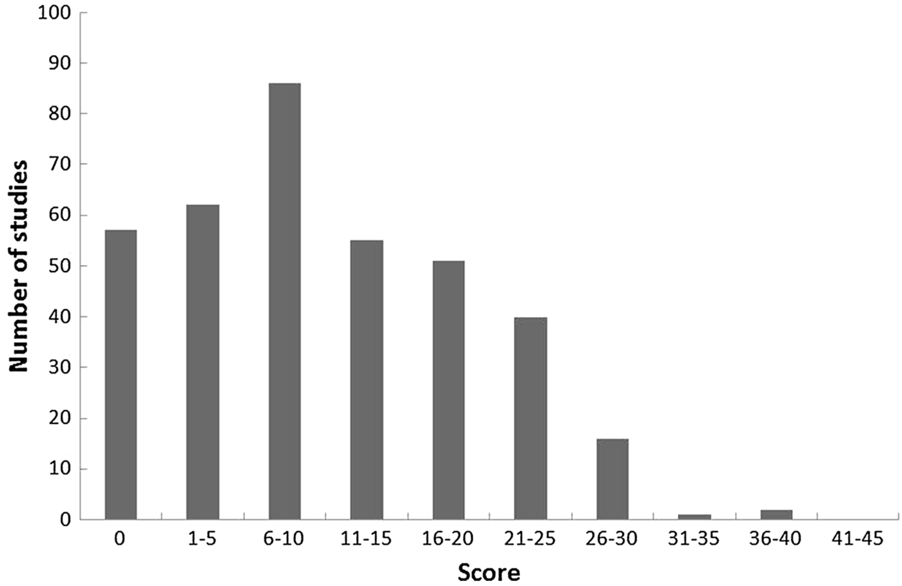


**Fig. 4** Frequency histogram for all acoustic telemetry studies detection range accountability scoring

no distinct trends in how comprehensively studies accounted for acoustic detection range over time (Fig. 5). The highest mean scores were achieved between 1999 and 2001, but this observation is confounded by the small number of studies published during this period (n = 8). Over the past decade, since passive telemetry studies have been more prevalent, mean scores have ranged between 6.7 and 12.9. Considering that a maximum score of 45 represents a study that has fully accounted for acoustic detection range, it is apparent that the majority of studies published in the past decade have not adequately accounted for this factor. It must be noted that the inclusion in the scoring assessment of studies less concerned with 'detection range' only, but instead 'detection efficiency' as a whole, may have resulted in a negative bias in the results. Though, due to the large number of studies assessed, we are confident that the general trends are still representative for the field.

Of the 378 studies, 321 (84.9 %) directly acknowledged detection range in the text, while 57 (15.1 %) did not consider this point resulting in the 0 scores presented above. Of these 321 studies, 161 (50.2 %) presented a fixed detection range, while 160 (49.8 %) stated range to be variable. Of the studies that considered acoustic range, 156 (48.6 %) stated some form of range testing had been conducted (see Sect. 4.4), while for 165 (51.4 %) none was conducted.

## Parameters affecting detection range in aquatic environments

The detection range of receivers can be highly variable in aquatic environments due to a number of parameters summarized in Table 3. Of the 321 studies that mentioned detection range, 172 (53.6 %) did not specify any external parameters that may influence the detection range of their receivers. Of the 149 studies that detailed effects of these parameters, 81 (54.4 %) considered only a single parameter, while 68 (45.6 %) considered multiple. The most commonly considered parameters were: (1) physical and chemical properties (56 studies; 37.6 %), (2) sea state/surface conditions (45 studies; 30.2 %), and (3) water depth and tides (39 studies; 26.2 %; Table 3). Other parameters that were mentioned included: bathymetry/substrate/obstruction (24 studies; 16.1 %), background/ambient noise (23 studies; 15.4 %), transmitter type (22 studies; 14.8 %), receiver location (21 studies; 14.1 %), water flow (11 studies; 7.4 %), water body type (6 studies; 4.0 %), biofouling (3 studies; 2.0 %), and transmitter location on animal (1 study; 0.7 %; Table 3).

Given the number of parameters that can affect detection ranges (Table 3), surprisingly few have been directly and systematically tested. A recent study in a sub-Arctic lake by Gjelland and Hedger (2013), investigated the relationship between detection rate/

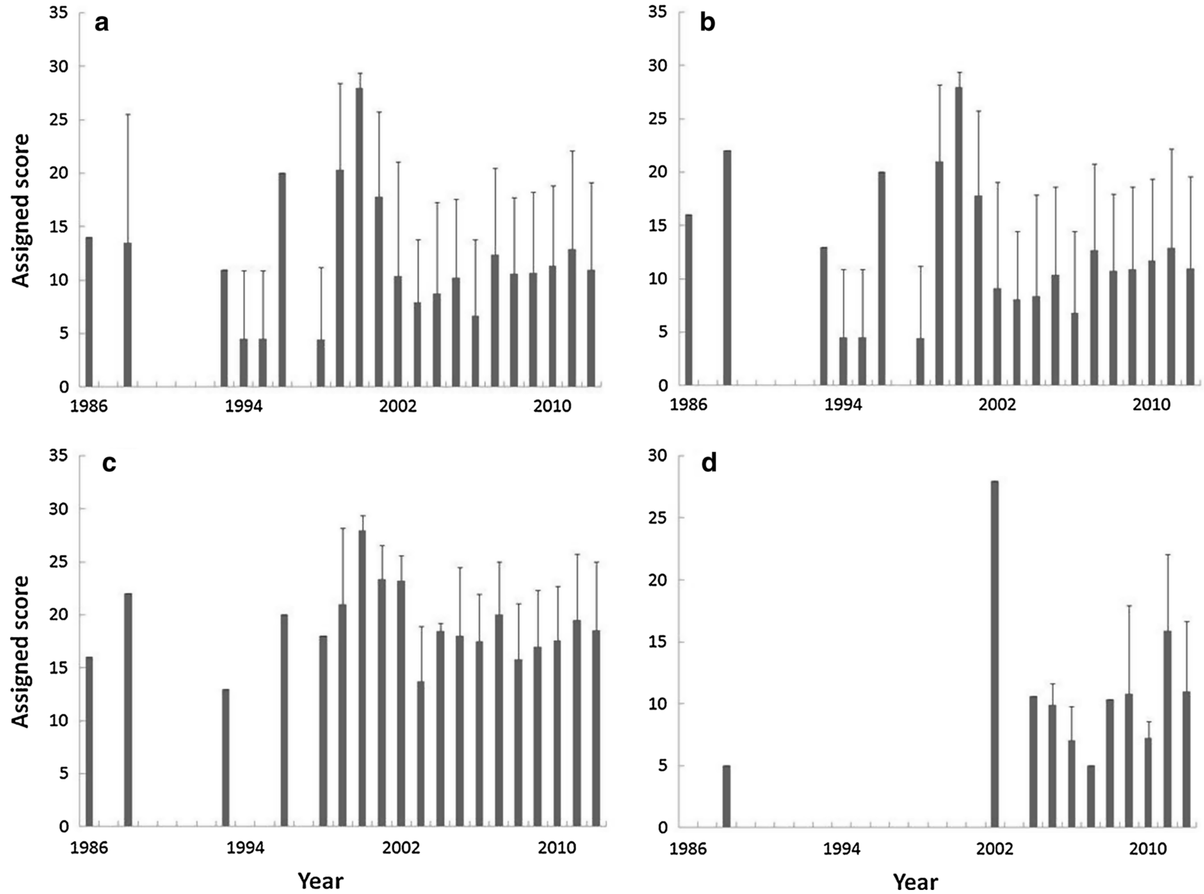


**Fig. 5** Mean published study scores by year of publication; error bars represent one standard deviation; **a** all assessed studies (n = 370); **b** all assessed studies that did not source detection range by referencing another publication (n = 345); **c** all assessed studies that conducted some form of detection range tests (n = 170); and **d** all assessed studies that sourced detection range by referencing another publication (n = 25)

