Habitat manipulations for the rearing of fish in British Columbia

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Summary

WARD, B.R., and P.A. SLANEY. 1993. Habitats manipulations for the rearing of fish in British Columbia, p. 142-148. *In* G. Shooner et S. Asselin [éd.]. Le développement du Saumon atlantique au Québec: connaître les règles du jeu pour réussir. Colloque international de la Fédération québécoise pour le saumon atlantique. Québec, décembre 1992. Collection *Salmo salar* n°1: 201 p.

Habitat improvement structures to enhance salmonids in some streams of British Columbia were evaluated for durability and fish use. Boulder structures in coastal streams and, more recently, woody debris catchers and placements in larger inland rivers were installed and evaluated. Durability of boulder clusters was related to stream discharge and bedload movement in coastal conditions. Boulder clusters placed in a moderate-size (mean annual discharge, or MAD, 9,24 m^3/sec) coastal stream, the Keogh River, were intact after 12 to 15 years, and use by steelhead (*Oncorhynchus mykiss*) parr remained high, at about one fish per boulder (or 8 parr/100 m^2 of stream) in treated sites which initially had densities near zero. Coho fry (*O. kisutch*) also significantly increased in abundance at the treated sites where scour occurred. Boulder clusters placed in the more unstable Salmon River (MAD 62,9 m^3/sec) on Vancouver Island were largely not durable after only 3 years, whereas structures remained in tributaries utilized by trout parr. Woody structures installed along the margins of the large Nechako River were highly colonized by juvenile chinook (*O. tshawytscha*) and adult rainbow trout. The debris catchers were durable during flows >200 m^3/sec. Boulder clusters have become a common tool for mitigating urban, highway, and logging impacts to fish habitat, particularly in the United States. Boulder clusters and woody debris placements have also been employed successfully in small urban streams to enhance the salmon and trout rearing habitat, but only on a limited scale regardless of benefits to wild fish. Evaluations indicate that these rearing habitat alterations are a viable tool for improving the carrying capacity of salmonid habitat in streams. To ensure success we encourage a site-specific approach involving careful planning, selection of in-stream structures adapted to local conditions of stream flow and bedload movement, use of pilot treatments where channel stability is uncertain, and post-placement evaluations.

Résumé

La durabilité et l'utilisation par le poisson de structures d'amélioration d'habitat pour favoriser les salmonidés dans certains cours d'eau de la Colombie-Britannique ont fait l'objet d'une évaluation. L'efficacité et la durabilité de structures de pierres installées dans des ruisseaux côtiers et de capteurs de débris en bois installés plus récemment dans des rivières plus importantes à l'intérieur des terres ont ainsi été évaluées. La durabilité d'amoncellements de pierres a été mesurée en relation avec le débit du cours d'eau et le déplacement de matériaux du lit de la rivière en conditions côtières. Ainsi, des structures en pierres installées dans un cours d'eau côtier de taille moyenne, la rivière Keogh (débit annuel moyen = 9,24 m^3/sec) étaient demeurées intactes après une période de 12 à 15 ans; de plus l'utilisation par des Truites arc-en-ciel juvéniles (*Oncorhynchus mykiss*) demeure élevée, se maintenant à environ une truite par pierre (ou 8 juvéniles/100 m^2 de rivière) dans des sites aménagés où les densités naturelles étaient près de zéro. L'abondance des alevins de Saumon coho (*O. kisutch*) a aussi augmenté de façon significative dans les sites aménagés où de l'érosion active se produisait. Des amoncellements de pierres installés dans la rivière Salmon, beaucoup moins stable (débit annuel moyen = 62,9 m^3/sec), sur l'île de Vancouver, n'ont en général pas duré plus de trois ans, alors que des structures semblables installées dans les tributaires utilisés par des truites juvéniles sont demeurées intactes. Des constructions en bois installées près des rives de l'importante rivière Nechako ont été fortement colonisées par des Saumons chinook juvéniles (*O. tshawytscha*) et des Truites arc-en-ciel adultes. Les capteurs de débris ont même résisté à des débits supérieurs à 200 m^3/sec. Les amoncellements de pierres sont devenus un outil très employé comme mesure d'atténuation des impacts sur l'habitat du poisson de développements urbains, de constructions de routes et d'exploitations forestières, surtout aux États-Unis. Les amoncellements de pierres et les capteurs de débris ont aussi été employés avec succès dans des petits cours d'eau en milieu urbain pour améliorer les habitats de croissance du saumon et de la truite, mais seulement à petite échelle malgré les bénéfices évidents pour les communautés ichthyennes indigènes. Des évaluations de ces modifications aux habitats de croissance démontrent que ces structures sont un outil efficace pour améliorer la capacité de support des habitats de salmonidés en ruisseau. Pour garantir le succès de ces aménagements, nous recommandons une approche site-par-site impliquant une planification détaillée, la sélection de structures adaptées aux conditions locales de débit et de déplacement du matériel du lit de la rivière, l'emploi d'aménagements expérimentaux où la stabilité du chenal est incertaine, et des évaluations périodiques de l'efficacité des structures.

