Facts and Issues Associated with Restricting Terminal Gear Types in the Management of Sustainable Steelhead Sport Fisheries in British Columbia

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Introduction

Regulations governing when and where bait may be used to angle for steelhead in British Columbia have been applied at various times and places with no apparent pattern or consistent rationale. Different rivers with widely divergent run timings, stock sizes, stock status, accessibility, angling pressure and real or perceived harvest rates have been regulated on a “no organic bait” or “no salmon roe” basis for more than 60 years. Restrictions sometimes came and went for reasons that went unrecorded and remain unknown to any present day fishery managers. For example, regulations banning the use of salmon roe or roe products on the north shore rivers of the Lower Mainland and the Squamish system have been in effect from before 1935, while proximal and similar streams have not been subject to that restriction. On Vancouver Island, a region-wide ban on the use of salmon roe existed from at least the early 1940s through to 1955 but was rescinded without explanation in 1956.

In the latter half of the 1970s, when staffing levels and operational budgets were finally sufficient to commence monitoring steelhead abundance and evaluating stock status, it rapidly became evident that angling harvest was more of a threat to the health of populations than previously believed. The years that followed saw progressive reduction of harvest quotas and an increasing trend toward management of steelhead stocks on a catch and release basis, often in concert with mandatory single hooks and prohibition of organic baits. Today, with the exception of winter steelhead streams on the northern coastal mainland and the Queen Charlotte Islands and both summer and winter steelhead tributaries of the northernmost major Pacific drainages (Stikine and Taku rivers), all streams in the province are managed on a wild steelhead release basis. A much smaller fraction of them incorporate bait restrictions. Recent measures to expand the application of bait restrictions on some Vancouver Island streams have re-kindled debate that has existed within the angling community from the earliest records of sportfishing in British Columbia.

The objective of this exercise is to acknowledge and summarize relevant information on the influence of different terminal gear types on salmonids and, where appropriate, discuss that information relative to steelhead sport fisheries in the province. It is understood there is a range in the quality and quantity of data that may be applied to a specific river. That uncertainty will always fuel impassioned debate within the sportfishing sector. However, it is equally understood there have been a large number of very credible studies that reveal significant patterns that provide instruction to those whose mandate is to sustain both fish populations and fishing opportunity. It is hoped that this review will illustrate the consistently documented results of terminal gear studies and serve as a basis for informed decision making among all elements of the sportfishing community.

Central Issues

Most of the discussion on the efficacy of bait restrictions is focused on the associated mortality rate relative to rates attributed to other gear types. Mortality rate is commonly a significant factor but it must not be viewed to the exclusion of other factors such as the angling effort that is applied in a given situation, the proportion of anglers using different gear types, the catch per unit effort (CPUE) of those different gear types and the status of the stock (i.e., actual relative to target abundance). Additional factors such as sub-lethal effects associated with single and multiple recapture frequencies, the incidental catch of sympatric threatened or endangered species (e.g., cutthroat, Dolly Varden, bull trout) or juvenile fish, water temperature and the potential for disease transfer are oftentimes secondary but not unimportant. Of equal or perhaps greater significance to the health and survival of caught and released fish are the fish handling practices of anglers themselves.

1. Mortality and Severe Hooking Injury Rates

Despite the long history and broad geographic distribution of regulatory measures associated with different terminal gear employed in steelhead fisheries there is a paucity of data specific to steelhead to guide decisions (Mongillo, 1984; Pauley and Thomas, 1993). The only published report dealing with mortality rates among steelhead caught on bait and artificial lures was from British Columbia (Hooton, 1987). That report referred to two sets of data that have been quoted extensively in the fisheries management arena ever since. One set related to steelhead broodstock collection on Vancouver Island during the decade of the 1980s. The second resulted from investigations undertaken at Keogh River on northern Vancouver Island in 1984 and 1985. It would appear from repeated citations of the broodstock collection data that the fisheries management community has accepted those as definitive evidence the mortality associated with bait fishing for steelhead is negligible (e.g., Mongillo, 1984; Pauley and Thomas, 1993; Trotter, 1995; Anon, 1999). A summary of all applicable data sets discussed in the sections that follow is included in Appendix A.

1.1 Vancouver Island Steelhead Brood Stock Collection Data in Context

The steelhead brood stock collection data related to endemic wild fish captured mostly, but not exclusively, by angling. Angling was generally prosecuted by highly trained, skilled and optimally equipped agency staff. The large majority of all fish they captured were taken using clusters of steelhead or salmon eggs on single hooks (often barbed) in the size range used by most other steelhead anglers of the day (size 1/0 through 3/0). The collection records, together with similar records compiled from limited fish tagging experiments, revealed a mortality rate of 3.4% among 3,715 adult steelhead held for brood stock purposes (Hooton, 1987). Those data were gathered from eight winter steelhead stocks and two summer steelhead stocks over a period of up to seven years. It is important to understand that these mortality rates were essentially instantaneous rates for reasons outlined below.

In numerous published references to the Vancouver Island steelhead brood stock collection data only one acknowledged that the observed hooking mortality figure was minimal and that caution needed to be applied in its interpretation (Horton and Wilson-Jacobs, 1985). Inherent factors included: 1) the occasional release of injured and/or bleeding fish that were assumed to have had a higher chance of survival in the river than if handled, confined and transported to a holding facility; 2) counting any fish that died more than 24 hours after capture as a holding mortality rather than a hooking mortality; 3) occasional (legal) harvest of a mortally injured hatchery fish rather than inclusion of it in the data base; and 4) higher standard of fish handling than would be expected from “average” anglers.

Records on factors one and two are incomplete and/or no longer available. With respect to the second factor, it is instructive that over the same years angled brood stock contributed to the 1987 data set there were also several occasions where brood fish were beach seined. Seine caught fish numbering at least into the low hundreds, handled by the same trained professionals involved in brood stock angling displayed zero mortality as a result of capture and, according to the best recollections of staff, rarely died during confinement in the same pre-spawning holding facilities as angled brood stock. Negligible mortality among net caught control group fish has been observed in hooking mortality investigations in Alaska (Vincent-Lang et al. 1993; DeCicco, 1994) and California (Parmenter, 2000; Jenkins, 2001). Also, there are numerous references in the published literature on hooking mortality to support that delayed mortality among sport caught salmonids can be a significant issue (see, for example, Warner, 1979; Hulbert and Engstrom-Heg, 1980; Nuhfer and Alexander, 1992; Wilkie et al., 1996). The fourth factor is entirely subjective and unquantifiable although two of the studies reviewed acknowledged that fish capture and handling overseen by trained professional staff likely minimized the mortality rates observed (McKinley, 1993; Palermo et al., 2000). Thomas (1995) also presented results supporting “fish friendlier” behavior of anglers in the presence of professional staff conducting a hooking mortality study.