range and several environmental factors: water temperature, wind, rain and depth. Wind was found to have the greatest influence on detection range, with tag/receiver depth and rain also significantly affecting variability. They concluded that reduced detection range by wind and rain was not a result of the ambient noise but rather the entrainment of air bubbles in the littoral zone. Gjelland and Hedger (2013) demonstrated that detection probability could be accurately modeled with an acceptable model for sound propagation in water. The presented model, addressing detection probability as a function of the attenuation coefficient, therefore has wide applicability for future assessments. The effect of the entrainment of air bubbles as a result of wind is most relevant to studies that focus on the near surface zone of aquatic environments. For monitors deployed in deeper waters, detection range variability will be predominantly due to other factors. The specific influence of environmental parameters will vary greatly between study systems and are largely dependent on the physical properties of those study systems.

Other studies investigated the influence of various factors on detection range. Through simultaneous detection range testing and environmental monitoring, Singh et al. (2009) found that detection range was strongly dependent on the degree of water column stratification, identifying the importance of considering the depth of receiver deployment. Heupel et al. (2006) found a $\sim$200 m detection range difference between adjacent receivers in estuarine and freshwater environments most probably as a result of density

**Table 3** Parameters identified in the literature that have an influence over acoustic detection range variability

| Parameter | Description | References |
|---|---|---|
| Physical and chemical properties | Physical and chemical elements of the study site that can vary over time, including temperature/thermocline, salinity, turbidity and suspended solids | Farmer and Ault (2011), Finstad et al. (2005), Gjelland and Hedger (2013), Heupel et al. (2006), Sakabe and Lyle (2010), Singh et al. (2009), Starr et al. (2000), Thorstad et al. (2000), Topping and Szedlmayer (2011b) |
| Sea state/surface conditions | The surface conditions of the water body relative to wind and wave action, resulting in air entrainment | Finstad et al. (2005), Gjelland and Hedger (2013), Kerwath et al. (2007), Klimley and Holloway (1999), Payne et al. (2010), Simpfendorfer et al. (2002), Thorstad et al. (2000), |
| Water depth and tides | Variability in water depth between locations and tidal states | Claisse et al. (2011), Gjelland and Hedger (2013), Heupel and Hueter (2001), Humston et al. (2005), Ohta et al. (2001), Sakabe and Lyle (2010), Singh et al. (2009), Zargars et al. (2012) |
| Bathymetry, substrate and obstruction | Any physical dimensions of the study site, including vegetation, that may restrict the passage of sound waves | Claisse et al. (2011), Farmer and Ault (2011), Heupel and Hueter (2001), Kerwath et al. (2007), Marshell et al. (2011) |
| Transmitter/tag type | The physical dimensions and power characteristics of the transmitters employed | Cooke et al. (2012), Girard et al. (2007), How and de Lestang (2012), Lino et al. (2011), Simpfendorfer et al. (2008), Taquet et al. (2007) |
| Background/ambient noise | Additional noise in the study system that may interrupt or overpower/mask the transmitted signal | Bessudo et al. (2011), Farmer and Ault (2011), Girard et al. (2007), Payne et al. (2010), Simpfendorfer et al. (2002), Zargars et al. (2012) |
| Receiver location | A combination of parameters specific to a given location can influence detection range at that site relative to another | Andrews et al. (2007), Clements et al. (2005), Field et al. (2011), Heupel et al. (2006), Heupel and Hueter (2001), Lembo et al. (2002) |
| Water flow | River/stream flow or current | D'Anna et al. (2011), Fairchild et al. (2009), Gilroy et al. (2010), Kerwath et al. (2009), Lacroix et al. (2010), Voegeli et al. (1998) |
| Water body | A combination of parameters specific to different water body types can influence detection range between them | Chittenden et al. (2008), Hindell et al. (2008), Melnychuk et al. (2007), Walsh et al. (2012), Welch et al. (2011), Whitty et al. (2009) |
| Biofouling | Biofouling, specifically around the hydrophone of the receiver can reduce the ability to detect the transmitted signal | Dawson and Starr (2009), Heupel et al. (2008), Hindell (2007), Reyier et al. (2011) |
| Transmitter/tag location | The difference between internally implanted and externally attached transmitters | Jackson et al. (2005) |

stratification due to a strong salinity gradient. From fairly extensive detection range testing (score = 27), Thorstad et al. (2000) found considerably reduced range on some river mouth receivers relative to those further out in the fjords. In that case the authors hypothesized that the variation was most likely caused by turbulence and the entrapment of air bubbles. Detection range testing conducted by Finstad et al. (2005) on Norwegian fjord receivers found that detection range varied between 45 and 650 m as a result of wave action, salinity stratification and depth. Heupel et al. (2008) found that receiver performance, and thus detection range, was reduced by direct biofouling on receivers. The method of mounting the receiver has also been found to strongly influence detection efficiency (Clements et al. 2005), again highlighting the importance of considering all aspects of the array design process, including mooring design.

Tag type/characteristics were only considered in 18 studies. Accounting for tag type/characteristics is essential, as overall detection range is defined by a combination of receiver sensitivity, transmitter power of a given tag, and sound propagation properties between tag and receiver (Cooke et al. 2012). As a result, studies that use multiple tag types need to consider this variation when examining detection range, along with environmental and physical factors. Through systematic investigation, How and de Lestang (2012) demonstrated a direct relationship between range variability and acoustic tag power output, as would be expected. Although several studies accounted for the variability associated with use of multiple tag types by range testing all tags (e.g. Sulak et al. 2009; Westmeyer et al. 2007; Topping and Szedlmayer 2011b; Lowe et al. 2009; Filmalter et al. 2011), several studies employed multiple tag types, range tested only one or two tag types, and then assumed a consistent detection range for all tags (e.g. Williams et al. 2012; Speed et al. 2011; Fujioka et al. 2010b). In studies employing multiple tag types, detection range testing should ideally include all tag types deployed in the study animals and the variability in detection ranges between tags accounted for in data analysis and interpretation. Alternatively, with a comprehensive understanding of the power, acoustic frequency and directionality of all used tags, detection range testing for one tag can be undertaken and detection ranges for all other tags modeled using these observations combined with a suitable propagation model (Medwin and Clay 1997).

With coded single frequency based telemetry systems, one factor that influences detection range indirectly is code collisions. Code collisions can occur when multiple tags, within the detection range of a given receiver, produce overlapping transmission at or around the same frequency (Heupel et al. 2006; Singh et al. 2009). This hinders the receiver's ability to decode the detection and thus the transmission is not recorded, even though both transmitters may be within the physical detection range of the receiver. Collisions should not be listed as a variable affecting detection range, but they need to be accounted for in the interpretation of any detection range test data. One possible method to determine the level of collisions is to examine the receiver's event data and estimate the volume of transmitted 'pings' for a given period relative to the number of recorded codes (Simpfendorfer et al. 2008). If detected pings are far in excess of recorded codes, high collision rates are occurring and can be used to normalize detection range test data.