Introduction

Salmonids which rear in streams may be limited by the availability of their preferred habitats in summer (Chapman, 1966; Bowlby and Roff, 1986; Fausch *et al.*, 1988) and winter (Bustard and Narver, 1975; Tschaplinski and Hartman, 1983; Cunjak and Power, 1986). The availability of habitat suitable for fish in streams is a prime factor in determining overall production; models designed to predict fish standing crop which were recently reviewed by Fausch *et al.* (1988) were based on habitat criteria. It follows that methods applied to maintain or increase fish habitat in streams will positively affect the carrying capacity and productivity of that environment.

Density dependence in stream-resident fish is closely linked to habitat. For steelhead (*Oncorhynchus mykiss*), the «bottleneck» to production occurs mainly between the fry and parr life stages, in relation to density and habitat availability (Bjornn, 1978; Ward and Slaney, 1992). Similar conclusions have been derived from work on Atlantic salmon (Chadwick, 1985), and on the critical early stages of brown trout (*Salmo trutta*) life history (Elliott, 1989). Thus, techniques to improve the quantity and quality of rearing habitat at this life stage should result in increased returns of adults. Applied techniques which improve conditions favouring high survival and abundance, thus increasing the carrying capacity, should benefit the resource, particularly under conditions of exploitation or stress from human or environmental factors (Saunders and Smith, 1962; Hunt, 1969; House and Boehme, 1985).

The life cycle of Atlantic salmon (*Salmo salar*) is similar to steelhead trout; the main difference is in fall spawning by salmon versus spring by trout. The two are most similar in the freshwater rearing stage, where several years may be spent in the streams before smoltification. Like Atlantic salmon, steelhead may repeat spawn, unlike Pacific salmon on the west coast of North America.

Efforts towards fish habitat improvement have been numerous on the west coast in recent years (Frissell and Nawa, 1992). These efforts were largely based on earlier habitat experiments in the central U.S. by White (1975), Hunt (1976, 1969), and Shetter *et al.* (1949). Many of the recent projects in coastal streams (House and Boehme, 1985) were similar to our earlier work (Ward and Slaney, 1979, 1981) where boulder clusters were found to be both durable in moderate-size streams and preferred by rearing steelhead parr and coho fry.

Initial results of our earlier evaluations demonstrated that some designs may prove inadequate in coastal conditions where extreme winter freshets are prevalent, and longer term assessment was required of those more cost-effective designs, especially boulder clusters. Several of the recent attempts at creation of artificial habitat in Washington and Oregon streams have not been durable (Frissell and Nawa, 1992), which was related to both structural design, particularly for the wooden devices, and stream flow dynamics. Few researchers have returned to the sites of habitat creation to examine the durability and fish use of habitat improvement structures several years after installation, although the economic evaluation of this enhancement tool often involves the assumption that benefits associated with the structures as measured one or two years after installation are maintained for 10 and 20 years, as we assumed (Ward and Slaney, 1979).