1.2 The Keogh River Hooking Mortality Study in Context

The Keogh hooking mortality investigations were undertaken specifically to address differences between barbed versus barbless hooks and bait versus artificial lures. Once again the immediate mortality rates (i.e., within 24 hours) were relatively low (5.6% for baited hooks and 3.8% for artificial lures, although barbed baited hooks resulted in a 9.1% mortality rate) (Hooton, 1987). Additional observations from the original Keogh investigations have gone unnoticed or been ignored. Those relate to the efficiency or CPUE of the two gear types and the incidence of hooking in critical anatomical locations with each gear type.

During the Keogh experiment, it quickly became evident that, in order to obtain the requisite sample size of steelhead hooked on artificial lures, it was necessary to commence angling sessions with that gear type. Despite a strong bias towards artificial lure fishing prior to using bait, lures caught 99 fish while bait produced 236 or 2.38 times as many for similar hours fished (data on file, Ministry of Environment, Lands and Parks (MELP), Nanaimo). Additionally, artificial lure caught fish were hooked deep inside the mouth or gill arches and bleeding heavily in 4 of 99 cases (4.04%) where those data were recorded. Bait caught fish were similarly hooked in 26 of 236 records (11.02%) or 2.72 times as often (data on file, MELP, Nanaimo). Thirteen of the 26 heavily bleeding fish caught on bait (50%) died within 24 hours, while all four caught on artificial lures (100%) expired in that same period (Hooton, 1987). The combination of higher CPUE and higher injury rate for bait fishing compounded the differences between the two gear types but that feature of the Keogh results has never been considered in addressing mortality rates associated with sport fisheries elsewhere.

Anecdotal and not unrelated observations on the efficiency of bait versus artificial lures appeared in Roderick Haig-Brown's *Western Angler* more than 60 years ago. Haig-Brown (1939) conducted his own experiment to satisfy himself that his personal opposition to fishing with roe was, in fact, justifiable. In an afternoon of fishing on the Campbell River, Haig-Brown produced a CPUE of one steelhead per hour and caught no other fish on his preferred and proven artificial lure. Following that, he angled with fresh steelhead eggs and produced a CPUE of 2.67 steelhead per hour and 8.33 “trout” per hour. The approach of starting with artificial lure and following with bait mirrored (not by design) the Keogh experiment. The CPUE for steelhead from Haig Brown's limited experiment and the Keogh data were remarkably similar.

1.3 Other British Columbia Data

A search of regional offices of MELP uncovered additional hooking mortality data sets that warrant mention here. Among 436 steelhead brood stock reportedly captured by angling with bait in Thompson River tributaries between 1982 and 1995, seven (1.61%) were recorded as “direct mortalities”. On the Coquihalla River, another 306 steelhead brood stock were bait caught between 1985 and 1995. Only one (0.31%) direct mortality was reported. On the Squamish River, between 1985 and 1991, 209 steelhead were angled on artificial lures and 9 (4.31%) direct mortalities were recorded. On the Somass River system, Lirette (1988) reported 6 (7.9%) immediate hooking mortalities among 76 bait caught summer steelhead and 8 (4.1%) immediate hooking mortalities among 195 winter steelhead. Lirette (1989) also reported 6 (8.7%) immediate hooking mortalities for 69 bait angled summer steelhead in the Campbell River. Lastly, during a radio telemetry program on the Chilliwack River in 1999 and 2000, a total of 226 steelhead were angled, radio tagged and tracked for variable periods of time thereafter. Virtually all the steelhead tagged by project technicians were angled on baited hooks (personal communication, Troy Nelson, Resource Management Biologist, LGL Environmental Research Associates, Sidney, BC). Post-release tracking data suggested not more than two fish (0.9%) died for reasons that could be attributed conclusively to the initial angling event (Nelson et al., 2001).

Qualifications that should be applied to the data retrieved from regional MELP offices include: 1) none of the projects was intended to be a hooking mortality study; 2) the terms “immediate” and “direct” mortality were not defined; 3) the Thompson and Coquihalla samples were summer steelhead angled, in closed times/places, by agency staff, under cold water temperatures, many months after freshwater entry (circumstances that are frequently assumed to reduce mortality); 4) the Squamish sample was comprised of winter steelhead recently arrived from salt water and caught mostly by volunteer anglers; and 5) the Chilliwack River data applied to newly arrived winter steelhead angled by trained specialists but related only to fish that were selected as specimens for radio tag application. An additional consideration with respect to the Chilliwack study is that elsewhere in the province there have been several studies involving angler caught and radio tagged steelhead. Frequently the survival and reproductive performance of tagged fish has not reflected the results that are interpreted from the Chilliwack River data. (MELP, data on file).

Perhaps the most instructive feature of all of the above is that, regardless of the time, place or objectives involved in ministry steelhead capture programs, agency staff has predominantly used bait to capture fish by angling because it is clearly understood that CPUE is maximized with this gear type. Steelhead assessment and brood capture programs are costly undertakings. Maximizing the CPUE is a logical way to manage staff time commitment and keep program costs affordable.

Thomas (1995) investigated hooking mortality among steelhead (and coho) angled with passively fished gear on the lower Skeena River near the upstream limit of tidal influence. His results gave short-term mortality rates of 4.55% among 21 steelhead captured and 2.27% among 44 coho. There was no indication of mortality related to physiological stress associated with transition from marine to freshwater environment. Remarkably, even though fish specific records on hook size, hook type, hook location, degree of blood loss, handling time, handling procedures, etc., were presented, the report’s authors made no mention of bait versus artificial lure and whether or not that had any bearing on their results.

Palermo et al. (2000) examined coho caught on passively fished baited hooks and reported mortality rates of between 14% for fish hooked on the periphery of the mouth but 46% for those that “swallowed” the hook. These fishing methods may not be directly applicable to most steelhead fisheries in the province but the study results illustrated clearly the significance of the hook penetration site.

