Journal of Aquatic Animal Health 17:160–169, 2005

DOI: 10.1577/H04-037.1

[Article]

Methodological Approaches and Opinions of Researchers Involved in the Surgical Implantation of Telemetry Transmitters in Fish

GLENN N. WAGNER*[1] AND STEVEN J. COOKE

Centre for Applied Conservation Research, Department of Forest Sciences, University of British Columbia, 3022-2424 Main Mall, Vancouver, British Columbia V6T 1Z4, Canada

Abstract.—The purpose of the present study was to characterize the surgical methods researchers use to implant telemetry transmitters in fish and obtain their opinions on fish surgical techniques. The majority of respondents (74%) use monofilament suture to close transmitter incisions, mirroring recent findings that monofilament can help reduce tissue inflammation and promote wound healing. An equal number also believe that maintaining sterile equipment between surgeries is important to preserve fish health. Despite the difficulty of maintaining sterile surgical equipment and surgery areas in field conditions, this opinion does coincide with those of veterinarians. Opinions about what component of surgery is the most hazardous for fish were mixed: 37% believed it to be the initial incision, closely followed by wound closure (23%), insertion of the transmitter and its components (22%), and anesthesia and the handling of the fish (18%). A large proportion (73%) of researchers practice at least occasionally to maintain or improve their surgical skills. The fact that approximately 18% of fish surgeons do not practice was a surprise. Although responses regarding any observations between surgical experience/volume and outcome (e.g., survival) were disparate, the majority (69%) of respondents identified this as an important research area. Furthermore, the majority of researchers (62%) believed it was important to use the individual surgeon for each fish as a covariate when analyzing the data obtained during a study involving multiple surgeons. Despite the variety of practices and opinions of fish surgeons, the majority of responses conformed with or promoted the use of surgical techniques that would benefit the health and welfare of fish. This information should help fisheries researchers refine their surgical techniques and assist governing agencies in forming important regulations on laboratory and field surgical procedures.

Telemetry transmitters have been used to track fish since the mid 1950s (Trefethen 1956) and currently are used to assess daily activity and habitat use (Lucas and Baras 2000; Aarestrup et al. 2002; Hinch et al. 2002), energy expenditure (Standen et al. 2002), migratory routes (Candy and Quinn 1999; Meka et al. 2003), anthropomorphic impacts (Magee et al. 2001; Scruton et al. 2002), and physiological condition (Anderson et al. 1998; Cooke et al. 2004). Early transmitter attachment techniques focused on the use of gastric insertion (Groot et al. 1975; McCleave and Stred 1975) or external mounts (Lonsdale and Baxter 1968). The first detailed account of surgical techniques for the implantation of telemetry transmitters into the peritoneal cavity of fish was published by Hart and Summerfelt (1975). As is the current practice, these techniques were modified from those used for mammalian surgery (Stoskopf 1993) and included maintenance of anesthesia, aseptic method, protection of the viscera, and incision closure with sutures. The basic procedure involves insertion into the fish of a transmitter through an incision into the peritoneal cavity that is subsequently sealed. The majority of the surgery methods used have remained unchanged, and little empirical testing has been done (Wagner et al. 2000). Although telemetry can provide a wealth of ecological and physiological information, if the health of fish is compromised by the tagging procedure, any data so acquired will be suspect. Physiological compromise can lead to changes in behavior (Adams et al. 1998a, 1998b; Wagner and Stevens 2000), the very thing the study is attempting to be measured.

Surgical procedures for use on nonmammalian vertebrates generally fall under the governance of institutional animal care and use committees (IACUC). In North America the agencies in-

* Corresponding author: glenn.wagner@stonybrook.edu
[1]Present address: Marine Sciences Research Center, Stony Brook University/SUNY, Stony Brook, New York 11794-5000, USA.

Received June 22, 2004; accepted October 28, 2004
Published online May 27, 2005

volved in animal care are the Canadian Council on Animal Care (CCAC) in Canada and the National Research Council (NRC) in the United States. In the United Kingdom, the Animal Procedures Section of the Home Office enforces the Animals (Scientific Procedures) Act, 1986 (GOASPA). These federal bodies have many regulations pertaining to surgical methods for mammals, and even some for birds, reptiles, and amphibians, but currently there are no established protocols for surgical procedures on fish (GOASPA 1986; CCAC 1993; NRC 1996; Mulcahy 2003a)—although some guidelines are forthcoming from the CCAC. For development of proper protocols for fish surgery, it is important to understand that the vast majority of studies involving surgical implantation of transmitters are performed in the field (see review by Jepsen et al. 2002). Remote study sites create several challenges for researchers, including battery operation of water pumps and lights, adverse weather conditions, and difficulty in maintaining sterile equipment and surgical fields. Moreover, given that the water used during surgery and in which the fish are subsequently placed is in no way sterile, it becomes obvious that any methodological regulations for surgery on fish will require unique modifications if they are to be applied by the researchers they are intended to target (Mulcahy 2003b).

The primary purpose of the present study was to characterize the surgical methods researchers use to implant telemetry transmitters in fish and obtain their opinions on fish surgical techniques. This study summarizes a portion of the results from an online survey that was distributed to individuals who engage in surgical implantation of telemetry transmitters in fish. The design and respondent characteristics match those of Cooke and Wagner (2004), who summarize another portion of the survey concerning surgical training and education. Our intention is for this information to be used by fisheries researchers in their refinement of surgical techniques and by governing agencies that must balance the need to regulate fish surgical procedures with the practical limitations involved in many field studies.

