# Chapter 7: Guidelines for calculating and enhancing detection efficiency of PIT tag interrogation systems

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# Chapter 7.—Guidelines to Indirectly Measure and Enhance Detection Efficiency of Stationary PIT Tag Interrogation Systems in Streams

Patrick J. Connolly[1]


## Abstract

With increasing use of passive integrated transponder (PIT) tags and reliance on stationary PIT tag interrogation systems to monitor fish populations, guidelines are offered to inform users how best to use limited funding and human resources to create functional systems that maximize a desired level of detection and precision. The estimators of detection efficiency and their variability as described by Connolly et al. (2008) are explored over a span of likely performance metrics. These estimators were developed to estimate detection efficiency without relying on a known number of fish passing the system. I present graphical displays of the results derived from these estimators to show the potential efficiency and precision to be gained by adding an array or by increasing the number of PIT-tagged fish expected to move past an interrogation system.


## Introduction

Use of passive integrated transponder (PIT) tags in fish monitoring and research has rapidly increased over the last decade. These tags have become a primary tool for monitoring juvenile salmonid movement and for estimating survival past large hydroelectric dams in the Columbia River basin (Achord et al., 1996; Skalski et al., 1998; Muir et al., 2001a, 2001b; Paulsen and Fisher, 2001). Much valuable information has been gained by adapting similar technology in streams to detect movement or presence of PIT-tagged fish (Armstrong et al., 1996; Zydlewski et al., 2001; Connolly et al., 2005). Although detection of PIT tags by an interrogation system depends on multiple levels of technology associated with transceivers and antennas, along with their wiring and data management linkages, this paper primarily focuses on the part that has the greatest connection with the stream and its fish: the antenna and the arrays that antennas form.

Under normal operating conditions, a PIT tag passing through the rectangular opening of a properly designed and sized antenna should have very high potential to be detected, but factors such as tag orientation (Zydlewski et al., 2006) and presence of another tag (Greenberg and Giller, 2000) can decrease this potential. In many cases, the antenna or an array of multiple antennas cannot be sized for expectations of reading all PIT tags passing, such as when the stream width is wider or the water column is deeper than the maximum-sized antenna or arrays that can be supported by a transceiver unit. However, if the entire channel can be spanned, pass-through antennas may be appropriate for maximizing detection efficiency. As Connolly et al. (2008) noted, this orientation is likely to provide the best probability of detecting a PIT-tagged fish, and it is very suitable for: (1) stable-flow streams; (2) streams with little or no large debris; and (3) studies limited to investigating fish movement during low-flow periods. It also is of use if deployed in a manner that allows the antenna to break away under a predetermined load and to be readily repositioned. The pass-through orientation is particularly suited for taking advantage of existing structures such as bridge crossings, culverts, or engineered study streams.

In other situations, it may be best to anchor antennas so that they are parallel with the stream substrate in a pass-by orientation. As reported by Connolly et al. (2008), this orientation can perform exceptionally well during low-flow conditions, but the column of water available to fish during high water may be more likely to exceed the read range of the antenna. The efficiency of an antenna or array under these conditions may be particularly reliant on the behavior of the fish (e.g., bottom vs. surface-oriented movers). Pass-by and hybrid antennas described in Connolly et al. (2008) have been proven to hold during flow and debris conditions that would have disabled most pass-through antennas. Table 1 lists some of the potentially complex combinations of biological and physical aspects that should help guide where, when, and how antennas are installed.

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**Table 1.** Some primary factors to consider about antenna placement and array configuration.

| Biological factors |
|---|
| • Behavior of fish<br>  • Extent of lateral movement zone<br>  • Extent of vertical movement zone<br>  • Seasonality<br>• Density of PIT-tagged fish passing antennas (i.e., tag detection can be inhibited if two tags are in the field at the same time)<br>• Potential for fish to stage near the antennas (i.e., a stationary tag could inhibit reading of a passing tag) |
| **Physical factors** |
| • Amount of interference from ambient electromagnetic fields (i.e., “noise”)<br>• Ability to provide and maintain power to the system (e.g., plug-in, batteries, solar assisted)<br>• Ability to anchor antennas given expected water velocities, substrate movement, and debris loads<br>• Percent coverage of stream by arrays: laterally and vertically, based on read distance of tag (function of antenna construction and the type and size of PIT tags used) |

Where possible, the use of a known population of PIT-tagged fish, such as salmonid smolts with a strong one-way migratory tendency, would likely prove to be the best method for determining detection efficiency. If direction of fish movement is known, the derivation of detection efficiency is rather simple, and variability can be assessed with replication under similar flow, stream temperature, and other conditions influencing fish movement behavior. However, use of a known tagged fish population passing the interrogation site to assess detection efficiency is not always feasible because of cost and permitting restrictions on fish handling and releasing for the species or life stage of interest.