1.4 Relevant Non-British Columbia Steelhead and Salmon Data

Published or readily available hooking mortality data sets that relate specifically to steelhead or salmon in freshwater are also scarce outside British Columbia. Mongillo (1984) conducted an exhaustive literature search on salmonid hooking mortality and reported finding no studies that directly assessed the mortality of different angling practices on steelhead. More recently, another thorough review of the subject by Muoneke and Childress (1994) reached a similar conclusion. Mongillo cited limited brood stock collection data from Washington State that revealed higher direct mortality from hooking (11% mortality among 390 angled steelhead brood stock) but the capture and handling methodology were not necessarily directly applicable to conventional angling.

Whereas he concluded that baited hooks penetrated critical areas roughly five times as often as artificial lures (i.e., 50% with bait versus 10% with artificials) and that bait related mortality was a significant issue among resident stream dwelling salmonids (especially rainbow trout). He also concluded that these findings were not applicable to adult winter steelhead because data from the Vancouver Island brood stock collection program up to 1983 showed otherwise. Mongillo's ultimate conclusion was that the use of eggs for winter run steelhead fishing produced less than 10% hooking mortality. Based largely on Mongillo (1984) and personal communication of the raw data eventually published in Hooton (1987) Horton and Wilson-Jacobs (1985) recommended that Oregon use a figure of 10% hooking mortality for management considerations until or unless more conclusive data became available.

Bendock and Alexandersdottir (1993) employed radio telemetry to assess hooking mortality of adult chinook salmon released in the Kenai River. They documented rates ranging from 4.1% to 10.6% with no significant difference between bait and artificial lure. The authors noted the strong relationship between mortality and the anatomical site of hooking. The angling methods involved were probably not a good proxy for those employed on most British Columbia steelhead streams.

Vincent-Lang et al. (1993) reported 69.3% mortality for coho caught in the estuary of an Alaskan River and 11.7% for similarly caught fish further upstream in the same river. Their work involved the use of size 2/0 single hooks and clusters of salmon eggs drifted along the river bottom, methods that are common to many steelhead fisheries in British Columbia. They observed that 48% of the fish captured in the tidal reaches of the river were hooked in the gills or gullet and, of these, most were bleeding. In contrast 20% of the fish caught in non-tidal waters upstream were similarly hooked and bleeding. The probability of dying was significantly related to the anatomical location of hooking. The authors speculated that the physiological transformation anadromous fish experience during transition from marine to freshwater environments was likely a significant factor in the high mortality among estuarine caught fish. They also suggested that fish closest in time and space to their normal feeding environment may be more susceptible to fatal injury associated with baited hooks. MELP staff involved with steelhead radio telemetry studies also recorded high mortalities among treatment fish captured in estuarine or tidal freshwater environments (see, for example, Beere, 1991; Alexander and Koski, 1995) thus suggesting the results of Vincent-Lang et al may be applicable to more than just coho.

A potential issue raised by recent observations in Washington State related to the frequency of critical hook injury (i.e., hook penetrating eye, tongue, gill or esophagus) among kelt steelhead and how that might influence the contribution of repeat spawners to a population. Among 48 steelhead angled for scale collection purposes, there were 27 bait caught pre-spawners of which 1 (3.7%) was critically injured. Twenty-one bait caught kelts produced seven (33.0%) critically injured fish. Among 32 artificial lure caught fish, there were 29 pre-spawners and 3 kelts but no critical injuries among either group (personal communication, Curtis Kraemer, fisheries management biologist, Washington Department of Fish and Wildlife, Mill Creek, Washington). Given that repeat spawners are generally larger, more fecund fish with larger individual egg size their contribution to population egg deposition is greater than their numerical representation among spawners. Kraemer expressed the concern that angling related mortality could be of disproportionately greater significance from a population perspective in the later stages of the angling season when kelts began to appear.

1.5 Experiences with Non-Anadromous Salmonids

In contrast to the relative scarcity of data directly applicable to mortality by gear type in freshwater anadromous fisheries there is an abundance of data on resident salmonids. A consistent pattern is readily apparent. Specifically, resident fish caught on bait experience significantly higher mortality than those caught on artificial lures or flies. This result is confirmed repeatedly in numerous review papers (Wright, 1970; Wydoski, 1977; Mongillo, 1984; Horton and Wilson-Jacobs, 1985; Taylor and White, 1992; Muoneke and Childress, 1994; Trotter, 1995). The reviews are not completely independent because several have used some of the same data to make their point. Nonetheless, the data confirm overwhelmingly that hooking mortality applicable to the use of bait was consistently at least three to nine times higher than that associated with the use of artificial lures. Mortality associated with the use of flies was consistently the lowest for all three gear types. The typical observation was that baited hooks were taken more deeply than artificial lures or flies and that rupture of blood vessels was the primary cause of mortality.

Specific examples emphasize the point. Wydoski (1977), in a multi species investigation, settled on a figure of 25% mortality for bait fishing and 5% for artificial lures or flies. Warner and Johnson (1978) found 35% mortality among bait caught landlocked Atlantic salmon but only 4% for those caught on flies. Mongillo (1984) reported bait angling for rainbow trout produced mortalities of roughly 30% but only 5-10% for artificial lure or fly. For cutthroat trout the difference was even greater (50% for bait but still 5-10% for other gear). Taylor and White (1992) looked at studies on a variety of non-anadromous trout and found an average mortality of 43.6% when bait was used but only 5.1% for artificial lures. Pauley and Thomas (1993) worked with anadromous coastal cutthroat trout and found 39.5 – 58.1% mortality among bait caught fish and 10.5 – 23.8% for those caught on lures. Schisler (1995) investigated the mortality associated with scented artificial baits versus flies and lures on rainbow trout and reported mortalities were 5.8 to 12.9 times higher per unit time fished with the scented product. Trotter (1995) cited some of the above studies plus others on non-anadromous trout and concluded that the overall mean mortality for baited hooks was 31.4% but only 4.9% for lures and 3.8% on flies.