Survey Methods

Detailed information regarding the survey design is presented in Cooke and Wagner (2004). Briefly, an online survey was emailed to approximately 300 individuals known to have participated in fish telemetry studies. These individuals had published or presented studies involving fish telemetry, participated in telemetry conferences, or belonged to fisheries-related list serves. Participants had to have had experience with surgically implanting transmitters into the peritoneal cavity of fish. The actual number of these ''fish surgeons'' who received our invitation to participate is unknown because we encouraged all participants to forward the survey to other colleagues with surgical experience.

Responses to individual questions were tabulated and the percentages reported are rounded to the nearest whole number. Cross-tabular statistics were performed by using Pearson product-moment correlation with a significance level of $P < 0.05$.

Respondent Characteristics

A complete reporting of the respondent characteristics is provided in Cooke and Wagner (2004). Of 41 questions posed in the survey, we report here on the 13 related to surgical methodology. In total, 177 fish surgeons from 17 countries participated, with the majority residing in the United States, Canada, and Europe. Self-reported surgical experience suggested that 12% were ''novice,'' 57% were ''competent,'' and 31% were ''expert'' surgeons. The accuracy with which respondents self-reported their own experience level was good (Cooke and Wagner 2004). Current employment of the respondents included government (38%), academic (25.5%), student (17. 5%), consulting (12%), nongovernmental organization (4%), and 3% ''other.''

Surgical Methodology and Opinions

What type of anesthetic do you use most frequently for fish surgery?

Although tricaine methanesulfonate (MS-222) still is the most commonly used fish anesthetic (47%), the use of clove oil (main active ingredient, eugenol) has increased to the point where it now is a close second (32%). Only a few respondents use other anesthetics (7.5%), such as benzocaine, 2-phenoxy-ethanol, and metomidate hydrochloride. Several researchers specified the use of carbon dioxide (7.5%) or no anesthetic at all (6%), particularly in studies involving the immediate release of wild-captured fish.

Anesthetics generally are used on fish for the purpose of physiological investigations, surgery, tagging, tissue sampling, transport, and euthanasia. For surgical purposes, anesthetics cause a loss of sensation in fish by depressing their central and peripheral nervous systems in order to immobilize them (Summerfelt and Smith 1990; Ross and Ross 1999). Clove oil is an anesthetic that has emerged as an equally effective alternative to MS-222 for use on fish (Keene et al. 1998; Cho and Heath 2000; Wagner et al. 2003). This parity on use is probably attributable to the recognized benefits of clove oil (noncarcinogenic, rapid induction, relatively short recovery time, comparable low cost) over MS-222. Currently only MS-222 is approved for use on fish in the United States (FDA 2002), but several unapproved anesthetics are effective on fish (Iwama and Ackerman 1994) and are in fact preferred by some researchers.

The use of anesthetics during surgery on fish should be standard practice (Mulcahy 2003a); however, some studies involving surgery have not used anesthesia (Groot et al. 1975; Stanley 1983; Thorstad et al. 1998). Studies involving large pelagic fish such as sharks generally rely on tonic immobility (i.e., restraint of the fish in an inverted position leading to the cessation of movement) instead of anesthesia during surgical tagging (Holland et al. 1999). No studies to our knowledge have examined the physiological response of fish during this procedure, but Culik et al. (1990) found that tonic immobility in penguins did not prevent distress during handling. Although it is unlikely that fish feel the actual sensation of pain (Rose 2002), noxious stimuli are known to elicit negative physiological responses in conscious fish (Chervova 1997; Sneddon 2003; Sneddon et al. 2003). Any acute handling stress without anesthesia will cause a stress response in fish that can alter their physiology for up to 48 h (Wendelaar Bonga 1997; Wagner et al. 2003). This physiological disturbance can result in behavioral changes as well as an increased susceptibility to infection because of suppression of immune function (Pickering and Pottinger 1987; Maule et al. 1989; Mock and Peters 1990). Although some anesthetics also can elicit a stress response (Iwama et al. 1989), it stands to reason that performing a surgical procedure without first anesthetizing the fish qualifies as an intense stressor and should be avoided.

What wound closure material do you use most often for fish surgery?

The majority of fish surgeons use monofilament to close incisions, 47% using absorbable filament and 27% using nonabsorbable filament. A further 13% use silk sutures and 8% use surgical staples. Not surprisingly, none of the respondents uses glue as the sole means of closure, although 5% use a combination of various suture materials and glue.

Glues (typically cyanoacrylate) have been reported to successfully close wounds in a few studies (Moccia et al. 1984; Nemetz and MacMillan 1988; Petering and Johnson 1991). However, the incidence of wounds reopening, tissue inflammation, and necrosis is much higher with adhesives, especially when used in conjunction with sutures (Petering and Johnson 1991; Kaseloo et al. 1992; Lowartz et al. 1999).

Surgical staples have been used to close incisions in several studies (Mulford 1984; Filipek 1989; Mortensen 1990), with accounts of fast placement and subsequent reduced surgery times. Good incision healing has been reported for several fish species after recapture from telemetry studies (Swanberg et al. 1999; G. Betteridge, Algonquin Fisheries Assessment Unit, Algonquin Provincial Park, Ontario, Canada, personal communication), but others studies have suggested that stapling increased mortality and transmitter loss (Haeseker et al. 1996; Starr et al. 2000). If staples are used, it is important to match proper staple size to the species to prevent tissue tearing and to ensure that the edges of the incision are not puckered together and so prevent necrosis at the wound margins.