In this paper, we review a selection and evaluation process for habitat improvement structures designed for anadromous and resident rainbow trout, based on immediate post-placement investigations (Ward and Slaney, 1979, 1981) and examination of sites for durability and fish use after 12 years. Installation guidelines are included in Ward and Slaney (1979), and in a Fish Habitat Enhancement Guide (revised Salmonid Enhancement Program guide; Adams and Whyte, 1990). We further emphasize the conclusions of Frissell and Nawa (1992) that failure of structures is caused mainly by hydraulic conditions. In addition, structures constructed to capture woody debris in inland rivers (Slaney et *al.*, in prep.) are described, including evaluations of fish use.

Methods

Study areas

The Keogh River, on northern Vancouver Island, B.C., has been extensively described in the scientific literature (Ward and Slaney, 1979, 1988; Irvine and Ward, 1989; Johnston *et al.*, 1990), as well as elsewhere in these proceedings (Slaney and Ward, 1992). A more complete description of the habitat and experimental manipulations to create habitat for steelhead trout and coho salmon (*O. kisutch*) can be found in Ward and Slaney (1979) which presents results of early experiments at the Keogh River. The Salmon River, also on northern Vancouver Island, was likewise described in the paper on stream fertilization contained in these proceedings (Slaney and Ward, 1992), and in a previous symposium where the initial durability of boulder clusters was reported (Ward and Slaney, 1981). Debris placements and catchers were installed on the Nechako River, a major tributary to the Fraser River at Prince George. The Nechako River has been described by Slaney *et al.* (in prep.) and has been the site of intensive studies associated with an agreement between Alcan Aluminum Ltd., the Government of Canada and the Province of B.C. (Nechako Fisheries Conservation Program). Debris structures were installed in the large river 5 to 25 km from Cheslatta Falls (mean annual flow 61 m^3/s). The late-spring freshet in the Nechako River has been shifted to mid-summer for the protection of sockeye salmon (*O. nerka*). The upper Nechako River and its sports fish are more fully described by Slaney (1986). An experimental set of debris catchers was also installed in the West Kettle River located near the towns of Beaverdell and Westbridge in the southern interior. The system supports a sports fishery for rainbow trout and whitefish (*Prosopium williamsoni*). Structures designed to entrap woody debris in the West Kettle River were installed where the gradient is approximately 0.5 % (Griffith, 1991) and mean annual discharge at Westbridge is 9.24 m^3/s (Griffith, 1991).

Keogh River Boulder Structures

The process of designing habitat for fish assumes adequate knowledge of their preferred macro- and micro-habitats. Habitat requirements of juvenile steelhead and rainbow trout were determined from the literature (Hartman, 1965; Chapman and Bjornn, 1969; Bustard and Narver, 1975) and studies of use of B.C. streams by steelhead parr (Facchin and Slaney, 1977). Parr were frequently found amongst boulders in 40-70 cm depth and near the bottom at velocities of 20-35 cm/sec (Pearlstone, 1976; Everest and Chapman, 1972). In the Keogh River, highest parr abundance occurred in runs and riffles with large boulder cover (Ward and Slaney, 1979). The relation between parr abundance and boulder riffles was used to estimate production capability and subsequent smolt yield for several Vancouver Island streams (Lirette *et al.*, 1987).

Accordingly, a number of habitat improvement devices were selected which would provide in-stream cover with greater depth and velocity for juvenile steelhead trout and coho salmon (Fig. 1). Boulder clusters were most successful; average fish density was high and the clusters were durable through 3 years of fall and winter storm events (Ward and Slaney, 1979, 1981). The next phase involved intensive placement of boulder clusters which were cost-effectively transported by helicopter from a three-chain sling (Tsumura and Ward, 1987), treating both an upper and middle reach of the river (Ward and Slaney, 1981). Fish use was examined one year post-placement by standard Delury or removal methods (Seber and LeCren, 1967) using electrofishing and stop-seine enclosures in the 10 to 20 m study sites. Subsequently, fish sampling was repeated 12 years post-placement in the upper reach of the Keogh River where >300 boulders (1 to 2 m diameter, maximum 800 kg/boulder) were placed in clusters in a one km section by helicopter (Bell 206B Long Ranger).