It is important to acknowledge there have been some hooking mortality studies that did not necessarily demonstrate the pattern evident in the large majority of the information reviewed. DeCicco (1994) reported that there was no statistically significant difference in mortality between baited hooks and artificial lures in his experiments with anadromous Dolly Varden in streams in northern Alaska. He observed only 2.5% mortality for baited hooks and 1.1% mortality for artificial lures but methods employed (e.g. very small hooks) may have been a factor. Another Alaskan study on Arctic char in a hatchery environment revealed mortality rates of 5.5% and 10.0% for baited single and treble hooks respectively but 0% mortality for artificial lures (McKinley, 1993). Again, very small hooks may have influenced these results. The author noted a strong relationship between gill hooked fish and mortality. Most recently, a Californian study designed to address the efficacy of innovative hook types (circle hooks and "Shelton" hooks) in reducing mortality among bait caught fish revealed 0% mortality for control and fly caught fish and 0% to 8.7% mortality for various combinations of bait and barbless hook type (Jenkins, 2001). The author also reported that 100% of fly caught fish were hooked in the "mouth area" whereas between 23% and 78% of the bait caught fish were hooked in the esophagus.

In a companion experiment Jenkins (2001) attempted to address other factors in hooking mortality but abandoned the effort when only 5 fish could be caught on artificial flies compared to 129 fish taken on baited hooks with similar angling effort.

1.6 Other Considerations

Anadromous fish are, on average, larger than the resident species studied in the vast majority of the research on salmonid hooking mortality. Some researchers suggest anadromous fish are therefore not subject to the same mortality rates as resident fish (e.g., Bendock and Akexandersdottir, 1993). Others have observed no size related difference in mortality (Schill, 1996; Pauley and Thomas, 1993) as well as an inverse relationship between size and mortality (Palermo et al., 2000). Pauley and Thomas (1993) stated that the only studies available where anadromous trout had been observed following hooking were Reingold (1975), Pettit (1977) and Hooton (1987). Interestingly, the first two of these studies did not look at differences in mortality for different gear types. The latter did but, as noted above, the results have generally been taken out of context.

The evidence from the comprehensive literature on gear related hooking mortality among resident fish and the results of the Keogh River investigations suggests strongly that the ratio of serious hooking injury among bait caught versus artificial lure caught salmonids is similar, independent of fish size.

Bruesewitz (1995) examined the location of hooking among creeled summer and winter steelhead in different Washington State streams in the 1992, 1993 and 1994 sport fisheries. She found that the single hook and bait combination resulted in a 2.33 times higher incidence of hooking in critical locations (14.9% versus 6.4%) than did single hooks and artificial lures. It was not possible to determine what proportion of total catch released fish represented or if released fish would have displayed any different hooking pattern.

The relationship between hooking injury rate and mortality rate is not understood perfectly. The Keogh River study indicated that seriously bleeding fish did not always die although their reproductive success was unknown (Hooton, 1987). Other investigators have noted the strong relationship between bait use and deep hooking, (not necessarily bleeding) and also found that such badly hooked fish do not always die within a time frame that would confirm death resulted from the hooking injury (Nuhfer and Alexander, 1989; Schisler, 1995; Schill, 1996; Parmenter, 2000; Jenkins, 2001).

2. Sub-lethal Impacts and Other Potential Influences

The published information that relates to potential influence of catch and release angling on subsequent health, behavior and spawning success of steelhead is limited and none of it necessarily relates specifically to the terminal gear employed. Reingold (1975) investigated the ability of hooked and released hatchery steelhead to return to their spawning stream following displacement and found that experimental and treatment fish returned about equally well. Pettit (1977) examined the eyed egg survival for spawned hatchery steelhead that had been subjected to a single hooking incident versus a control group that had not been angled. He concluded that angling did not influence the animal's ability to return to their target spawning stream and reproduce successfully. Noteworthy in Pettit's work was the fact that 60% of the experimental steelhead did not return to the hatchery of origin. He speculated this was attributable to straying more than to a high degree of angler-caused mortality. Similar research for Atlantic salmon has demonstrated equally high survival of gametes following a single catch and release incident (Booth et al., 1995) although, again, the study referenced did not examine gear types or the influence of severe hooking injuries.

The hatchery steelhead programs in southwestern British Columbia afford ample evidence that angled steelhead, when delivered in healthy condition to a holding facility and confined for periods of several days to many weeks until ripe, will produce a high average egg survival. Fish that do not survive, do not mature or that produce few or no viable eggs or sperm may be exhibiting post angling effects. However, the influence of angling relative to handling and confinement cannot be partitioned and therefore no clear associations can be drawn. The relationship between egg production and survival in an artificial environment relative to those same parameters in nature is unknown. Also, there is no evidence to suggest that any problems that may be evident are necessarily associated with the terminal gear employed in angling.

In the interpretation of results of steelhead culture programs founded on angled brood stock it should be recognized that brood fish are routinely treated to prevent infection and thereby maximize survival to spawning and egg viability. This could serve to mask mortality or sub-lethal effects associated with angling that might otherwise have surfaced.

Researchers working with Atlantic salmon have conducted a number of studies whose results may also be applicable to steelhead fisheries. Booth (1994) noted three principle factors that operate singly or in combination to influence mortality – exhaustive exercise, water temperature and exposure to air. Whereas he found no significant effect of a single angling event on egg survival he noted that the ability of fish to ascend streams to preferred areas, select mates and spawn successfully could be impeded by exhaustive exercise and that this would not show up in his experiments because he sampled fish immediately prior to spawning, in relatively cold water and under artificial spawning circumstances. Booth (1994) also noted other researchers have shown that acute stress during the reproductive cycle may adversely affect gamete viability.

Ferguson and Tufts (1993) reported disturbingly higher mortality among domestic rainbow trout subjected to air exposure after mimicked angling events than for control fish or experimental fish not exposed to air. Their data revealed 100% survival among control fish and 88% survival among exercised (i.e., “angled”) fish. Among fish that were exercised and then exposed to air for 30 and 60 seconds immediately thereafter, survival dropped to 62% and 28% respectively. The authors stressed their results had important implications for Atlantic salmon sport fisheries where the marked trend was toward catch and release but where anglers habitually hold fish out of water for significant periods of time prior to release.

Brobbel et al. (1996) looked at physiological effects of catch and release on Atlantic salmon at different stages of freshwater migration. Their experiments revealed 12% mortality (3 of 25 fish) among fish newly arrived from marine environments but no mortality (0 of 24) among angled kelts. Wilkie et al. (1996) also looked at physiology and survival among angled wild Atlantic salmon and reported significant temperature related effects. They concluded that salmon angled in warm summer waters experienced impaired restorative processes and increased susceptibility to delayed post angling mortality. They also speculated that salmon angled in warmer summer water could be more susceptible to diseases known to influence survival and reproductive performance. Winter steelhead would not likely be as significantly influenced by water temperatures but summer steelhead may not be dissimilar to Atlantic salmon in that respect.