## Published sources of detection range

Of all 378 studies assessed, 285 (75.4 %) detailed acoustic detection ranges for receivers from various sources of information. Of these, 77 (27.0 %) sourced detection ranges from un-described range tests where no methods were presented. Without detailed methods, it is difficult to assess if appropriate testing was conducted, which lowers confidence in the reported detection ranges. Thirty-one studies (10.9 %) obtained detection ranges from described range tests, but only limited details were provided on the type of testing, without specific details on test duration, number of replicates, or timing. Thirty-eight studies (13.3 %) presented detailed range tests conducted during the study from which detection ranges were derived. This should ideally be the minimum requirement in future studies of this kind.

In 78 studies (27.4 %) detection range was stated with no explanation or justification. In 33 studies (11.6 %), acoustic detection ranges were obtained from other published studies. For referencing to represent a sufficient source of acoustic detection range, the following criteria should ideally be met: (1) the referenced study completed comprehensive and detailed range testing; (2) the referenced study was from the same study location and instrumented with the same array, since station location will be a factor influencing detection range; (3) the referenced study was during the same period, since there is temporal variability in detection range (How and de Lestang 2012; Fig. 3); (4) the tags used in the referenced study have the same characteristics (frequency, transmit power, directionality and coding scheme) as the tags used in the current study, though programming can vary; and (5) the detection range presented is consistent with the source paper. The results of the detection range accountability scoring (Fig. 5) showed that publications that referenced detection range from an existing publication scored generally lower ($10.6 \pm 1.2$) than those that conducted/presented detection range tests ($18.4 \pm 0.5$). This indicates that either the referenced publications had generally scored lower than the mean or the scoring criteria presented above were generally not all met. Starr et al. (2002) provides a good example where all the defined detection range criteria were met (score = 28), except that range testing was conducted the year after the study period. If multiple publications are based on various aspects of the same study, presenting detection range test information and data in all papers is inefficient and not necessary. However, if the presented criteria cannot be sufficiently met relative to the original publication, details of the detection range assessment should ideally be provided in place of the reference.

Twenty-four studies (8.4 %) sourced acoustic ranges from unpublished data. Rather than simply referring to unpublished data, such data should ideally be included as a part of the overall study as this provides vital data from which reviewers can assess the validity of the data interpretation. Finally, eight studies (2.8 %) estimated detection ranges with little or no justification and five studies (1.8 %) claimed to have sourced the detection range directly from the receiver manufacturer. Citing detection ranges given by the receiver manufacturer is prone to significant error. Manufacturers state that their detection ranges are variable and specific to a given study environment and that any detection ranges they provide are merely a guide that must be tested in the field. The most ideal source of detection range data is a detailed detection range test presented as part of a given study, or a reference to another manuscript that meets the above criteria.

## Methods of detection range testing

Of 72 studies that described the range test methods used, 43 (59.7 %) conducted 'boat based' range testing (see Table 4 for description). Several benefits are associated with boat based range testing. The primary advantage is that testing can be conducted in situ at the receiver sites and during the execution of a study. Also, these in situ detection range tests can be conducted at various times throughout the study, making it possible to address the issues of temporal changes in detection range (Hedger et al. 2008; Thorstad et al. 2000; Reynolds et al. 2010). Since the boat-based testing is mobile it allows for multiple receiver stations to be assessed, addressing potential variability in detection range between receiver sites. In certain instances, studies have undertaken a comprehensive assessment at all receiver sites within their array; Andrews et al. (2007) assessed all but one of their seven receiver sites in both north and south plains, while Maljkovic and Cote (2011) and Sakabe and Lyle (2010) assessed all receiver sites in their array in four different axes, north, south, east and west. This technique of assessing a range of axes is very thorough and should ideally be adopted with all forms of detection range testing, whenever logistically possible.

There are, however, several limitations to boat-based range tests. One limitation is that this approach is inherently biased towards periods with benign sea-states (Lembo et al. 2002). However, Chittenden et al. (2008) conducted boat based range tests in a 'range of environmental conditions', while Humston et al. (2005) assessed range over various tidal states. Nevertheless, it is unlikely that boat based range tests are conducted during high sea-states, when air entrainment and noise from breaking waves will affect sound propagation and therefore the detection range (Gjelland and Hedger 2013). This could be counter-acted by monitoring wind speeds at the array site and modifying the detection range with appropriate algorithms (Gjelland and Hedger 2013). Also, boat based testing does not effectively deal with refraction effects due to stratification (Singh et al. 2009).

For boat-based range testing, specialized high-resolution tags transmitting with a 5–10 s delay should be used, to maximize the assessment of detection range at each set distance between tag and receiver. However, with high-resolution tags in coded single frequency based systems, the potential for collisions is greater if tagged animals are present during testing. Preferably, the tags used for the tests should be the same model and power output as those deployed in the study animals, though programming can justifiably vary. Thus, if multiple tag types have been deployed on animals, either all should be used during range testing, or the most common tag tested and appropriate modeling conducted to define the detection ranges for the remaining tags. However, if using multiple tag types simultaneously, again possible code collisions should be accounted for in coded single frequency based systems. Boat engines should be turned off while testing to minimize noise interference. A final consideration is the depth of the range test tag, which will depend on the behaviour of the study animals. If the animals are known to stay close to the bottom, the tag only needs to be moved in a horizontal plane near the bottom. However, if the animals being studied make use of the whole water-column it will be necessary to repeat the testing at several depths.

The second most commonly used range test technique is to place a single tag at different distances from a fixed receiver for a given period of time (Table 4). Of the 72 studies that discussed range test methods, 14 (19.4 %) studies adopted this approach. This technique provides a robust method to test detection

**Table 4** Methods of acoustic detection range assessment described in the existing passive telemetry based literature

| Method | Description | References |
|---|---|---|
| Boat/vessel based | Any method that involves assessing detection range by lowering a tag over the side of a vessel at distance intervals from the monitor, or drifting/driving away from the monitor with the tag constantly deployed and the track recorded, with distances extrapolated from GPS data | Adams et al. (2009), Andrews et al. (2007), Anras et al. (a) (1999), Arendt et al. (2001a), Bansemer and Bennett (2009), Bessudo et al. (2011), Bishop et al. (2010), Campbell et al. (2012), Campbell et al. (2010), Chittenden et al. (2008), Coleman et al. (2011), Dagorn et al. (2007a), Dewar et al. (2008), Fairchild et al. (2009), Farmer and Ault (2011), Field et al. (2011), Filmalter et al. (2011), Fox et al. (2002), Girard et al. (2007), Hedger et al. (2008a), Heupel and Hueter (2001), Humston et al. (2005), Jorgensen et al. (2010), Kerwath et al. (2009), Klimley and Holloway (1999), Klimley et al. (2003), Klimley et al. (1988), Lembo et al. (2002), Maljkovic and Cote (2011), Meyer et al. (2009), Moser and Lindley (2007), Ohta et al. (2001), Pautzke et al. (2010), Reynolds et al. (2010), Sakabe and Lyle (2010), Speed et al. (2011), Sulak et al. (2009), Taquet et al. (2007), Thorstad et al. (2000), Topping et al. (2006), Topping and Szedlmayer (2011a), Westmeyer et al. (2007), Zargars et al. (2012) |
| Single tag at different intervals | A single tag is placed at different distances from a given receiver for a given period | Childs et al. (2008a), Comeau et al. (2002), DeCelles and Cadrin (2010), Espinoza et al. (2011b), Kawabata et al. (2010), Lino et al. (2011), Marshell et al. (2011), Olsen and Moland (2011), Serrano et al. (2009a), Serrano et al. (2009b), Szedlmayer and Schroepfer (2005), Wingate and Secor (2007), Zamora and Moreno-Amich (2002), Zargars et al. (2012) |
| Fixed sentinel tags | A set of tags are fixed at set distances from the receiver for varying periods of time up to the duration of the study | Bassett and Montgomery (2011), Claisse et al. (2011), Egli and Babcock (2004), Espinoza et al. (2011a), Kerwath et al. (2007), O'Toole et al. (2011), Simpfendorpher et al. (2002), Starr et al. (2000), Topping and Szedlmayer (2011b), Whitty et al. (2009) |
| Fixed tag with receivers at set distances | One tag is fixed in a location and several receivers are set at distance intervals | Bertelsen and Hornbeck (2009), Farmer and Ault (2011), Topping and Szedlmayer (2011a), Zargars et al. (2012) |
| Tag placed at single distance | A single tag is placed at a single distance from a receiver to confirm that distance | Lindholm et al. (2007) |
| Post analysis | Detection range is somehow deduced from the results of the study | Anras et al. (1999b), Dick et al. (2009), Kerwath et al. (2007) |
| Diver based | Divers carry tags through the study area | Bansemer and Bennett (2009), Farmer and Ault (2011) |