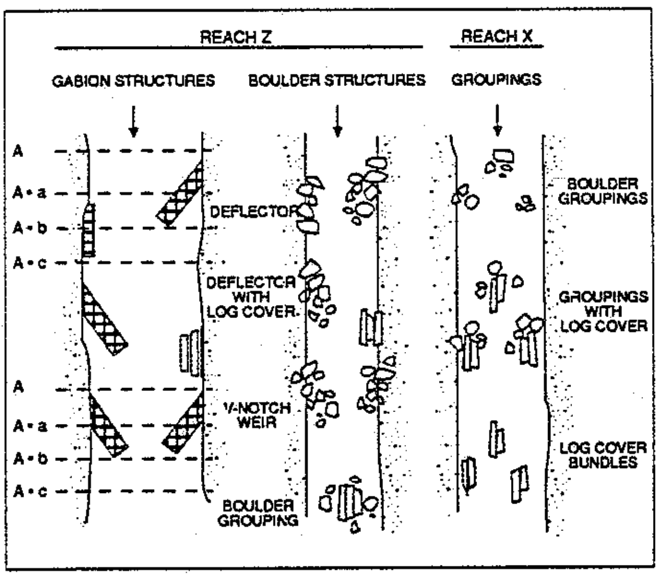

Fig. 1. Designs of boulder and gabion structures (simplified) installed in the Keogh River, B.C., during early experiments (1977) to evaluate durability and use by steelhead parr and coho fry (from Ward and Slaney, 1979). Reach Z was in the upper Keogh River and reach X, the middle river. The arrow indicates direction of stream flow.

Salmon River Boulder Structures

Placement of boulder clusters on the Salmon River in 1980 was described in Ward and Slaney (1981). Fish use was not examined in the Salmon River because the objective was to test the durability of large (0.6 to 2 m diameter) boulders in a large, intensively logged watershed associated with highly variable flows and greater bedload movement than in the Keogh River. Approximately 300 boulders were placed by helicopter or loader during the summer in three test sections then re-examined the next spring (1981) for displacement and numbers remaining above the substrate. These index sites were visited annually thereafter to visually estimate longevity and integrity of boulder clusters.

Nechako River and West Kettle River Woody Debris Structures

A number of designs of log placements and woody debris catchers in the Nechako River have been examined (Slaney *et al.*, in prep.). A smaller, more aesthetic design of debris catcher has been developed for resident trout streams (Fig. 2) as described in Griffith (1991a, 1991b). Fish use of seven debris catchers was determined by electrofishing and underwater counts; evaluations are incomplete and final results will be reported elsewhere.

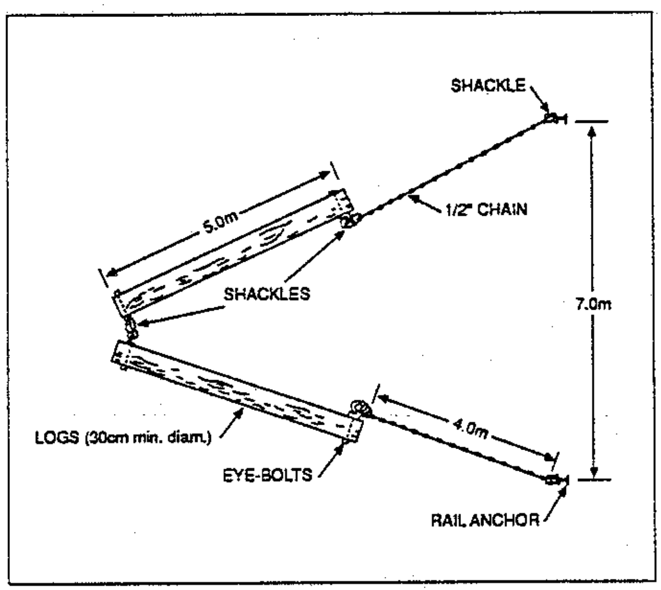

Fig. 2. Design of woody debris catcher installed in the West Kettle River, B.C. (from Griffith, 1991). Additional chain installed between logs was subsequently attached to more effectively entrap debris during freshet events. A variety of similar (and larger) structures have been tested in the Nechako River (Slaney *et al.*, 1991).