The major difference between the scientific literature on angling related impacts on Atlantic salmon and that related to steelhead is angling methods. For anadromous Atlantic salmon, all of the literature relates to situations where flies were the angling method used or mimicked. None of the studies reviewed indicated anything other than hooking on the periphery of the mouth or jaws. Hooking in critical anatomical locations, commonly associated with baited hooks in steelhead and other salmonid fisheries, was not an issue among Atlantic salmon, presumably because the North American fisheries are generally regulated on a fly fishing only basis.

The influence of multiple captures of individual steelhead is another element of many British Columbia steelhead fisheries that remains to be evaluated. Catch and tag recovery data from a large number and range of Ministry programs indicate that in many heavily fished streams steelhead are commonly caught two or more times. It is reasonable to conclude the frequency of these occurrences has increased steadily over the past two decades. The emerging and unanswered questions are whether or not there are cumulative effects associated with multiple captures and how significant these are from a population perspective? It is clear from the available CPUE (and mortality rate) data presented above, however, that any risk of sub-lethal effects associated with multiple captures would be skewed markedly toward gear types and procedures that increased an individual fish’s frequency of exposure to those circumstances.

3. Incidental Catch

Steelhead are rarely, if ever, exclusive occupants of a stream. Along the coast of British Columbia there are a few streams where summer steelhead ascend migration obstacles that are barriers to other anadromous fish. However, the vast majority of streams that produce steelhead also produce a variety of other species, both resident and anadromous. Whereas these other species may not be targeted by steelhead anglers they are oftentimes vulnerable to capture. Foremost among them in the context of the present discussion are coastal cutthroat trout (*Oncorhynchus clarki ssp*), Dolly Varden (*Salvelinus malma*), bull trout (*Salvelinus confluentus*) and resident rainbow trout (*Oncorhynchus mykiss*). Juvenile steelhead are not exempt from the discussion.

Cutthroat are well understood to be highly catchable and vulnerable to hook injury and mortality (see, for example, Mongillo, 1984; Schill et al., 1986; Pauley and Thomas, 1993). This has been confirmed frequently by agency staff who have employed snorkel surveys to locate anadromous cutthroat brood stock prior to capturing them by angling with baited hooks. Such techniques commonly remove a high percentage of the available fish, sometimes with high mortality rates (data on file, MELP, Nanaimo.). As noted earlier, bait is commonly used in such programs to maximize catch rate and, therefore, reduce costs.

The relative scarcity of cutthroat in streams once known to support substantial numbers of the species is undoubtedly at least partially related to angling. Haig-Brown's accounts (1939) of catches available and common among Campbell River anglers gave at least some historic perspective as did Williams (1935) and Richardson (1978) on streams such as the Little Qualicum, Salmon, Coquihalla, Couquitlam, Chilliwack and several other anadromous streams throughout the province. Pochin (1946) is replete with references to the ready availability of cutthroat throughout the lower mainland, oftentimes in streams where that species has long since been extirpated. In many streams where steelhead angling is still prosecuted cutthroat abundance is so low there is no case to be made there is any target fishery for the species. The common belief that small tributary streams critical to population maintenance have been seriously impacted by logging and urban development does not always explain the status of stocks. Some formerly popular steelhead fisheries (e.g., Oyster and Little Qualicum rivers on Vancouver Island and Bella Coola River on central coast) have shown marked improvement in wild cutthroat abundance and population age distribution despite the fact that habitat conditions have remained relatively unchanged. How much of the improvement is related to restrictions on angling is unknown but it does not go unnoticed that the most pronounced increases in fish numbers and size have come following the closure of the steelhead fishery in recent years. A striking example of an increase in non-target species pursuant to angling closures has been observed in the Campbell/Quinsam, Puntledge and Big Qualicum rivers where resident rainbow trout are now encountered more frequently than at any time in the history of snorkel surveys on those streams (data on file, MELP, Nanaimo).

Provincial fisheries managers are in close agreement that both Dolly Varden and bull trout are more susceptible to angling, particularly with bait, than any other species co-habiting steelhead streams. Whereas there are frequent anecdotal accounts of the effectiveness of angling at capturing the available supply of these fish (sometimes repeatedly), there are no conclusive data to confirm any difference in hooking mortality rates between bull trout or Dolly Varden and any of the other salmonid species of concern here.

Similar to cutthroat trout, it is speculated that the present distribution and abundance of Dolly Varden and bull trout in accessible and frequently fished habitats has been influenced strongly by past angling. Any analysis of present circumstances should be viewed in that context (see, for example, Lambert, 1907; Williams, 1935; Pochin, 1946). Williams (1935) noted that in the Vedder River "Dolly Varden, with which the river used to be alive, are now more or less scarce". The historic and sometimes still prevalent view that these species are ravenous predators of salmon and trout has not enhanced their profile or treatment by some anglers. The inverse relationship between Dolly Varden and bull trout abundance and human settlement throughout the province would lend support to the view that these species have not done well when subjected to significant angling pressure (see, for example, MELP, 2000).

The conservation status of bull trout is well documented in the United States (USFWS, 1999) but less so in British Columbia (Cannings and Ptolemy, 1998; MELP, 2000). Rivers in the Puget Sound area of Washington State, immediately adjacent to southern Vancouver Island, support bull trout populations that are listed as threatened and endangered. Those listings generally obligate managers to regulate fisheries with particular attention to any methods that might cause incidental mortality. Dolly Varden, a visibly similar species, are now proposed for listing under endangered species legislation (USFWS, 2001). In British Columbia bull trout are not known to inhabit rivers of coastal islands (e.g. Vancouver Island, Queen Charlotte Islands). Dolly Varden are present but apparently at seriously reduced abundance throughout much of their original range (personal communication, Gordon Haas, Species at Risk Biologist, Ministry of Agriculture, Food and Fisheries, University of BC, Vancouver). Bull trout are categorized as "blue listed" in British Columbia ("A sensitive or vulnerable indigenous species that is not immediately threatened but is particularly at risk for reasons including low or declining numbers, a restricted distribution or occurrence at the fringe of their global range" – Cannings and Ptolemy, 1998). Both Dolly Varden and coastal cutthroat trout, as species, are included on the "blue" list by the province but it is clear that individual stocks are frequently endangered (i.e. meet "red" list criteria) or extirpated (Slaney et al., 1996).