ranges over set distance intervals for prolonged periods of time. It is also the preferred method, over boat based testing, if high-resolution range test tags are not available, as longer deployments enable the acquisition of sufficient data from regular tags with longer delays. However, given the fact that only one tag is typically used for this type of range test, this technique can be subject to similar limitations as boat based range tests. Espinoza et al. (2011a) placed a single tag for 2 h periods at various locations around their Vemco Positioning System (VPS) array and found that detection range (>85 % detection efficiency) varied between 350 and 900 m. The authors concluded that their predetermined receiver spacing of 250 m was sufficient to gain overlapping coverage for the period of interest. Although very conservative, as the range test tag was only deployed for short periods and did not provide a continuous assessment of detection range, it is not possible to confirm this conclusion. Whitty et al. (2009) placed high resolution range test tags, one for each type used, at 50 m intervals from their receivers for a minimum of 4 min at each location. Through thorough statistical analysis they also determined that their predetermined receiver spacing was sufficient to ensure gate-wide range overlap. Similar to Espinoza et al. (2011a), these results can only be guaranteed for the period of range testing. Interestingly, Comeau et al. (2002) placed a single range test tag inside a dead cod to mimic a live tagged fish, the only study to date to report this. As the sound properties of fish flesh are similar to those of water and the tag is typically located close to the skin, it is not expected that detection range obtained from this approach will differ significantly from using a tag only in most instances.

Of the studies that described range test methods, 10 (13.9 %) deployed fixed sentinel tags for various time periods (Table 4). The first reported use of this technique was Starr et al. (2000), who deployed a set of sentinel tags at a range of fixed distances during the entire study. Based on the proportion of scheduled transmissions that are detected, once a receiver is downloaded and, if necessary accounting for potential collisions, the actual detection range can be inferred and the animal detection probability corrected accordingly. Because this technique inherently monitors variability in the detection range as a function of all anthropogenic and natural parameters, this provides the most comprehensive technique for assessing acoustic range and should be adopted whenever possible. Independent monitoring of environmental parameters, such as wind speed and sea-state using this approach will also enable an assessment of how the detection range in a particular study is affected by these parameters.

Following a similar methodology, Simpfendorfer et al. (2002) moored eight tags at fixed distance intervals from a receiver for a 4 days period. As expected, they found a significant linear decline in detection probability with increasing distance from the receiver. Egli and Babcock (2004) used a set of fixed sentinel tags to assess the range of their receivers over a one week period. Kerwath et al. (2007) later used two fixed sentinel tags to assess acoustic range prior to fish tagging and actually altered the dimensions of their Vemco Radio Acoustic Positioning (VRAP) system based on the test results. Bassett and Montgomery (2011) also deployed a set of sentinel tags to assess receiver range over a one week period, and O'Toole et al. (2011) deployed temporary sentinel tags for an undefined period following array deployment. Claisse et al. (2011) used a set of sentinel tags to assess range at each of their receivers along four different axes. Tags were fixed at set distances from each receiver along each axis and left for 40 min before being moved to the next set of locations. Although some of these range tests were very comprehensive (e.g. Claisse et al. 2011), the deployment of sentinel tags for short time periods removes the temporal benefits of having fixed tags deployed throughout the course of a study.

Following short-term range testing of all receiver sites, sentinel tags could be deployed at the most representative receiver location and left for the duration of the study, thus providing a true measure of detection range variability. To minimize collisions with tagged animals and extend battery life, the time between acoustic transmissions should be increased significantly during programming. Alternatively, Bertelsen and Hornbeck (2009) deployed a single fixed tag and multiple receivers placed at set distance intervals prior to deploying the receivers. This preliminary approach can be useful to aid array design if completely unfamiliar with what detection range can be expected in a particular system. However, this should not be considered a substitute to in situ assessment and should ideally be followed up by further range testing during the course of the study.

With the increasing use of positional systems, arrays are more commonly designed in some form of structured grid. Within these designs, a carefully placed sentinel tag, or set of tags, if more than one type is used, can be deployed to assess detection range. This 'spider web' approach to range testing can provide comprehensive data on numerous tag-monitor distances. Additionally, some positional systems require a set of sync tags for accurate post processing of tag (animal) locations. Following appropriate programming, these tags can be used to assess the detection range of an array or receiver without the associated costs of purchasing dedicated range test tags. Topping and Szedlmayer (2011b) used a single tag within a grid-like array to enable various distance calibrations to each receiver in the grid for the duration of the study. Although in principle it is an efficient and cost effective method for assessing detection range over the course of a study, the spacing of receivers in their array design resulted in only two of the five distance parameters, 400 and 700 m, falling within the expected range (<1,000 m) of the receivers (Topping and Szedlmayer 2011b). With the addition of only one or two more sentinel tags, detection range of more distance parameters could have been assessed improving the overall experimental design.

Adopting the fixed sentinel tag range testing technique in any study results in increased costs associated with the purchase of multiple sentinel tags, however, this cost can be reduced through a carefully designed array and range test layout. Adjacent receivers can be used to provide multiple distance intervals from a small number of tags. Also, if only one detection range test location is possible for a particular study, it is important to select the most representative receiver site allowing for greater relevance of detection range results. If an array is distributed throughout waters with different properties, e.g. river, estuary and coastal (e.g. Chittenden et al. 2008), it is advisable to deploy one set of fixed sentinel tags within each water body type (Heupel et al. 2006; Thorstad et al. 2000). The additional costs associated with the purchase of dedicated sentinel tags can be further justified as long programming delays can greatly extend battery life allowing the tags to be used multiple times in subsequent studies. Fixed sentinel tags may not be appropriate or logistically possible where arrays and receiver stations are established on the edge of steep drop offs, such as seamounts and shelf edges to monitor pelagic animals. For these situations, extensive boat based range testing can be employed.

Of the 72 studies that described detection range test methods, 3 (4.2 %) used post analysis of the recorded detection data, both passive and additional active tracking data, to determine acoustic detection range (Table 4). Anras et al. (1999) deduced acoustic detection range from "results from the array", with no further detail provided. In addition to two-fixed sentinel tags, Kerwath et al. (2007) compared active tracking locations to fixed receiver detections when study animals moved through the array to retrospectively define acoustic detection range.