The preference by respondents for monofilament sutures to close incisions mirrored findings that monofilament can help reduce tissue inflammation and promote wound healing. Several studies have recommended monofilament sutures over silk because the latter can increase inflammation and lengthen healing times of the incisions in rainbow trout *Oncorhynchus mykiss* and blue tilapia *Oreochromis aureus* (Kaseloo et al. 1992; Thoreau and Baras 1997; Wagner et al. 2000). The increased inflammation prevalent with incisions closed with silk sutures also can alter the swimming behavior of fish in which transmitters have been implanted (Wagner and Stevens 2000).

During a typical transmitter implantation surgery, what component of the surgery do you believe is potentially the most risky to the fish?

Responses to the question of the most hazardous component of surgery were very mixed: 37% replied that it is the initial incision, 23% the wound closure, and 22% the insertion of the transmitter (including the antenna and other components). A large proportion of researchers (18%), mostly self-identified as ''experts'' (Table 1) suggested separately that anesthesia and the handling of the fish present the greatest risk during surgery. Indeed, in human and veterinary medicine, postoperative

TABLE 1.—Cross-tabulation of respondents' opinions about their level of expertise and the riskiest component of fish surgery. The asterisk indicates that the Pearson product-moment correlation was significant at $P = 0.003$. ''Competent'' surgeons believed the initial incision is the critical step, whereas the opinions of ''experts'' and ''novices'' were mixed.

	Riskiest component			
Level of expertise	Initial incision	Insertion of the transmitter	Closing the wound	Other
Expert	11	4	9	28
Competent	43*	14	20	21
Novice	8	3	6	4

care and recovery from anesthesia are considered crucial elements of the surgical procedure.

Any one of the components of surgical implantation, if performed improperly, can cause changes in physiology or lead to delayed mortality. These consequences can affect the outcome of telemetry studies by changing movement patterns, altering behavior, or reducing sample sizes. Few in-depth reports of mortality appear in the literature, but the problems experienced by researchers seem to depend greatly on the species of fish used in the study and the environmental conditions involved (see review by Jepsen et al. 2002). In postmortem analyses of juvenile largemouth bass *Micropterus salmoides* implanted with transmitters, Cooke et al. (2003) reported that all nicks observed in viscera were a result of the initial incision.

Channel catfish *Ictalurus punctatus* have recovered from 5- to 7-cm incisions that were not closed (Carmichael 1991); whitefish *Coregonus* spp., on the other hand, are well known for their fragile health, as is evident from the 50% mortality observed by Morris et al. (2000) after transmitter implantation. Although we do not promote the failure to close surgical incisions—and agree with Mulcahy (2003a) that this should be avoided—some limited evidence suggests nonclosure may benefit species without scales because sutures can more easily cause skin lacerations and impede healing (Baras and Jeandrain 1998). Proper closure also may help prevent transmitter loss through the incision, although losses may still occur by transintestinal expulsion (Summerfelt and Mosier 1984; Chisolm and Hubert 1985; Marty and Summerfelt 1986) or across the body wall by pressure necrosis (Marty and Summerfelt 1986; Lucas 1989; Knights and Lasee 1996). Differences in expulsion rates usually are the result of species-specific tissue reactions (Lucas 1989) or of environmental conditions such as water temperature that can affect the healing of transmitter incisions (Bunnell and Isely 1999). Higher temperatures do not seem to affect wound-healing time, but they can promote tissue inflammation and bacterial infection (Roubal and Bullock 1988; Knights and Lasee 1996; Jepsen et al. 2002). Although expensive to the researcher, long-term transmitter losses as high as 60–70% do not necessarily correlate with increased mortality in different species (Summerfelt and Mosier 1984; Chisolm and Hubert 1985).

Is it important that fish surgery is conducted in a sterile manner (e.g., sterilize tools between fish, wear gloves, etc.)?

Only 12% of researchers performing surgery on fish do not believe that aseptic technique is important. The popular opinion (73%) is that maintaining sterile equipment between surgeries is important to preserve fish health. The remaining 15% had no opinion on the matter.

Although Mulcahy (2003a) also is a strong proponent of the complete sterilization of all surgical equipment and disinfection of the surgery area, it may be impossible to maintain these conditions even within laboratory settings because the aquatic environment in which fish live is not sterile (AFS, AIFRB, and ASIH 2004). One ''expert'' respondent concurred, stating that

> [s]terile tagging is more or less a delusion and impossible to conduct in practice. You simply can't avoid contact with water and fish [mucus]. Fish also seem to be highly resistant to germs at least in low temperatures. Keeping the equipment and surfaces clean is sufficient enough and reasonable.

One can, however, further minimize the introduction of bacteria and foreign materials into the incision by thoroughly cleaning and disinfecting all surgical equipment between surgeries and occluding water from the site. These steps should help to optimize the recovery of fish from surgical procedures. Another possible step is the disinfection of the incision site, but the use of topical antiseptics is not recommended because they do not improve wound healing; in fact, they can disrupt the protective cutaneous mucus layer of the fish, allowing easier penetration by pathogenic organisms (Hart and Summerfelt 1975; Briggs 1995; Wagner et al. 1999). The use of wet surgical gloves also should help to protect the mucus layer, though handling the fish may be somewhat more difficult.

Should water be kept out of the open wound while performing surgery on fish?

Most of the respondents (78%) believe it is important to keep water away from the open wound

TABLE 2.—Cross-tabulation of respondents' opinions about the need for maintaining sterility during fish surgery and keeping water out of the telemetry incision. Asterisks indicate that the Pearson product-moment correlation was significant at $P = 0.01$. Respondents who believed surgeries should be sterile also believed water should be prevented from entering the incision.