Resident rainbow trout are rare or non-existent in most of the coastal steelhead streams in southwestern British Columbia. Interior tributaries of major Pacific drainages such as the Fraser, Skeena, Nass, Stikine and Taku rivers generally support both anadromous and non-anadromous stocks of rainbow. Lambert (1907) presented remarkable observations on angler catches of resident rainbow trout (and Dolly Varden) in, for example, the Thompson River at the turn of the last century. Almost all of these catches were made on flies because, as he noted, salmon roe was illegal at the time. Lambert also remarked that the Capilano and Coquitlam, on the doorstep of a population then 40,000 strong, had already been "much overfished".

The relative abundance of the resident rainbow trout stocks in steelhead streams throughout the province would appear, once again, to be inversely related to angling pressure. Skeptics need only sample remote tributaries of the Stikine and Taku rivers in northern British Columbia to be impressed at the numbers of rainbow, Dolly Varden and bull trout that can be caught incidentally while targeting steelhead. Given that these are relatively unproductive habitats when compared to more southerly streams, one can begin to appreciate the observations of Lambert (1907), Williams (1935) and Richardson (1979) and what may once have existed in the more traveled steelhead streams in heavily populated parts of the province.

The historic influence of one gear type versus another may be academic at this stage in the evolution of many fisheries in the province. However, it would be prudent to apply existing knowledge on gear related angling mortality to any situation where catch rates, conservation, and/or recovery of stocks and species are still subject to management influence.

4. Disease Transmission Considerations

Anadromous salmonids are carriers of diseases that can be transmitted through their eggs. Some of the diseases such as bacterial kidney disease are ubiquitous and therefore of relatively minor concern from a transplant perspective. Others such as infectious pancreatic necrosis (IPN) have never been detected in the province and every effort must be made to reduce the risk of its introduction. Fish pathologists have opinioned that the IPN virus is not likely to cause severe effects in Pacific salmon but trout, including rainbow and steelhead, could be adversely affected (personal communication, Sally Goldes, Fish Health Biologist, Ministry of Agriculture, Food and Fisheries, Nanaimo).

Anglers targeting steelhead and other salmonid and non-salmonid fishes frequently use mature salmon and steelhead eggs for bait. Fish pathogens often occur on the surface of salmonid eggs or in the ovarian tissue to which they are attached. Fish that come in contact with the pathogens run the risk of being infected and transmitting that infection to other fish. Commonly employed practices for preserving or treating the eggs prior to use include salting, boraxing and freezing. These treatments may be used singly, in combination or not at all (i.e. eggs are used "raw"from a freshly eviscerated fish). Treatment does not kill some of the pathogens of concern, notably the aforementioned two that both occur inside the egg. Noteworthy in the discussion of disease transfer concerns is that fish health protection regulations require all movements of live salmonid eggs between watersheds to be referred to the Federal – Provincial Fish Transplant Committee. The committee will not approve any movement of eggs that have not been disinfected in strict accordance with their prescriptions.

The risk of transferring an exotic disease through the use of eggs as bait is probably small but not inconsequential. It is understood that anglers have transported eggs around the province for as long as angling has been practiced. However, that does not infer using eggs from Great Lakes chinook or farm raised Atlantic salmon when angling in British Columbia waters (both have been observed recently) is condoned by fish pathologists or fisheries managers. It has only been in relatively recent times that pathologists have recognized the practice of using eggs is pervasive. They understand the difficulties in developing “proof” of the risk and they accept the reality that changing the status quo would be a formidable task.

Discussion

Throughout much of southern British Columbia, most notably among stocks entering the Georgia Basin between Vancouver Island and the mainland, steelhead are far below target escapements (data on file, MELP, Nanaimo). In fact, almost all the historically popular fisheries along eastern Vancouver Island have been either partially or totally closed to fishing for the past three seasons to conserve remnant populations. It is entirely reasonable and appropriate to assume that non-target stocks such as cutthroat, Dolly Varden and/or bull trout, resident rainbow, juvenile steelhead, etc. are in equally poor, if not worse, shape in many of these same streams.

A commonly held view on the primary reason for the impoverished status of many southern British Columbia steelhead stocks is that the survival of smolts entering the marine environment has been at historic lows in recent years (Ward, 2000; Welch et al. 2000). The evidence in support of low survival is striking and conclusive. What tends to escape notice is the fact that the numbers of smolts produced in freshwater has also been at historic low levels over this same period. If forces are operating to minimize smolt production initially, ocean survival should not be the singular focus. Every attempt should be made to augment smolt production to buffer recent trends in smolt survival. Angling regulations and their influence on smolt recruitment may be significant issues as are habitat protection and improvement initiatives. Introductions of hatchery fish and the large increases in angling effort with concomitant angling related impacts on co-habiting wild steelhead is an emerging concern. There is also the possibility that hatchery origin fish spawning in the wild may be adversely impacting both wild steelhead smolt production and survival (Chilcote, 2000).

The importance of repeat spawning steelhead to populations and how such frequencies may be influenced by angling appears not to have been considered to date. Steelhead that enter popular streams earliest in the fishing season contribute the most to the angling community by virtue of their longer residence. Fish that return earliest also tend to be the earliest spawners. Increased vulnerability of post-spawners or kelts due to their longer exposure to fishing effects and/or greater tendency to swallow baited hooks could serve to significantly reduce the ability of a population to compensate for a weak return of maiden spawners the following year. At the province’s steelhead research facility on the Keogh River, the relative contribution of repeat spawners has been shown to be critical to the total egg deposition in some years (personal communication, Bruce Ward, Senior Anadromous Biologist, Ministry of Agriculture, Food and Fisheries, University of BC, Vancouver).