Five studies (6.9 %) used more than one method to assess acoustic detection range (Table 4). As stated above, Kerwath et al. (2007) used a combination of two fixed sentinel tags and post analysis using active tracking data of study animals to assess acoustic detection range in their system. This involved assessing detection range before the study, followed by adjustments to the array design, and continued range assessment for the duration of the study. Bansemer and Bennett (2009) employed a combination of boat and diver based range testing (Table 4). This technique may have additional value as a tool to assess the influence of physical obstructions on detection range in relatively close receiver proximity. Topping and Szedlmayer (2011a) assessed acoustic detection range using a combination of boat based range tests and a single 'control' sentinel tag. Although one can argue that a single sentinel tag, within this particular array design, was not sufficient for effective detection range testing, the combination of fixed tags for the duration of the study and boat based point assessments is a favorable one. Wherever possible, at least one set of fixed distance range test tags should be deployed for the duration of a given study. This can ideally be supplemented by periodic boat based range testing to account for site-specific variability.

## Presenting detection range and detection range testing in publications

Given the importance of detection range, it is advisable that detection range testing and detailed methods on this testing be included in the reporting of passive acoustic telemetry studies. Without sufficient information about detection range, it is often impossible to evaluate and validate the accuracy of the data presented. Therefore, detection range testing should be viewed as an integral component of passive acoustic telemetry studies and detection range test data, including methods and data analysis, should be presented. Referencing of detection ranges from existing manuscripts should ideally only take place if the criteria presented in Sect. 4.3 of this review are sufficiently met. Claisse et al. (2011) and Whitty et al. (2009) are both good examples of well presented use of detection range tests.

We recommend initially defining detection range within the context of a study, i.e. what proportion of detections at a given distance represents effective range. It is also recommended that the terminology used to describe acoustic detection range be standardized. In the exiting literature, the terms 'range', 'radius', 'zone', 'distance', 'coverage', 'sensitivity' and 'field' have all been used to detail acoustic detection range in passive telemetry papers. We suggest that given the vast majority of these papers have adopted the term 'range' for this purpose, this should be the chosen term. Furthermore, the term should be expanded to always be preceded by 'detection'. This is as the physical acoustic range, i.e. the distance from which the receiver can hear a transmitted ping, can be greater than the distance from which it is possible to receive a full transmission to be decoded and logged. 'Detection range' is therefore a more accurate definition than 'acoustic range'.

## Recommendations for future studies

Comprehensively assessing acoustic detection range and accounting for its temporal variability should be considered a crucial component of passive acoustic telemetry based studies. Indeed, given the many ways in which detection range can vary, it is necessary to create a culture of detection range testing among the scientific community when conducting passive acoustic telemetry research. Detection range testing should ideally be completed at all stages of the field study. To aid array design in new systems, preliminary short-term detection range tests should be conducted in the most representative area of the study system. During the actual study a set of fixed distance sentinel tags should ideally be deployed at the most representative receiver site within the array. In addition, the monitoring of as many influencing parameters as possible should be undertaken to allow for modeling of detection range variability over time. In many cases, environmental data from weather stations can be obtained and incorporated to model temporal detection range variability. Derived detection ranges should then be incorporated into the analysis of study animal detections and assessed against apparent behaviours (for example see Payne et al. 2010). With a growing number of analytical software tools available for analysis of acoustic telemetry data (e.g. V-Track; Campbell et al. 2012) it would seem logical to embed modules for modeling variation in detection efficiency within them. Finally, individual detection range testing should ideally be conducted in all dissimilar water bodies within a study system. Budget restrictions may limit the extent of detection range testing that is possible, but due to the importance of such testing, the costs should be considered at the proposal stage of the study design.

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## References

Aarestrup K, Thorstad EB, Koed A, Svendsen JC, Jepsen N, Pedersen MI, Okland F (2010) Survival and progression rates of large European silver eel *Anguilla anguilla* in late freshwater and early marine phases. Aquat Biol 9(3):263–270. doi:10.3354/ab00260

Adams A, Wolfe RK, Barkowski N, Overcash D (2009) Fidelity to spawning grounds by a catadromous fish, *Centropomus undecimalis*. Mar Ecol Prog Ser 389:213–222. doi:10.3354/meps08198

Andrews KS, Levin PS, Katz SL, Farrer D, Gallucci VF, Bargmann G (2007) Acoustic monitoring of sixgill shark movements in Puget Sound: evidence for localized movement. Can J Zool Rev Can Zool 85(11):1136–1142. doi:10.1139/z07-088

Anras MLB, Gyselman EC, Jorgenson JK, Kristofferson AH, Anras L (1999) Habitat preferences and residence time for the freshwater to ocean transition stage in Arctic charr. J Mar Biol Assoc UK 79(1):153–160

Arendt MD, Lucy JA, Evans DA (2001) Diel and seasonal activity patterns of adult tautog, *Tautoga onitis*, in lower Chesapeake Bay, inferred from ultrasonic telemetry. Environ Biol Fishes 62(4):379–391. doi:10.1023/a:1012266214143

Balfry S, Welch DW, Atkinson J, Lill A, Vincent S (2011) The effect of hatchery release strategy on marine migratory behaviour and apparent survival of Seymour river steelhead smolts (*Oncorhynchus mykiss*). PLoS ONE 6(3):12. doi:10.1371/journal.pone.0014779

Bansemer CS, Bennett MB (2009) Reproductive periodicity, localised movements and behavioural segregation of pregnant *Carcharias taurus* at Wolf Rock, southeast Queensland, Australia. Mar Ecol Prog Ser 374:215–227. doi:10.3354/meps07741

Bassett D, Montgomery J (2011) Home range use and movement patterns of the yellow moray eel *Gymnothorax prasinus*. J Fish Biol 79(2):520–525. doi:10.1111/j.1095-8649.2011.03018.x

Bellquist LF, Lowe CG, Caselle JE (2008) Fine-scale movement patterns, site fidelity, and habitat selection of ocean whitefish (*Caulolatilus princeps*). Fish Res 91(2–3):325–335. doi:10.1016/j.fishres.2007.12.011

Bertelsen RD, Hornbeck J (2009) Using acoustic tagging to determine adult spiny lobster (*Panulirus argus*) movement patterns in the Western Sambo Ecological Reserve (Florida, United States). NZ J Mar Freshw Res 43(1):35–46

Bessudo S, Soler GA, Klimley AP, Ketchum JT, Hearn A, Arauz R (2011) Residency of the scalloped hammerhead shark

(*Sphyrna lewini*) at Malpelo Island and evidence of migration to other islands in the Eastern Tropical Pacific. Environ Biol Fishes 91(2):165–176. doi:10.1007/s10641-011-9769-3

Campbell HA, Watts ME, Dwyer RG, Franklin CE (2012) V-Track: software for analysing and visualising animal movement from acoustic telemetry detections. Mar Freshw Res 63(9):815–820. doi:10.1071/MF12194

Chittenden CM, Sura S, Butterworth KG, Cubitt KF, Plantalech Manel-la N, Balfry S, ØKland F, McKinley RS (2008) Riverine, estuarine and marine migratory behaviour and physiology of wild and hatchery-reared coho salmon *Oncorhynchus kisutch* (Walbaum) smolts descending the Campbell River, BC, Canada. J Fish Biol 72(3):614–628. doi:10.1111/j.1095-8649.2007.01729.x