	Keep water out				
Maintain sterility	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Strongly agree	34*	17	6	1	1
Agree	15	32*	9	3	0
Neutral	3	11	8	2	0
Disagree	6	6	4	2	0
Strongly disagree	0	2	0	0	0

and peritoneal cavity while performing surgery. Some researchers did not have an opinion (17%) and only 5% believed the occlusion of water was not an important issue. Responses to this question correlated strongly with people's opinions on the need for surgical sterility (Table 2) and correspond with findings that water entering the peritoneal cavity of fish can promote bacterial growth (Nemetz and MacMillan 1988; Wagner and Stevens 2000). The water in which fish live and that is used to irrigate and deliver anesthetic to the gills during surgery is not completely sterile, especially under field conditions. Although it is unrealistic to assume that every drop of water can be occluded from contacting the incision site, keeping water out of the wound if possible seems fairly intuitive. An issue of greater concern may be the healing period of fish because as one ''expert'' respondent stated, ''Fish are returned to nonsterile environments and pressure changes result in water in the body cavity regardless of technical ability.'' One possible solution for use with smaller telemetry devices is their placement under the skin of fish, without penetrating the peritoneal cavity (Healey et al. 2003). This technique would protect the integrity of the peritoneal cavity and allow water to only enter the wound itself during the healing period. However, possible resulting skin infections such as fungal growth can lead to mortality as well, and this method may not be suitable for larger transmitters.

Is the level of methodological detail associated with fish surgery adequately reported in publications?

Researchers were evenly split about whether surgical methods are adequately reported—34% believing they are, 33% believing they are not, and 33% having no opinion on the matter. The fact that a fairly high number of people believe that methodological reporting needs to improve does raise some concern. It has been our experience that attempting to repeat the methods used in previous studies or to compare and contrast results can at times be a frustrating task. If basic information such as fish lengths and weights, incision size and placement, or incision closure techniques and materials are not included, much of the information gained by the study remains interesting but not very useful. On occasion we have been asked by reviewers to reduce the length of the surgical methods section and simply to refer to other studies. Because of the importance of the surgical procedures to the outcome of the study objectives, however, we believe the inclusion of detailed surgical procedure descriptions is of the utmost importance and encourage journal reviewers and editors to require them.

Surgical Skills

Do you ever practice your suturing skills?

Only a small number of researchers (15%) practice often to maintain or improve their wound-closure skills. A larger proportion of fish surgeons never practice (18%), and 9% of respondents noted this question did not apply to them (probably because of the use of staples or other closure methods). Still, 58% of researchers who perform surgery on fish do occasionally practice to maintain or improve their skills. We understand that some of those who do not practice may not have to because they are constantly performing surgeries (several reported more than 1,000). However, it is highly recommended that all novice surgeons practice proper surgical techniques on nonliving specimens or a nonanimal model before attempting transmitter implantations on live fish. Repeatedly performing incisions and tying sutures can only help to improve surgical deftness, thus decreasing surgery times and improving the outcome of the procedures (Seki 1987; Engelhorn 1997; Datta et al. 2002; Cooke et al. 2003). One respondent appropriately summed up this need to practice by saying, ''Speed comes with practice, speed keeps fish alive. I require my students to tie at least 100 sutures before I will let them conduct a surgery on a live fish.''

If you practice your suturing skills on a nonanimal model, what is it?

The two most common nonanimal models used in practicing suturing skills involved a type of cloth or rubber (36%), typically ''stretched over a tin can,'' or a type of foam, sponge, or neoprene (34%). Practice units made of different types of cloth and foam generally are available for purchase from the medical stores of human and veterinary hospitals where doctors are trained. The use of synthetic materials was followed closely by various food products (25%), mostly fruits such as bananas and oranges. The tissues of these fruits can provide decent simulation of animal tissues because of the thick skin and softer inner pulp. Cardboard and clear plastic bottles were used in 5% of the responses, but we are uncertain about their effectiveness.

Do you practice surgery on a new species prior to initiating a formal research study on that species?

The majority of researchers always (42%) or almost always (19%) practice surgery on a new species before beginning a study. Many still only occasionally practice beforehand (26%), whereas a few never (9%) or almost never (4%) practice.

How do you prepare for transmitter implantation surgery on a species you are not familiar with?

Responses to the question of working on a new species were fairly evenly divided between those who simply apply their previous knowledge (27%) and those who contact or observe others who are experienced with that species (25%). A large proportion would practice either on dead (22%) or live specimens (15%) before beginning a study, but only 3% would use a nonanimal model. Very few researchers (6%) would contact a veterinarian, which may be indicative of apprehension about veterinarians' knowledge of fish or fish-specific surgical techniques. This opinion is exemplified by the comments of two ''expert'' respondents, ''Do not use a vet. Their mortality rate is high due to slowness''; and ''Veterinarians kill fish. They are too worried about sterility and anesthesia.'' Our viewpoint, however, is that fish surgeons can only benefit from the surgical training possessed by veterinarians. In fact, many veterinarians are just as eager to gain knowledge about fish, and consultations between the two parties can be reciprocal.