The influence of ever more intensive angling pressure on steelhead stocks is an issue that commands attention. Catch rates, injury rates and mortality rates associated with different terminal gear types must be viewed in the context of that increasing pressure. The most alarming trends and signals come from catch data compiled through standardized annual mailed questionnaire surveys of steelhead angler licensees (i.e., Steelhead Harvest Analysis). Close examination of SHA data reveals a consistent pattern on streams where hatchery steelhead have been introduced. The years immediately following first returns of harvestable hatchery fish display pronounced increases in angling effort and record high estimates of wild steelhead caught and released (mandatory). Catches tend to have been sustained despite conclusive evidence of declining abundance in index streams (data on file, MELP, Nanaimo).

The catch estimates obtained through annual mail surveys are known to be positively biased, perhaps to an increasing degree over time. However, even with the most liberal adjustments for this bias the data lead to the conclusion that, in many popular streams, every wild steelhead is being caught more than once. The fact that fewer fish caught repeatedly can produce the same or higher catch estimate as more fish caught less frequently escapes notice. Documented accounts of multiple captures of individual fish, even on the same day, are now commonplace. The technology applied to fishing equipment, fishing information and access to fishing is accelerating on an unprecedented scale yet is unaccounted for in the assessment of catch data. Commercial enterprises focused on freshwater steelhead fishing are also operating on an unprecedented scale and contributing to illusions of abundance.

For some of the larger, more remote steelhead streams in the province and among those where target escapements are being met or exceeded the concerns over terminal angling gear and its consequences are less important. On many smaller streams and where conservation is definitely an issue managers must be more cognizant of the vulnerability of steelhead. Data from the ongoing Keogh River population dynamics monitoring emphasizes this point.

During the Keogh hooking mortality study discussed earlier a total of 130 and 206 steelhead were angled in study years 1985 and 1986 respectively (Hooton, 1987). The weir count of adult steelhead over the period that angling occurred downstream from the fence was used to provide a reasonable approximation of the percentage of the run captured in the time allocated. In 1985, the data revealed that project staff fished 117 hours to catch 130 steelhead that represented about 27% of the fish available. In 1986, 121 hours were angled to catch 206 fish that represented about 19% of the supply. In other words two anglers fishing an average of one hour per day over a two month period caught roughly one quarter of the population one year and one fifth the next. All of that occurred in about 50m of river.

More recently Keogh project technicians involved in requisite sampling of steelhead upstream from an electronic counter captured 45%, 62% and 30% of the total available supply of steelhead in 1998, 1999 and 2000 respectively. For 2001 to date the figure stands at 51% (personal communication, Bruce Ward, Senior Anadromous Biologist, Ministry of Agriculture, Food and Fisheries, University of BC, Vancouver). These catch rates resulted from two staff fishing for an hour or two per day over several kilometers of a river that is not held to be particularly accessible or “fishable” by most steelhead anglers. All of the fish were angled with bait.

Proving to the satisfaction of all that angling, or that angling with specific gear types, is negatively influencing small and declining wild steelhead populations and co-habiting non-target species is probably impossible. The same might well be true even with unlimited resources dedicated to researching the issues. Direct mortality can be modeled by reference to existing data but not without assumptions about the rate of mortality for particular gear types, the CPUE associated with those gear types, the frequency of use of gear types in the fishery and the status of the stock(s). Further, delayed mortality or sub-lethal effects that may be associated with single or multiple capture events is poorly understood and therefore even more difficult to account for. What we can say, however, is that angling with baited hooks is prevalent in streams where it is legal, that angling with bait generally results in substantially higher catch rates and mortality rates for both target and non-target fish than angling with any other gear type, that many of the wild steelhead stocks subjected to this combination of factors are far below target escapement and that the status of non-target stocks and/or species is frequently as bad or worse than steelhead.

Any notion that steelhead, particularly winter fish, are as abundant or more abundant in southern British Columbia now than in the recent or distant past is unsupportable. To the contrary there is a steady accumulation of information that points to less fish and greater catching power of anglers. Catch and release may have been oversold in that there tends to be a pervasive opinion it can be prosecuted limitlessly with no influence on the status or health of steelhead or sympatric species. With respect to fluvial resident trout populations it was accepted long ago fish are too catchable and prone to hooking mortality to sustain fishing with certain gear types. Resident fish are simply that – stationary inhabitants of the available habitat. Arguably, steelhead in most of British Columbia's short coastal streams, are effectively resident trout. Their vulnerability is entirely comparable to fluvial resident trout.

In fact, from both temporal and spatial perspectives, steelhead occupying almost any of the historically popular steelhead streams entering the Strait of Georgia are probably more available to anglers than are resident trout in streams elsewhere in the province where ultra conservative regulations have prevailed for many years.

Given today's realities of steelhead stock status, ocean survival trends and predictions, steadily rising angling efficiency, and that there must be an upper limit to the amount and type of fishing steelhead populations can absorb, managers will be challenged in days ahead. The angling community may wish to contemplate leaving a smaller and softer footprint on all wild fish or risk the steady erosion of longer term opportunity. A sobering reality is that the trends in stream fishing opportunity throughout virtually all of southwestern British Columbia have manifested themselves in a very few generations of steelhead. Ignoring history and assuming trends will be stabilized or reversed in the absence of attention to fishing impacts is unlikely to produce a desirable outcome.

Summary and Conclusions

1. Hooking mortality is commonly expressed as the proportion of fish caught that die shortly afterwards due to injury or stress directly attributable to specific angling gear. In the context of fishery management the issues that must be considered extend beyond the application of a simple mortality rate derived from elsewhere. Equally important but virtually never considered are the catch per unit of effort for different gear types employed in a fishery and the proportion of anglers using those gear types. Additionally, factors such as higher water temperatures and the length of time an angler holds a fish out of water have been shown to influence post release survival significantly. At the stock or population level the real sportfishing impact is the cumulative total of all factors bearing on that fishery.

2. The fisheries literature on hooking mortality rates for steelhead commonly refers to figures derived from various steelhead management investigations conducted on Vancouver Island through the late 1970s and early 1980s. The singular focus was on the immediate or short term mortality rate, not on any of the other important factors known to be associated with high use steelhead fisheries. Failure to recognize and account for known limitations and/or qualifications associated with the original data has likely served to underestimate the stock or population level consequences. Doubling of the oft cited 3.5 - 5% mortality rates derived from those original investigations would more accurately reflect what transpires in the steelhead sport fisheries in the province where angling with bait is prevalent.