Chittenden CM, Beamish RJ, Neville CM, Sweeting RM, McKinley RS (2009) The use of acoustic tags to determine the timing and location of the juvenile coho salmon migration out of the Strait of Georgia, Canada. Trans Am Fish Soc 138(6):1220–1225. doi:10.1577/t09-037.1

Claisse JT, Clark TB, Schumacher BD, McTee SA, Bushnell ME, Callan CK, Laidley CW, Parrish JD (2011) Conventional tagging and acoustic telemetry of a small surgeonfish, *Zebrasoma flavescens*, in a structurally complex coral reef environment. Environ Biol Fishes 91(2):185–201. doi:10.1007/s10641-011-9771-9

Clements S, Jepsen D, Karnowski M, Schreck CB (2005) Optimization of an acoustic telemetry array for detecting transmitter-implanted fish. North Am J Fish Manag 25(2):429–436. doi:10.1577/m03-224.1

Comeau LA, Campana SE, Castonguay M (2002) Automated monitoring of a large-scale cod (*Gadus morhua*) migration in the open sea. Can J Fish Aquat Sci 59(12):1845–1850. doi:10.1139/f02-152

Comeau LA, Sonier R, Hanson JM (2012) Seasonal movements of Atlantic rock crab (*Cancer irroratus* Say) transplanted into a mussel aquaculture site. Aquac Res 43(4):509–517. doi:10.1111/j.1365-2109.2011.02856.x

Conrath CL, Musick JA (2010) Residency, space use and movement patterns of juvenile sandbar sharks (*Carcharhinus plumbeus*) within a Virginia summer nursery area. Mar Freshw Res 61(2):223–235. doi:10.1071/mf09078

Cooke SJ, Niezgoda GH, Hanson KC, Suski CD, Phelan FJS, Tinline R, Philipp DP (2005) Use of CDMA acoustic telemetry to document 3-D positions of fish: relevance to the design and monitoring of aquatic protected areas. Mar Technol Soc J 39(1):31–41

Cooke SJ, Iverson SJ, Stokesbury MJW, Hinch SG, Fisk AT, VanderZwaag DL, Apostle R, Whoriskey F (2011) Ocean Tracking Network Canada: a network approach to addressing critical issues in fisheries and resource management with implications for ocean governance. Fisheries 36(12):583–592

Cooke SJ, Hinch SG, Lucas MC, Lutcavage M (2012) Biotelemetry and biologging. In: Zale AV, Parrish DL, Sutton TM (eds) Fisheries techniques, 3rd edn. American Fisheries Society, Bethesda, MD, pp 819–860

Dagorn L, Holland KN, Itano DG (2007) Behavior of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna in a network of fish aggregating devices (FADs). Mar Biol 151(2):595–606. doi:10.1007/s00227-006-0511-1

D'Anna G, Giacalone VM, Pipitone C, Badalamenti F (2011) Movement pattern of white seabream, *Diplodus sargus* (L., 1758) (*Osteichthyes, Sparidae*) acoustically tracked in an artificial reef area. Ital J Zool 78(2):255–263. doi:10.1080/11250000903464059

Davidsen JG, Rikardsen AH, Halttunen E, Thorstad EB, Okland F, Letcher BH, Skardhamar J, Naesje TF (2009) Migratory behaviour and survival rates of wild northern Atlantic salmon *Salmo salar* post-smolts: effects of environmental factors. J Fish Biol 75(7):1700–1718. doi:10.1111/j.1095-8649.2009.02423.x

Domeier ML (2005) Methods for the deployment and maintenance of an acoustic tag tracking array: an example from California's channel Islands. Mar Technol Soc J 39(1):74–80

Egli DP, Babcock RC (2004) Ultrasonic tracking reveals multiple behavioural modes of snapper (*Pagrus auratus*) in a temperate no-take marine reserve. ICES J Mar Sci 61(7):1137–1143. doi:10.1016/j.icesjms.2004.07.004

Espinoza M, Farrugia TJ, Lowe CG (2011a) Habitat use, movements and site fidelity of the gray smooth-hound shark (*Mustelus californicus* Gill 1863) in a newly restored southern California estuary. J Exp Mar Biol Ecol 401(1–2):63–74. doi:10.1016/j.jembe.2011.03.001

Espinoza M, Farrugia TJ, Webber DM, Smith F, Lowe CG (2011b) Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. Fish Res 108(2–3):364–371. doi:10.1016/j.fishres.2011.01.011

Fairchild EA, Rennels N, Howell H (2009) Using telemetry to monitor movements and habitat use of cultured and wild juvenile winter flounder in a shallow estuary. In: Nielsen JL, Arrizabalaga H, Fragoso N, Hobday A, Lutcavage M, Sibert J (eds) Tagging and tracking of marine animals with electronic devices. Reviews-methods and technologies in fish biology and fisheries, vol 9. Springer, Dordrecht, pp 5–22. doi:10.1007/978-1-4020-9640-2_1

Field IC, Meekan MG, Speed CW, White W, Bradshaw CJA (2011) Quantifying movement patterns for shark conservation at remote coral atolls in the Indian Ocean. Coral Reefs 30(1):61–71. doi:10.1007/s00338-010-0699-x

Filmalter JD, Dagorn L, Cowley PD, Taquet M (2011) First descriptions of the behavior of silky sharks, *Carcharhinus falciformis*, around drifting fish aggregating devices in the Indian Ocean. Bull Mar Sci 87(3):325–337. doi:10.5343/bms 2010.1057

Finstad B, Økland F, Thorstad EB, BjØrn PA, McKinley RS (2005) Migration of hatchery-reared Atlantic salmon and wild anadromous brown trout post-smolts in a Norwegian fjord system. J Fish Biol 66(1):86–96. doi:10.1111/j.0022-1112.2005.00581.x

Fujioka K, Hobday AJ, Kawabe R, Miyashita K, Honda K, Itoh T, Takao Y (2010a) Interannual variation in summer habitat utilization by juvenile southern bluefin tuna (*Thunnus maccoyii*) in southern Western Australia. Fish Oceanogr 19(3):183–195. doi:10.1111/j.1365-2419.2010.00536.x

Fujioka K, Kawabe R, Hobday AJ, Takao Y, Miyashita K, Sakai O, Itoh T (2010b) Spatial and temporal variation in the distribution of juvenile southern bluefin tuna *Thunnus maccoyii*: implication for precise estimation of recruitment abundance indices. Fish Sci 76(3):403–410. doi:10.1007/s12562-010-0228-4

Girard C, Dagorn L, Taquet M, Aumeeruddy R, Peignon C, Benhamou S (2007) Homing abilities of dolphinfish (*Coryphaena hippurus*) displaced from fish aggregating devices (FADs) determined using ultrasonic telemetry. Aquat Living Resour 20(4):313–321. doi:10.1051/alr:2008005

Gjelland KØ, Hedger RD (2013) Environmental influence on transmitter detection probability in biotelemetry: developing a general model of acoustic transmission. Methods Ecol Evol. doi:10.1111/2041-210x.12057

Hannah RW, Rankin PS (2011) Site fidelity and movement of eight species of Pacific rockfish at a high-relief rocky reef on the Oregon coast. North Am J Fish Manag 31(3):483–494. doi:10.1080/02755947.2011.591239

Hedger RD, Fo Martin, Dodson JJ, Hatin D, Fo Caron, Whoriskey FG (2008) The optimized interpolation of fish positions and speeds in an array of fixed acoustic receivers. ICES J Mar Sci 65(7):1248–1259. doi:10.1093/icesjms/fsn109