While examining the relevant literature on the species in question was not listed as one of the choices, 2% of respondents added it. It is very important that this latter option was mentioned by several participants in the survey. The known literature is, of course, a great source of information for researchers. If details are available, the existing literature is the first tool one should use when learning about a new topic—a new fish species, in this instance. A combination of sources was supported by several of the respondents, one of whom stated, ''It is critical to study the morphology and anatomy of new species (literature and specimens should be used).'' We concur that it is important to practice surgical implantations on a new species if at all possible. This is especially true if using fish from families with which you are not familiar because the proper anesthetic dose, incision site, and placement of the transmitter may all be different. Failure to note these differences may increase recovery times, transmitter loss, or mortality rates.

Surgeons and Study Outcomes

Have you noted any relationship between the number of surgeries completed and the outcome (e.g., growth, survival, etc.) of any studies you have conducted?

The majority of researchers did not know (33%) or observed no correlation (33%) between the volume of surgeries and the outcome of a study. However, comparing the opinions of surgeons with different skill levels made it evident that most ''experts'' had an opinion on the study outcome, and ''novice'' surgeons did not (Table 3). A fair proportion of researchers observed a positive correlation (29%), whereas only three respondents (2%) reported observing negative effects of high surgery volume. Approximately 3% of researchers further noted observing a plateau in the skill level of surgeons, such that mortality levels were reduced to a certain level with increased experience but did not decrease further with more surgeries. One pertinent suggestion was, ''Volume should only be increased with additional competent surgical teams. Reducing time for each surgery has many benefits to the fish but should not come at the expense of the technique.'' Several of the re-

TABLE 3.—Cross-tabulation of respondents' opinions about their level of expertise and an observed relationship between the number of surgeries performed and the study outcome. The asterisk indicates that the Pearson product-moment correlation was significant at $P = 0.002$. ''Novices'' tended not to have an opinion on the effect of multiple surgeries on the study outcome, while ''experts'' and ''competent'' surgeons did.

	Relationship between the volume of surgeries completed and the outcome				
Level of expertise	Don't know	Positive correlation	Negative correlation	No correlation	Other observations
Expert	8	18	2	21	16
Competent	36	24	1	32	16
Novice	14*	3	0	3	2

spondents also noted that an excessive number of surgeries performed in a single day often resulted in an increase in mortality rates, probably because the surgeons became fatigued.

Is there a need for research evaluating the relationship between experience and outcome in fish telemetry surgery?

A large proportion of researchers (69%) agree there is a need to determine whether a connection exists between experience with fish surgery and the outcome of studies involving telemetry. Only 5% believe that this type of study is not required; 26% of the respondents do not have an opinion.

There is strong evidence from veterinary medicine that surgery times of novice medical surgeons are significantly longer than those of experienced surgeons because of less surgical dexterity (Annett 1971; Engelhorn 1997). The skill level of surgeons in human medicine also has been reported to improve with experience (Seki 1987) and affect the outcome of the procedures (Szalay et al. 2000; Datta et al. 2002). A similar observation has been made for surgical transmitter implantations in fish. Cooke et al. (2003) reported increased surgery times and mortality of largemouth bass for novice surgeons. Mortalities were attributed to damage to the viscera and obstruction of the digestive track by the transmitter antenna wire. These preventable complications reflect the lack of manual dexterity, efficiency, and anatomical knowledge that are acquired only through many hours of practice on dead and live specimens. This type of practice is mandatory for surgeons working on later-evolving vertebrates (Smeak 1999) but does not seem to be common for research on fish—making the actual experience level of a fish surgeon quite difficult to determine. An exception to this situation occurs in the United Kingdom, where a specific license is required to perform surgeries on fish and octopi. This license has to be obtained through course work and the display of surgical competency.

If using more than one surgeon in a study, should this be factored into the data analysis?

The majority of researchers (62%) believe it important to record which surgeon implanted each transmitter for later use in analyzing the data obtained during a study. Many people (29%) do not have an opinion, and only 9% do not believe the number of surgeons in a study will affect the results. Given the strong agreement that participation by multiple surgeons can have an effect on the outcome of the study, it probably is important to report this number and include it as a variable in analyses. This is especially true if the surgeons involved in the study have a wide range of experience or if outcomes are highly variable with respect to transmitter data quality, recorded fish behaviors, or mortality. To date, very few studies have reported on the use of multiple surgeons, and only one has quantitatively assessed whether this practice had an effect on the outcome of a telemetry study (Cooke et al. 2003).

Conclusions

Although the practices and opinions of fish surgeons did vary, the majority promote the use of surgical techniques and training that would benefit the health and welfare of fish. Preferred surgical techniques include the use of monofilament sutures, maintenance of aseptic conditions, and applying due care when anesthetizing the fish, making the initial incision, inserting the transmitter, and closing the wound. Most of the respondents also believe it is important to report detailed information about the surgical methods and the experience of the surgeons involved in the study.

We strongly agree with the general consensus that aseptic technique is necessary to maximize fish survival and promote proper animal care. However, maintaining completely sterile surgical equipment in surgeries involving fish is improbable. A program of diligent cleaning and disinfection of instruments between surgeries can be performed to optimize care of the patient. Although not currently preferred by members of the fisheries community, we believe a greater collaboration between fish surgeons and veterinarians can only improve surgery techniques and subsequent study outcomes. It is important to remember that any standardization and improvement of surgical techniques is related to improved and comparable results.