Connolly et al. (2008) used an indirect method for determining estimates of detection efficiency because they did not know the number of PIT-tagged fish that passed the interrogation system. While their work was based on results of tagging fish with full-duplex PIT tags, the results should be applicable to a wide range of biological and even inanimate objects (e.g., rocks, wood), and to use of half-duplex PIT tags and detection equipment. The current work uses estimators described by Connolly et al. (2008) to address the objective of providing useful guidelines for configuring the structure of antenna arrays to maximize learning about fish movement and survival, while considering cost and effort allocations.

# Methods

Following Connolly et al. (2008), I used the three-array detection probability model in the User Specified Estimation Routine (USER) program (Lady et al., 2003) to calculate the efficiency of detection, and the Delta method (Seber, 1982) to determine standard error and variance of this estimate. The USER program can be downloaded from the website http://www.cbr.washington.edu/paramest/user/ (accessed October 20, 2009), and a manual for the program is available in Skalski (2003). Formulas for the estimators are described in Connolly et al. (2008, appendixes 1 and 2).

A span of likely performance metrics for detection efficiency was used to generate continuous lines or curves for graphical display. Graphs were prepared to address practical questions about what configuration to install or what effort to expend on PIT tagging, such as: “If a second array was added, how much would detection efficiency be increased?” or “If the number of PIT-tagged fish was increased 10-fold, how much improvement in precision of the detection efficiency estimate would be gained?”

## Results

To help readers get a sense of how detection efficiencies and population estimates can be derived from an indirect methodology based on pattern of detection, I offer a simplified example in table 2. The theoretical discussion provided by Zydlewski et al. (2006) and the analysis tools suggested by Connolly et al. (2008) will aid the reader to deal with empirical data and with the much more complex calculations associated with deriving estimates of detection efficiency and its variability when three arrays are installed.

The overall estimate of detection efficiency for an interrogation system is much influenced by the detection efficiency of the individual arrays in the system, and the precision of the estimate is much influenced by the number of PIT tags passing the system (fig. 1). The overall detection efficiency of a system with two or more arrays generally is greater than any of its individual arrays. It takes at least two arrays to derive an estimate of efficiency when relying on an indirect method of estimation.

Adding a third array can further increase an interrogation system's overall detection efficiency (fig. 2). This addition of a third array also serves to enhance precision of the estimate of detection efficiency.

**Table 2.** A practical example of how detection efficiency is derived for a two-array interrogation system based on the differential pattern of PIT tag detection of the arrays.

*Example setting*: A two array PIT tag interrogation system is in place, and a number of PIT tags from known downstream migrating fish have been detected

*Data:*

- 700 PIT tags have been detected on the upstream-most array (A1).
- 500 PIT tags have been detected on the downstream-most array (A2), 350 of which had been detected on A1 and 150 of which were only detected on A2.

*Question*: What was the detection efficiency of the system?

- From the data above, we can conclude that A2 missed 350 that were read on A1, which equates to a 50% detection efficiency for A2.
- If the 500 tags read by A2 represents 50% of all tags available, then a total of 1,000 would have had to pass both A2 and A1.
- Because A1 detected 700 of the 1,000 tags that passed, then A1 must have had a 70% detection efficiency.
- Adding all unique tags read by A1 (=700) and A2 (=150) equates to 850, which means that the entire system had an 85% detection efficiency.

*Question*: How many PIT-tagged fish passed the system?

- 1,000 (as derived above).