Heupel MR, Webber DM (2012) Trends in acoustic tracking: where are the fish going and how will we follow them. Am Fish Soc Symp 76:219–231

Heupel MR, Semmens JM, Hobday AJ (2006) Automated acoustic tracking of aquatic animals: scales, design and deployment of listening station arrays. Mar Freshw Res 57(1):1–13. doi:10.1071/MF05091

Heupel MR, Reiss KL, Yeiser BG, Simpfendorfer CA (2008) Effects of biofouling on performance of moored data logging acoustic receivers. Limnol Oceanogr Methods 6:327–335

How JR, de Lestang S (2012) Acoustic tracking: issues affecting design, analysis and interpretation of data from movement studies. Mar Freshw Res 63(4):312–324. doi:10.1071/MF11194

Hubley PB, Amiro PG, Gibson AJF, Lacroix GL, Redden AM (2008) Survival and behaviour of migrating Atlantic salmon (*Salmo salar* L.) kelts in river, estuarine, and coastal habitat. ICES J Mar Sci 65(9):1626–1634. doi:10.1093/icesjms/fsn129

Humston R, Ault JS, Larkin MF, Luo J (2005) Movements and site fidelity of the bonefish *Albula vulpes* in the northern Florida Keys determined by acoustic telemetry. Mar Ecol Prog Ser 291:237–248. doi:10.3354/meps291237

Ireland LC, Barlow RB (1978) Tracking normal and blindfolded limulus in ocean by means of acoustic telemetry. Biol Bull 155(2):445–446

Jorgensen SJ, Kaplan DM, Klimley AP, Morgan SG, O'Farrell MR, Botsford LW (2006) Limited movement in blue rockfish *Sebastes mystinus*: internal structure of home range. Mar Ecol Prog Ser 327:157–170. doi:10.3354/meps327157

Kanwisher J, Lawson K, Sundnes G (1974) Acoustic telemetry from fish. Fish Bull 72(2):251–255

Kawabata Y, Okuyama J, Asami K, Okuzawa K, Yoseda K, Arai N (2010) Effects of a tropical cyclone on the distribution of hatchery-reared black-spot tuskfish *Choerodon schoenleinii* determined by acoustic telemetry. J Fish Biol 77(3):627–642. doi:10.1111/j.1095-8649.2010.02702.x

Kerwath SE, Gotz A, Attwood CG, Sauer WHH, Wilke CG (2007) Area utilisation and activity patterns of roman *Chrysoblephus laticeps* (Sparidae) in a small marine protected area. Afr J Mar Sci 29(2):259–270. doi:10.2989/ajms.2007.29.2.10.193

Kerwath SE, Thorstad EB, Naesje TF, Cowley PD, Okland F, Wilke C, Attwood CG (2009) Crossing invisible boundaries: the effectiveness of the Langebaan Lagoon Marine Protected Area as a harvest refuge for a migratory fish species in South Africa. Conserv Biol 23(3):653–661. doi:10.1111/j.1523-1739.2008.01135.x

Klimley AP, Butler SB (1988) Immigration and emigration of a pelagic fish assemblage to seamounts in the Gulf of California related to water mass movements using satellite imagery. Mar Ecol Prog Ser 49(1–2):11–20. doi:10.3354/meps049011

Klimley AP, Butler SB, Nelson DR, Stull AT (1988) Diel movements of scalloped hammerhead sharks, *Sphyrna lewini* griffith and smith, to and from a seamount in the Gulf of Galifornia. J Fish Biol 33(5):751–761

Lacroix GL, McCurdy P (1996) Migratory behaviour of post-smolt Atlantic salmon during initial stages of seaward migration. J Fish Biol 49(6):1086–1101. doi:10.1111/j.1095-8649.1996.tb01780.x

Lembo G, Spedicato MT, Okland F, Carbonara P, Fleming IA, McKinley RS, Thorstad EB, Sisak M, Ragonese S (2002) A wireless communication system for determining site fidelity of juvenile dusky groupers *Epinephelus marginatus* (Lowe, 1834) using coded acoustic transmitters. Hydrobiologia 483(1–3):249–257. doi:10.1023/a:1021360419150

Lindholm J, Auster PJ, Knight A (2007) Site fidelity and movement of adult Atlantic cod *Gadus morhua* at deep boulder reefs in the western Gulf of Maine, USA. Mar Ecol Prog Ser 342:239–247. doi:10.3354/meps342239

Lino PG, Bentes L, Oliveira MT, Erzini K, Santos MN (2011) The African hind's (*Cephalopholis taeniops*, serranidae) use of artificial reefs off Sal Island (Cape Verde): a preliminary study based on acoustic telemetry. Br J Oceanogr 59:69–76

Lowe CG, Anthony KM, Jarvis ET, Bellquist LF, Love MS (2009) Site-fidelity and movement patterns of groundfish associated with offshore petroleum platforms in the Santa Barbara Channel. Mar Coast Fish 1(1):71–89. doi:10.1577/c08-047.1

MacArthur LD, Babcock RC, Hyndes GA (2008) Movements of the western rock lobster (*Panulirus cygnus*) within shallow coastal waters using acoustic telemetry. Mar Freshw Res 59(7):603–613. doi:10.1071/mf07239

Maljkovic A, Cote IM (2011) Effects of tourism-related provisioning on the trophic signatures and movement patterns of an apex predator, the Caribbean reef shark. Biol Conserv 144(2):859–865. doi:10.1016/j.biocon.2010.11.019

Manel-la NP, Chittenden CM, Okland F, Thorstad EB, Davidsen JG, Sivertsgard R, McKinley RS, Finstad B (2011) Does river of origin influence the early marine migratory performance of *Salmo salar*? J Fish Biol 78(2):624–634. doi:10.1111/j.1095-8649.2010.02882.x

McKibben JN, Nelson DR (1986) Patterns of movement and grouping of gray reef sharks, *Carcharhinus amblyrhynchos*, at Enewetak, Marshall Islands. Bull Mar Sci 38(1):89–110

Medwin H, Clay CS (1997) Fundamentals of acoustical oceanography. Elsevier Science, Amsterdam

Melnychuk MC (2009) Estimation of survival and detection probabilities for multiple tagged salmon stocks with nested migration routes, using a large-scale telemetry array. Mar Freshw Res 60(12):1231–1243. doi:10.1071/MF08361

Melnychuk MC, Christensen V (2009) Methods for estimating detection efficiency and tracking acoustic tags with mobile transect surveys. J Fish Biol 75(7):1773–1794. doi:10.1111/j.1095-8649.2009.02428.x

Melnychuk MC, Walters CJ (2010) Estimating detection probabilities of tagged fish migrating past fixed receiver stations using only local information. Can J Fish Aquat Sci 67(4):641–658. doi:10.1139/f09-199

Mitsunaga Y, Endo C, Anraku K, Selorio CM, Babaran RP (2012) Association of early juvenile yellowfin tuna *Thunnus albacares* with a network of payaos in the Philippines. Fish Sci 78(1):15–22. doi:10.1007/s12562-011-0431-y

Moore ME, Berejikian BA, Tezak EP (2010) Early marine survival and behavior of steelhead smolts through Hood Canal and the Strait of Juan de Fuca. Trans Am Fish Soc 139(1):49–61. doi:10.1577/t09-012.1