Most countries do not have federal-level animal care regulations for fish surgical procedures. Even the scientific societies that have attempted to provide proper animal care guidelines for fish researchers have failed to include any detailed instruction for the surgical implantation of transmitters or training standards for fish surgeons (AFS, AIFRB, and ASIH 2004). If the ethical treatment of fish is to be properly promoted, regulations that currently are the venue of individual institutions (Mulcahy 2003b) should be incorporated federally. We hope this information on the current methods of fish surgery used by fisheries researchers, along with their opinions on the topic, will be used by individuals to refine their techniques and by governing agencies to form important regulations on fish surgical procedures for the laboratory and field settings. We understand the general resistance to an increased level of regulations for biological studies; we believe, however, that improvements such as standards for the training of fish surgeons and improved reporting of surgical methods in the literature will help all fisheries scientists.

References

Aarestrup, K., C. Nielsen, and A. Koed. 2002. Net ground speed of downstream migrating radio-tagged Atlantic salmon (*Salmo salar* L.) and brown trout (*Salmo trutta* L.) smolts in relation to environmental factors. Hydrobiologia 483:95–102.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998a. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 127:128–136.

Adams, N. S., D. W. Rondorf, S. D. Evans, J. E. Kelly, and R. W. Perry. 1998b. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55:781–787.

AFS, AIFRB, ASIH (American Fisheries Society, American Institute of Fishery Research Biologists, and American Society of Ichthyologists and Herpetologists). 2004. Guidelines for the use of fishes in research. American Fisheries Society, Bethesda, Maryland.

Anderson, W. G., R. Booth, T. A. Beddow, R. S. McKinley, B. Finstad, F. Økland, and D. Scruton. 1998. Remote monitoring of heart rate as a measure of recovery in angled Atlantic salmon. Hydrobiologia 371/372:233–240.

Annett, J. 1971. Acquisition of skill. British Medical Bulletin 27:266–271.

Baras, E., and D. Jeandrain. 1998. Evaluation of surgery procedures for tagging eel *Anguilla anguilla* (L.) with biotelemetry transmitters. Hydrobiologia 371/372:107–111.

Briggs, C. T. 1995. The metabolic costs of activity of free swimming, adult rainbow trout (*Oncorhynchus mykiss*) estimated by electromyogram telemetry. Master's thesis, University of Calgary, Calgary, Alberta.

Bunnell, D. B., and J. J. Isely. 1999. Influence of temperature on mortality and retention of simulated transmitters in rainbow trout. North American Journal of Fisheries Management 19:152–154.

Candy, J. R., and T. P. Quinn. 1999. Behavior of adult Chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia coastal waters determined from ultrasonic telemetry. Canadian Journal of Zoology 77(7):1161–1169.

Carmichael, G. J. 1991. Recovery of channel catfish from abdominal surgery. Progressive Fish-Culturist 53:193–195.

CCAC (Canadian Council on Animal Care). 1993. Guide to the care and use of experimental animals, volume 1, 2nd edition. Bradda Printing Services, Ottawa, Ontario.

Chervova, L. S. 1997. Pain sensitivity and behaviour of fish. Vaprosy ikhtiologii 37:106–111.

Chisolm, I. M., and W. A. Hubert. 1985. Expulsion of dummy transmitters by rainbow trout. Transactions of the American Fisheries Society 114:766–767.

Cho, G. K., and D. D. Heath. 2000. Comparison of tricaine methanesulphonate (MS-222) and clove oil anaesthesia effects on the physiology of juvenile Chinook salmon *Oncorhynchus tshawytscha* (Walbaum). Aquaculture Research 31:537–546.

Cooke, S. J., and G. N. Wagner. 2004. Training, experience, and opinions of researchers who use surgical techniques to implant telemetry transmitters into fish. Fisheries 29(12):10–17.

Cooke, S. J., B. D. S. Graeb, C. D. Suski, and K. G. Ostrand. 2003. Effects of suture material on incision healing, growth, and survival of juvenile largemouth bass implanted with miniature radio transmitters: case study of a novice and experienced fish surgeon. Journal of Fish Biology 62:1360–1388.

Cooke, S. J., C. M. Bunt, K. G. Ostrand, D. P. Philipp, and D. H. Wahl. 2004. Angling-induced cardiac disturbance of free-swimming largemouth bass (*Micropterus salmoides*) monitored with heart rate telemetry. Journal of Applied Ichthyology 20:28–36.

Culik, B., D. Adelung, and A. J. Woakes. 1990. The effect of disturbance on the heart rate and behaviour of Adélie penguins (*Pygoscelis adeliae*). Journal of Experimental Biology 158:355–368.

Datta, V., M. Mandalia, S. Mackay, A. Chang, N. Cheshire, and A. Darzi. 2002. Relationship between skill and outcome in the laboratory-based model. Surgery 131:318–323.

Engelhorn, R. 1997. Speed and accuracy in the learning of a complex motor skill. Perception and Motor Skills 85:1011–1017.

FDA (U.S. Food and Drug Administration) 2002. Guidance for industry: status of clove oil and eugenol for anesthesia of fish. FDA, Guide 150, Rockville, Maryland.

Filipek, S. 1989. A rapid field technique for transmitter implantation in paddlefish. Pages 388–391 *in* C. R. Amlaner, Jr., editor. Biotelemetry X. University of Arkansas Press, Fayetteville.

GOASPA [Guidance on the Operation of the Animals (Scientific Procedures) Act, 1986]. 1986. Her Majesty's Stationary Office, London.

Groot, C., K. Simpson, I. Todd, P. D. Murray, and G. A. Buxton. 1975. Movements of sockeye salmon (*Oncorhynchus nerka*) in the Skeena River estuary as revealed by ultrasonic tracking. Journal of the Fisheries Research Board of Canada 32:233–243.