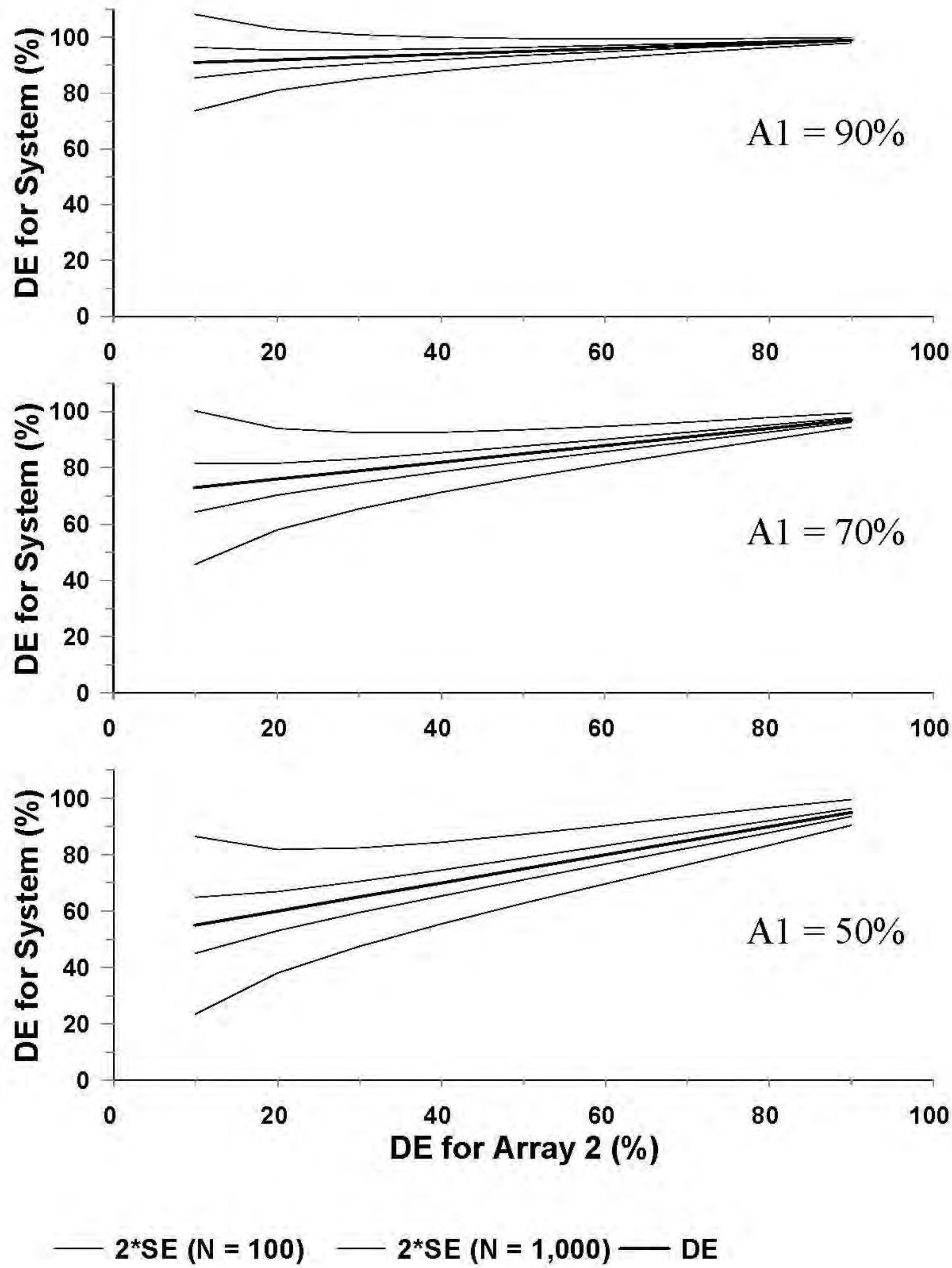


**Figure 1.** Effect on detection efficiency (DE) of adding a second array when the DE of the first array (A1) is 90%, 70%, or 50%. The sets of lines above and below the central line (estimate) represent variance of the estimate (± 2*SE) when the estimated number of PIT tags to pass the interrogation system is either 1,000 (inner set of lines) or 100 (outer set of lines).