3. Observed differences between hooking mortality rates for bait fishing versus artificial lure or fly fishing relate to the incidence of hooks penetrating critical anatomical locations. Angling with bait consistently produces the highest frequencies of hooking fish deep inside the mouth where rupture of blood vessels (gill structures and heart) and puncture of the esophagus is common. Such injuries commonly result in severe bleeding that, in turn, produces high mortality. Artificial lures result in consistently lower hooking injury and mortality rates, and flies consistently the lowest rates because fish are almost always hooked on the periphery of the mouth or in the jaws where blood vessels are not contacted. All else being equal the number of fish injured or killed by bait angling will exceed the number injured or killed by artificial lure angling by a significant margin and the number injured or killed by fly angling by a much greater margin.

4. Stock status is a fundamental issue in the assessment of fishing related impacts. Healthy/abundant stocks or those functioning well above replacement levels are not as great a biological concern as are those operating below replacement. At low levels of abundance, every spawner is deemed critical and angling related impacts on reproductive performance should be reviewed carefully in the context of the best information available and the precautionary principle.

5. Sub-lethal effects related to angling are poorly documented to date but possibly cumulative and of increasing significance in heavily used fisheries where multiple captures of individual fish are now common.

6. Sympatric non-target stocks of anadromous cutthroat trout and Dolly Varden or bull trout are commonly at risk (sometimes extirpated) in heavily fished steelhead streams in the southern parts of the province and vulnerable elsewhere. Angling for steelhead with bait has predictable but generally unacknowledged negative consequences in these mixed stock fisheries.

7. Disease transmission potential associated with the use of salmon and steelhead eggs in systems outside the watershed of origin is a concern among fisheries pathologists.

8. The most heavily fished streams in the province are those where hatchery fish have been introduced. Intensive effort is clearly invited by the availability of harvestable hatchery steelhead. Sympatric wild steelhead are protected by regulation from harvest but not from capture. Multiple captures of individual fish are commonplace thus increasing the risk of injury and death. Present information implies that many streams display a near worst case scenario – unprecedented catching power exerted on small wild steelhead populations, high incidence of the use of the most effective and damaging gear, high catch rates, frequent multiple captures and less than optimum fish handling procedures.

9. Angler efficiency and angling effort, singly or in combination, would seem to be maintaining CPUE and/or total catch of wild steelhead at levels that disguise their true abundance in many heavily fished streams. Angling regulations have, in general, failed to account for any such relationship.

10. The challenge for managers and anglers alike, especially in the southern parts of the province, is to maintain angling opportunity. The questions to be addressed are whether or not fish losses attributable to catch and release angling are affordable from both biological and social perspectives and should they/can they be minimized or avoided? Also, when do the benefits of catch and release management begin to be reversed by intensive fishing and multiple recaptures? All evidence points in the direction that impacts on non-target species are higher than they are for steelhead. Should the same considerations apply to impoverished non-target species? Terminal gear restriction should be viewed as one tool with a strong relationship to these important questions.

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Appendix A.

A summary of hooking mortality data sets referenced in the report.

Reference	Species	Mortality Rate			Comment
		Bait	Art'l Lure	Fly	
Hooton, 1987	Steelhead (W)	3.40%			Sample of 3715 brood stock
Hooton, 1987	Steelhead (W)	5.60%	3.80%		Sample of 335 from Keogh River
MELP, Kamloops	Steelhead (S)	1.61%			Sample of 436 brood stock
MELP, Surrey	Steelhead (S)	0.31%			Sample of 306 brood stock
MELP, Surrey	Steelhead (W)	4.31%			Sample of 209 angler tagged fish
Lirette, 1988	Steelhead (S)	7.90%			Sample of 76 brood stock
Lirette, 1988	Steelhead (W)	4.10%			Sample of 195 brood stock
Lirette, 1989	Steelhead (S)	8.70%			Sample of 69 fish angled for telemetry study
Thomas, 1995	Steelhead (S)	4.55%	4.55%		Terminal gear not specified
Nelson et al., 2001	Steelhead (W)	0.9%?			Radio telemetry study only
Mongillo, 1984	Steelhead	11.00%			Sample of 390 brood stock
Bendock and Alexandersdottir, 1993	Chinook	4.1-10.6%	4.1-10.6%		Three year radio telemetry study involving 446 tagged fish. No significant difference between bait and lure.
Palermo et al., 2000	Coho	14-46%			Passively fished gear in both tidal and non-tidal waters. Tidal n=292 (261 jacks); Non-tidal n=206 (168 jacks)
Vincent-Lang et al., 1993	Coho	11.7-69.3%			Highest mortality occurred in tidal water. Tidal water n=384; freshwater n=77
Thomas, 1995	Coho	2.27?	2.27?		44 fish passively angled but gear not specified.
Wydoski, 1977	Resident trout, diff. species	25%	5%	5%	Summary of other researchers' findings
Warner and Johnson, 1978	Landlocked Atlantic salmon	35%		4%	Sample of 177 hatchery origin fish in a natural environment over a 3-year period. Mean fish size 29-32 cm.
Mongillo, 1984	Rainbow trout	30%	5-10%	5-10%	Summary of other researchers' findings
Mongillo, 1984	Cutthroat trout (resident?)	50%	5-10%	5-10%	Summary of other researchers' findings
Taylor and White, 1992	Resident trout, diff. species	43.60%	5.10%		Summary of other researchers' findings
Pauley and Thomas, 1993	Cutthroat trout (anadromous)	39.5-58.1%	10.5-23.8%		Sample of 329 fish angled from two rivers in two separate years. Size not specified but appeared to average about 33 cm.
Schisler, 1995	Rainbow trout	(21.6-32.1%)		3.90%	Researcher employed <u>scented</u> artificial baits fished both actively and passively. Sample sizes of 457-511 fish per gear type. Passive gear produced highest mortality. Fish size data unavailable.
Trotter, 1995	Resident trout, diff. Species	31.40%	4.90%	3.80%	Summary of other researchers' findings
DeCicco, 1994	Dolly Varden (anadromous)	2.50%	1.10%		Mortality differences not significant. Total of 299 fish sampled in two rivers over two separate years. Mean fish size about 47cm.
McKinley, 1993	Artic char	5.5-10%	0.00%		Sample of 360 fish (mean length 35 cm) angled from hatchery raceway.
Jenkins, 2001	Rainbow trout	0-8.7%		0%	Sample of 900 fish angled from artificial environment on experimental hook types. Mean size 25 cm.