Haeseker, S. L., J. T. Carmichael, and J. E. Hightower. 1996. Summer distribution and condition of striped bass within Albemarle Sound, North Carolina. Transactions of the American Fisheries Society 125: 690–704.

Hart, L. G., and R. C. Summerfelt. 1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish (*Pylodictis olivaris*). Transactions of the American Fisheries Society 104:56–59.

Healey, M. C., R. Lake, and S. G. Hinch. 2003. Energy expenditure during reproduction by sockeye salmon of the early Stuart sockeye stock complex, British Columbia. Behaviour 140:161–182.

Hinch, S. G., E. M. Standen, M. C. Healey, and A. P. Farrell. 2002. Swimming patterns and behaviour of upriver-migrating adult pink (*Oncorhynchus gorbuscha*) and sockeye (*O. nerka*) salmon as assessed by EMG telemetry in the Fraser River, British Columbia, Canada. Hydrobiologia 483:147–160.

Holland, K. N., B. M. Wetherbee, C. G. Lowe, and C. G. Meyer. 1999. Movements of tiger sharks (*Galeocerdo cuvier*) in coastal Hawaiian waters. Marine Biology 134:665–673.

Iwama, G. K., J. C. McGeer, and M. P. Pawluk. 1989. The effects of five fish anaesthetics on acid−base balance, hematocrit, blood gases, cortisol, and adrenaline in rainbow trout. Canadian Journal of Zoology 67:2065–2073.

Iwama, G. K., and P. A. Ackerman. 1994. Anaesthetics. Pages 1–15 *in* P. W. Hochachka and T. P. Mommsen, editors. Biochemistry and molecular biology of fishes, volume 3. Elsevier, New York.

Jepsen, N., A. Koed, E. B. Thorstad, and E. Baras. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483:239–248.

Kaseloo, P. A., A. H. Weatherley, J. Lotimer, and M. D. Farina. 1992. A biotelemetry system recording fish activity. Journal of Fish Biology 40:165–179.

Keene, J. L., D. L. G. Noakes, R. D. Moccia, and C. G. Soto. 1998. The efficacy of clove oil as an anaesthetic for rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquaculture Research 29:89–101.

Knights, B. C., and B. E. Lasee. 1996. Effects of implanted transmitters on adult bluegills at two temperatures. Transactions of the American Fisheries Society 125:440–449.

Lonsdale, E. M., and G. T. Baxter. 1968. Design and field tests of a radio-wave transmitter for fish tagging. Progressive Fish-Culturist 30:47–52.

Lowartz, S. E., D. L. Holmberg, H. W. Ferguson, and F. W. H. Beamish. 1999. Healing of abdominal incisions in sea lamprey larvae: a comparison of three wound closure techniques. Journal of Fish Biology 54:616–626.

Lucas, M. C. 1989. Effects of implanted dummy transmitters on mortality, growth, and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson. Journal of Fish Biology 35:577–587.

Lucas, M. C., and E. Baras. 2000. Methods for studying the spatial behaviour of freshwater fishes in their natural environment. Fish and Fisheries 1:283–316.

Magee, J. A., T. A. Haines, J. F. Kocik, K. F. Beland, and S. D. McCormick. 2001. Effects of acidity and aluminum on the physiology and migratory behavior of Atlantic salmon smolts in Maine, USA. Water, Air, and Soil Pollution 130:881–886.

Marty, G. D., and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society 115: 577–589.

Maule, A. G., R. A. Tripp, S. L. Kaattari, and C. B. Shreck. 1989. Stress alters immune function and disease resistance in Chinook salmon (*Oncorhynchus tshawytscha*). Journal of Endocrinology 120: 135–142.

McCleave, J. D., and K. A. Stred. 1975. Effect of dummy telemetry transmitters on stamina of Atlantic salmon (*Salmo salar*) smolts. Journal of the Fisheries Research Board of Canada 32:559–563.

Meka, J. M., E. E. Knudsen, D. C. Douglas, and R. B. Benter. 2003. Variable migratory patterns of different adult rainbow trout life history types in a southwest Alaska watershed. Transactions of the American Fisheries Society 132:717–732.

Moccia, R. D., E. J. Wilkie, K. R. Munkittrick, and W. D. Thompson. 1984. The use of fine needle fibre endoscopy in fish for in vivo examination of visceral organs, with special reference to ovarian evaluation. Aquaculture 40:255–259.

Mock, A., and G. Peters. 1990. Lysozyme activity in rainbow trout, *Oncorhynchus mykiss*, stressed by handling, transport, and water pollution. Journal of Fish Biology 37:873–885.

Morris, W. A., E. H. Follman, J. C. George, and T. O'Hara. 2000. Surgical implantation of radio transmitters in Arctic broad whitefish in Alaska. Pages 193–201 *in* J. H. Eiler, D. J Alcorn, and M. R. Neuman, editors. Biotelemetry 15: proceedings of the 15th International Symposium on Biotelemetry. International Society on Biotelemetry, Wageningen, The Netherlands.

Mortensen, D. G. 1990. Use of staple sutures to close surgical incisions for transmitter implants. Pages

380–383 *in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editor. Fish-marking techniques. American Fisheries Society, Bethesda, Maryland.

Mulcahy, D. M. 2003a. Surgical implantation of transmitters into fish. ILAR Journal 44:295–306.

Mulcahy, D. M. 2003b. Does the Animal Welfare Act apply to free-ranging animals? ILAR Journal 44: 252–258.

Mulford, C. J. 1984. Use of surgical skin stapler to quickly close incisions in striped bass. North American Journal of Fisheries Management 4:571–573.