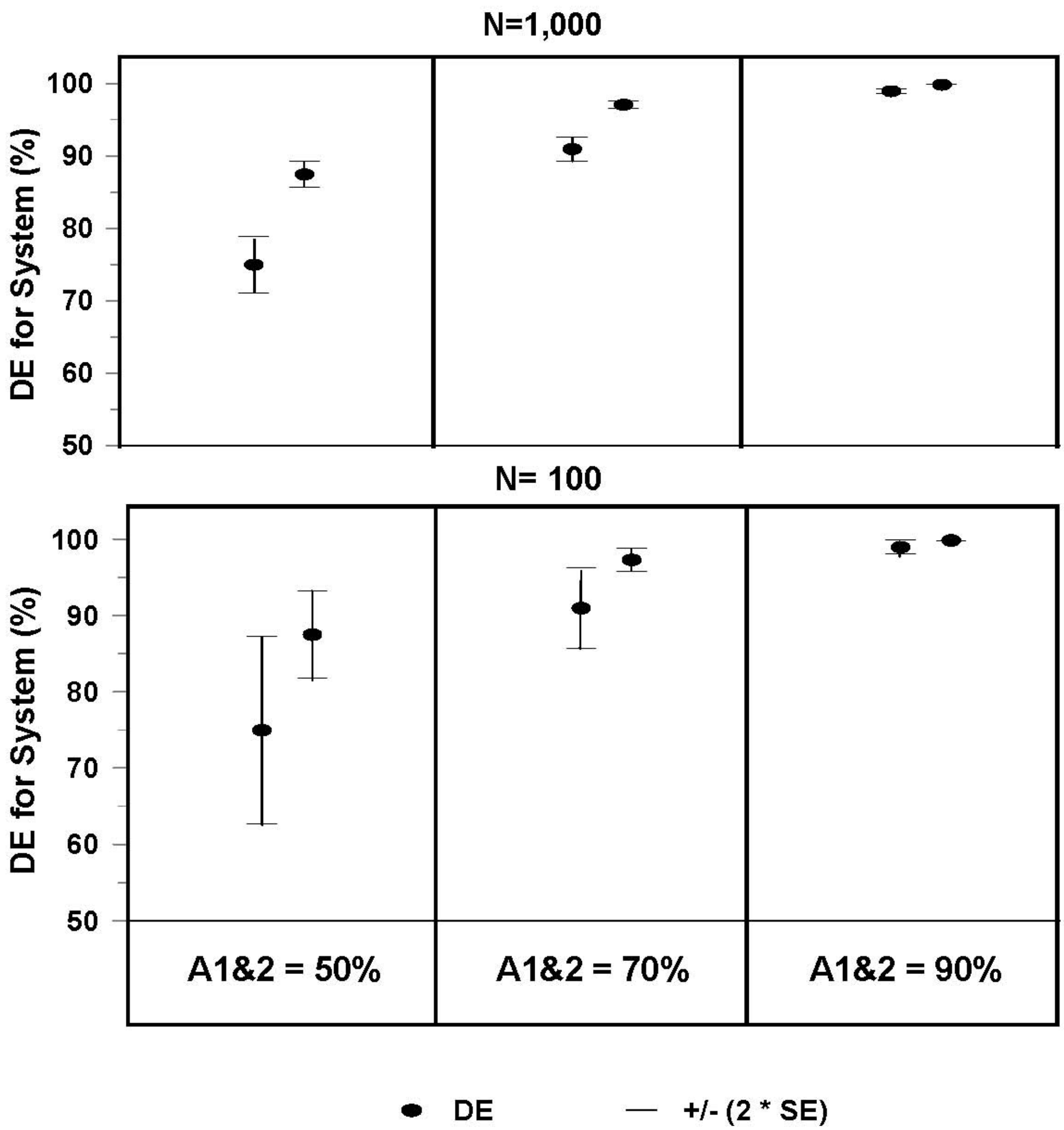


**Figure 2.** Effect on detection efficiency (DE) of adding a third array when the DEs of the individual first and second arrays (A1 and A2) are 50%, 70%, or 90%, and when estimated number of PIT tags to pass the interrogation system is either 1,000 or 100. The first and lower estimate in each panel is the DE for the system with two arrays, while the second and higher estimate is the DE when a third array of the same individual DE is added (e.g., the top left panel depicts the system's DE when all arrays have an individual DE of 50%, and when the number of PIT tags estimated to pass is 1,000).

## Discussion

A wide range of possible detection efficiencies from potential combinations of arrays has been graphically presented, which should provide guidelines for practical situations that field personnel and managers are likely to face. Even with intensive efforts to direct all or most fish within the read-range of instream antennas, tag detection efficiency is likely to be less than 100% for a number of reasons. Electrical properties of a PIT tag interrogation system can change with changes in water level, which may partially or completely expose an antenna to air, and with changes in water temperature, conductivity, and air temperature (Connolly et al., 2008). These problems can be partially or completely solved by using transceivers that automatically change their settings (self tune) to changing environmental conditions, thus improving performance. Ambient electromagnetic fields (EMF) of similar frequency, which can be generated by nearby power lines, electric fences, pumps, or electrical devices in homes or businesses (Zydlewski et al., 2006; Horton et al., 2007), can compromise a system's ability and consistency to detect tags. Multiple fish swimming through or holding in the detection field at the same time can compromise the ability to detect a tag (Greenberg and Giller, 2000). Because of these factors, investigators should strive to determine detection efficiencies for periods of time with similar conditions (Horton et al., 2007).

Study goals, target species, and budget will dictate need for specific designs of interrogation systems. The extra cost associated with interrogation systems that can help differentiate between upstream and downstream movement and that provide a high level of detection efficiency may not always be warranted. Although traps and weirs can be used to obtain similar life-history information, these tools are expensive to operate because of staffing needs, and can be difficult to operate year round due to high flow and debris loads. Antennas can be constructed to be placed in a variety of configurations and can be highly adaptable to the challenges of stream environments. By using the guidelines offered in this paper, it is hoped that users of PIT tag technology can better maximize their learning about fish movement and survival.

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