Results and Discussion

Boulder clusters in the upper Keogh River, where maximum flows were ca. 60 m^3/sec, were highly durable. Boulders remained within the area of placement and after the initial year, no boulder movement in clusters was detected, and after 15 years most had not moved. Of the few boulders that moved, they rolled once or less than a distance of 2 m. However, material used in structures tested earlier (deflectors and rock weirs) was displaced if under 0.4 m diameter. Over time, the large material culled from «rip rap» rock pits which was used to build boulder clusters became more natural in appearance as edges were rounded slightly by erosion and as moss accumulated. Some clusters were nearly dry during the summer low flow period in drought years as the river channel or thalweg shifted, but this was minor, and could be corrected by more careful placement of clusters near the thalweg within riffle sections. Scour around the boulder clusters changed little after 3 years post-placement, where small pools or «pockets» were associated with each group of 3 to 5 boulders. These pockets were less common around clusters placed in the middle reach of the Keogh River where maximum flow was ca. 100 m^3/sec but the substrate was comprised of larger cobble (>15 cm) material. Nevertheless, boulder clusters remained stable.

Salmon River flows and bedload movement were much higher (maximum flow in the treated area ca. 800 m^3/sec) which strongly influenced durability of structures. In an earlier report (Ward and Slaney, 1981) we documented that 13 % of boulders placed by helicopter remained functional, and larger boulders placed by machine were more durable, although 30 % of those were ineffective (visible but surrounded by bedload) one year post-placement. After 10 years and a 1-in-50 year flood event, virtually all structures at this site were no longer in the main channel due to channel shifts. A few clusters remained functional in one lower section where the river was associated with an adjacent flood plain. Clusters placed in smaller tributary streams (Springer Creek; Griffith, 1982) continue to function in 1993, in contrast to the larger, more unstable mainstem.

Utilization of boulder clusters by salmonids in the Keogh River is summarized in Ward and Slaney (1981). On average, steelhead parr abundance in the upper and middle reach was ca. one parr per metre of stream (0.1 parr/m^2, 7.4 g/m or 0.9 g/m^2), or about one parr per boulder added. Coho fry density and biomass in the upper river were 2.2 fry/m (0.3 fry/m^2) and 0.3 g/m^2. While there was a four-fold increase in the number of steelhead parr in the boulder-treated sites of the middle reach, coho numbers were not significantly different from pre-treatment levels in the middle reach probably due to lack of scour in the cobble substrate. In the upper reach, where scour was common, coho numbers also increased about 4-fold in boulder clusters one year post-placement, and 3-fold two years post placement (mean change in no/m: +2.2 in 1978, +1.4 in 1979) compared to pre-placement levels at the treated sites and no change in untreated control sites.

After 12 years, utilization of the boulder clusters in the upper Keogh River by steelhead parr has remained high. The positive relation between boulders at each site and parr use reported earlier (Ward and Slaney, 1979) was tested again by electrofishing within 13 sites, and although the slope of the relationship had changed and there was increased variability about the line, the relation was significant (Fig. 3; $r = 0.55$, $p < 0.05$). As the sites aged, one might expect more variable results as some sites improved while others may be preferred in some years but not others, depending on flow conditions. Thus, on the average, a treated site each year had approximately 6 parr associated with it, yet were virtually devoid of use by parr pre-treatment (Ward and Slaney, 1981). Mean survival of 1+ parr to smolt has been estimated at 63 % (Ward and Slaney, 1992). Thus, based on an estimate of 3 to 4 wild smolts per cluster of 5 to 7 boulders in the unproductive Keogh River, each treated site increased returns by 0.5 adult steelhead (Ward and Slaney, 1988), and likely provided for more numerically stable returns to this section of the river which was originally composed of riffle habitat lacking in-stream complexity.