NRC (National Research Council). 1996. Guide for the care and use of laboratory animals. National Academy Press, Washington, D.C.

Nemetz, T. G., and J. R. MacMillan. 1988. Wound healing of incisions closed with a cyanoacrylate adhesive. Transactions of the American Fisheries Society 117:190–195.

Pickering, A. D., and T. G. Pottinger. 1987. Crowding causes prolonged leucopenia in salmonid fish despite interrenal acclimation. Journal of Fish Biology 32:701–712.

Petering, R. W., and D. L. Johnson. 1991. Suitability of a cyanoacrylate adhesive to close incisions in black crappies used in telemetry studies. Transactions of the American Fisheries Society 120:535–537.

Rose, J. D. 2002. Neurobehavioral nature of fishes and the question of awareness and pain. Reviews in Fisheries Science 10(1):1–38.

Ross, L. G., and B. Ross. 1999. Anaesthetic and sedative techniques for aquatic animals. Blackwell Scientific Publications, Oxford, UK.

Roubal, F. R., and A. M. Bullock. 1988. The mechanism of wound repair in the skin of juvenile Atlantic salmon, *Salmo salar* L., following hydrocortisone implantation. Journal of Fish Biology 32:545–555.

Scruton, D., R. McKinley, N. Kouwen, W. Eddy, and R. Booth. 2002. Use of telemetry and hydraulic modeling to evaluate and improve fish guidance efficiency at a louver and bypass system for downstream-migrating Atlantic salmon (*Salmo salar*) smolts and kelts. Hydrobiologia 483:83–94.

Seki, S. 1987. Accuracy of suture techniques of surgeons with different surgical experience. Japanese Journal of Surgery 17:465–469.

Smeak, D. D. 1999. Accent on an alternative: skin and suture pattern simulator. Alternatives in Veterinary Medical Education Newsletter 10:2–3.

Sneddon, L. 2003. The evidence for pain in fish: the use of morphine as an analgesic. Applied Animal Behavior Science 83:153–162.

Sneddon, L. U., V. A. Braithwaite, and M. J. Gentile. 2003. Do fish have nociceptors?: evidence for the evolution of a vertebrate sensory system. Proceedings of the Royal Society of London B 270:1115–1121.

Standen, E. M., S. G. Hinch, M. C. Healey, and A. P. Farrell. 2002. Energetic costs of migration through the Fraser River Canyon, British Columbia, in adult pink (*Oncorhynchus gorbuscha*) and sockeye (*Oncorhynchus nerka*) salmon as assessed by EMG telemetry. Canadian Journal of Fisheries and Aquatic Sciences 59(11):1809–1818.

Stanley, C. A. 1983. Some effects of handling techniques on returns of tagged Australian salmon, *Arripis trutta* (Bloch and Schneider). Australian Journal of Marine and Freshwater Research 34(6):845–855.

Starr, R. M., J. N. Heine, and K. A. Johnson. 2000. Techniques for tagging and tracking deepwater rockfishes. North American Journal of Fisheries Management 20:597–609.

Stoskopf, M. K. 1993. Surgery. Pages 91–97 *in* M. K. Stoskopf, editor. Fish medicine. Saunders, New York.

Summerfelt, R. C., and D. Mosier. 1984. Transintestinal expulsion of surgically implanted dummy transmitters by channel catfish. Transactions of the American Fisheries Society 113:760–766.

Summerfelt, R. C., and L. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213–272 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Swanberg, T. R., D. A. Schmetterling, and D. H. McEvoy. 1999. Comparison of surgical staples and silk sutures for closing incisions in rainbow trout. North American Journal of Fisheries Management 19:215–218.

Szalay, D., H. MacRae, G. Regehr, and R. Reznik. 2000. Using operative outcome to assess technical skill. American Journal of Surgery 180:234–237.

Thoreau, X., and E. Baras. 1997. Evaluation of surgical procedures for implanting telemetry transmitters into the body cavity of tilapia *Oreochromis aureus*. Aquatic Living Resources 10:207–211.

Thorstad, E. B., T. G. Heggberget, and F. Økland. 1998. Migratory behaviour of adult wild and escaped farmed Atlantic salmon, *Salmo salar* L., before, during, and after spawning in a Norwegian river. Aquaculture Research 29:419–428.

Trefethen, P. S. 1956. Sonic equipment for tracking individual fish. U.S. Fish and Wildlife Service Special Scientific Report Fisheries 179.

Wagner, G. N., and E. D. Stevens. 2000. Effects of different surgical techniques: suture material and location of incision site on the behaviour of rainbow trout (*Oncorhynchus mykiss*). Marine and Freshwater Behaviour and Physiology 33:103–114.

Wagner, G. N., E. D. Stevens, and P. Harvey-Clark. 1999. Wound healing in rainbow trout following surgical site preparation with a povidone−iodine antiseptic. Journal of Aquatic Animal Health 11:373–382.

Wagner, G. N., E. D. Stevens, and P. Byrne. 2000. Effects of suture material and patterns on surgical wound healing in rainbow trout. Transactions of the American Fisheries Society 129:1196–1205.

Wagner, G. N., T. D. Singer, and R. S. McKinley. 2003. The ability of clove oil and MS-222 to minimize handling stress in rainbow trout (*Oncorhynchus mykiss* Walbaum). Aquaculture Research 34:1139–1146.

Wendelaar Bonga, S. E. 1997. The stress response of fish. Physiological Reviews 77:591–625.