Niezgoda G, Benfield M, Sisak M, Anson P (2002) Tracking acoustic transmitters by code division multiple access (CDMA)-based telemetry. Hydrobiologia 483(1–3):275–286. doi:10.1023/a:1021368720967

O'Toole A, Danylchuk A, Goldberg T, Suski C, Philipp D, Brooks E, Cooke S (2011) Spatial ecology and residency patterns of adult great barracuda (*Sphyraena barracuda*) in coastal waters of The Bahamas. Mar Biol 158(10):2227–2237. doi:10.1007/s00227-011-1728-1

Olsen EM, Moland E (2011) Fitness landscape of Atlantic cod shaped by harvest selection and natural selection. Evol Ecol 25(3):695–710. doi:10.1007/s10682-010-9427-9

Payne N, Gillanders B, Webber D, Semmens J (2010) Interpreting diel activity patterns from acoustic telemetry: the need for controls. Mar Ecol Prog Ser 419:295–301. doi:10.3354/meps08864

Reynolds BF, Powers SP, Bishop MA (2010) Application of acoustic telemetry to assess residency and movements of rockfish and lingcod at created and natural habitats in Prince William Sound. PLoS ONE 5(8):e12130

Rillahan C, Chambers M, Howell WH, Watson WH (2009) A self-contained system for observing and quantifying the behavior of Atlantic cod, *Gadus morhua*, in an offshore aquaculture cage. Aquaculture 293(1–2):49–56. doi:10.1016/j.aquaculture.2009.04.003

Roscoe DW, Hinch SG, Cooke SJ, Patterson DA (2011) Fishway passage and post-passage mortality of up-river migrating sockeye salmon in the Seton River, British Columbia. River Res Appl 27(6):693–705. doi:10.1002/rra.1384

Sakabe R, Lyle JM (2010) The influence of tidal cycles and freshwater inflow on the distribution and movement of an estuarine resident fish *Acanthopagrus butcheri*. J Fish Biol 77(3):643–660. doi:10.1111/j.1095-8649.2010.02703.x

Serrano I, Larsson S, Eriksson LO (2009) Migration performance of wild and hatchery sea trout (*Salmo trutta* L.) smolts-Implications for compensatory hatchery programs. Fish Res 99(3):210–215. doi:10.1016/j.fishres.2009.06.004

Simpfendorfer CA, Heupel MR, Hueter RE (2002) Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Can J Fish Aquat Sci 59(1):23–32. doi:10.1139/f01-191

Simpfendorfer CA, Heupel MR, Collins AB (2008) Variation in the performance of acoustic receivers and its implication for positioning algorithms in a riverine setting. Can J Fish Aquat Sci 65(3):482–492. doi:10.1139/f07-180

Singh L, Downey NJ, Roberts MJ, Webber DM, Smale MJ, van den Berg MA, Harding RT, Engelbrecht DC, Blows BM (2009) Design and calibration of an acoustic telemetry system subject to upwelling events. Afr J Mar Sci 31(3):355–364. doi:10.2989/ajms.2009.31.3.8.996

Speed CW, Meekan MG, Field IC, McMahon CR, Stevens JD, McGregor F, Huveneers C, Berger Y, Bradshaw CJA (2011) Spatial and temporal movement patterns of a multi-species coastal reef shark aggregation. Mar Ecol Prog Ser 429:261–275

Starr RM, Heine JN, Johnson KA (2000) Techniques for tagging and tracking deepwater rockfishes. North Am J Fish Manag 20(3):597–609. doi:10.1577/1548-8675(2000)020<0597:tftatd>2.3.co;2

Starr RM, Heine JN, Felton JM, Cailliet GM (2002) Movements of bocaccio (*Sebastes paucispinis*) and greenspotted (*S. chlorostictus*) rockfishes in a Monterey submarine canyon: implications for the design of marine reserves. Fish Bull 100(2):324–337

Sulak KJ, Randall MT, Edwards RE, Summers TM, Luke KE, Smith WT, Norem AD, Harden WM, Lukens RH, Parauka F, Bolden S, Lehnert R (2009) Defining winter trophic habitat of juvenile Gulf sturgeon in the Suwannee and Apalachicola rivermouth estuaries, acoustic telemetry investigations. J Appl Ichthyol 25(5):505–515. doi:10.1111/j.1439-0426.2009.01333.x

Thorstad EB, Økland F, Rowsell D, McKinley RS (2000) A system for automatic recording of fish tagged with coded acoustic transmitters. Fish Manage Ecol 7(4):281–294. doi:10.1046/j.1365-2400.2000.007004281.x

Topping DT, Szedlmayer ST (2011a) Home range and movement patterns of red snapper (*Lutjanus campechanus*) on artificial reefs. Fish Res 112(1–2):77–84. doi:10.1016/j.fishres.2011.08.013

Topping DT, Szedlmayer ST (2011b) Site fidelity, residence time and movements of red snapper *Lutjanus campechanus* estimated with long-term acoustic monitoring. Mar Ecol Prog Ser 437:183–200. doi:10.3354/meps09293

Topping DT, Lowe CG, Caselle JE (2006) Site fidelity and seasonal movement patterns of adult *California sheephead Semicossyphus pulcher* (Labridae): an acoustic monitoring study. Mar Ecol Prog Ser 326:257–267

Udyawer V, Chin A, Knip DM, Simpfendorfer CA, Heupel MR (2013) Variable response of coastal sharks to severe tropical storms: environmental cues and changes in space use. Mar Ecol Prog Ser 480:171–183

Walsh CT, Reinfelds IV, Gray CA, West RJ, van der Meulen DE, Craig JR (2012) Seasonal residency and movement patterns of two co-occurring catadromous percichthyids within a south-eastern Australian river. Ecol Freshw Fish 21(1):145–159. doi:10.1111/j.1600-0633.2011.00534.x

Welch DW, Boehlert GW, Ward BR (2002) POST "the pacific ocean salmon tracking project". Oceanol Acta 25(5):243–253

Welch DW, Rechisky EL, Melnychuk MC, Porter AD, Walters CJ, Clements S, Clemens BJ, McKinley RS, Schreck C (2008) Survival of migrating salmon smolts in large rivers with and without dams. PLoS Biol 6(10):e265

Welch DW, Melnychuk MC, Rechisky ER, Porter AD, Jacobs MC, Ladouceur A, McKinley RS, Jackson GD (2009) Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Can J Fish Aquat Sci 66(5):736–750. doi:10.1139/f09-032

Westmeyer MP, Wilson CA, Nieland DL (2007) Fidelity of red snapper to petroleum platforms in the northern Gulf of Mexico. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL (eds) Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society Symposium, vol 60. American Fisheries Society, Bethesda, pp 105–121

Whitty JM, Morgan DL, Peverell SC, Thorburn DC, Beatty SJ (2009) Ontogenetic depth partitioning by juvenile freshwater sawfish (*Pristis microdon*: Pristidae) in a riverine environment. Mar Freshw Res 60(4):306–316. doi:10.1071/mf08169

Williams GD, Andrews KS, Katz SL, Moser ML, Tolimieri N, Farrer DA, Levin PS (2012) Scale and pattern of broadnose sevengill shark *Notorynchus cepedianus* movement in estuarine embayments. J Fish Biol 80(5):1380–1400. doi:10.1111/j.1095-8649.2011.03179.x

Willis J, Hobday AJ (2007) Influence of upwelling on movement of southern bluefin tuna (*Thunnus maccoyii*) in the Great Australian Bight. Mar Freshw Res 58(8):699–708. doi:10.1071/mf07001