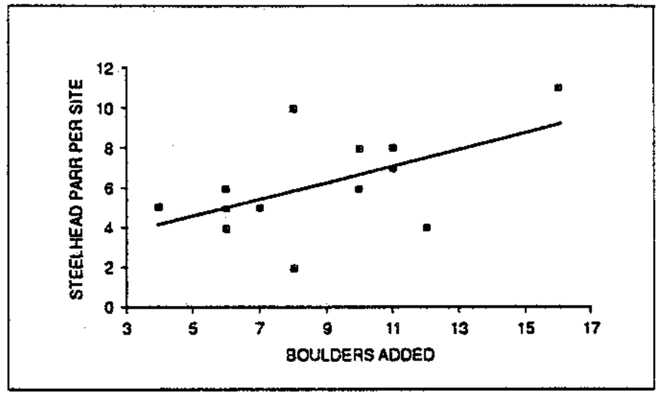

Fig. 3. The relation between the number of steelhead parr within treatment sites 12 years after placement of boulders and the number of boulders added per site in the upper Keogh River (Ward and Slaney, 1979).

Evaluations of debris bundles and catchers in the Nechako River indicated that the latter were durable, and most structures were highly colonized by underyearling chinook salmon (*O. tshawytscha*), and, to a lesser degree, adult rainbow trout (Slaney *et al.*, 1991). The majority of underyearling chinook enumerated over the 20 km margins of the study reach in June and July 1990 inhabited the debris structures. During late spring, when chinook fingerlings migrate downstream, there were 6 times as many counted in debris catchers than in debris bundles. Although the analysis of colonization by rainbow trout was limited to a single year (1991), 41 % of the debris structures were colonized by adult trout, at densities much higher than along the stream margins, or, on average, 2 adult trout per structure. Debris catchers were the most durable of several designs tested during 3 years with peak flows of 200 to 300 m^3/sec.

At the West Kettle River, debris catchers suspended by chain from steel rails driven to substrate level were durable through the annual spring freshet (peak 52.2 m^3/sec, 1992; D. Smith, B.C. Fish. Br., Penticton, pers. comm.). Preliminary counts of fish indicated high utilization by juvenile and adult trout by early summer, but low use late in the summer (data on file). However, the structures did not trap debris effectively, and this has been improved by incorporating additional chain between logs. Similar sets of debris catchers have been installed in three other interior streams of British Columbia to improve resident trout and char habitat.

Similar habitat improvement techniques have been applied in several streams in B.C., and in the western U.S., and habitat enhancement is likely to gain preference over hatcheries because of a renewed emphasis on wild fish management. The addition of anchored woody debris (root wads) to small urban streams has resulted in greater abundance of juvenile coho and cutthroat trout (Ptolemy, 1977). Shirvell (1990) also found that coho and steelhead trout preferred the habitat offered by root wad additions to a coastal stream, Kloiya Creek. Griffith (1982) summarized results of attempts to improve rearing habitat in three small streams in B.C. by boulder cluster addition, and concluded that durability after one year was high, while trout parr were 3 times more abundant in treated sections; trout and coho fry were also more abundant. Clusters of boulders have also been applied to mitigate the impacts of channelization resulting from highway construction (e.g., Coldwater and Coquihalla Rivers, and at several bridge crossings elsewhere). While there can be difficulties with land ownership and access, especially in urban and suburban areas, there are potentially high social benefits through community education with improvement of wild fish habitat in smaller streams (P. Caverhill, Sr. Fish. Biol., B.C. Fish. Br., Surrey, pers. comm.). Hands-on opportunities for schools and fishermen's groups to get involved in habitat restoration projects, rather than simply raising hatchery fish that may not return, should be strongly encouraged (Hilborn, 1993).

Reeves and Roelofs (1982) summarized a number of field applications in the U.S. (Pacific Northwest and Alaska) that have been utilized to rehabilitate and enhance stream habitat. Their summary included descriptions of placing of boulders in the John Day River, Beech Creek (Oregon), and Redcap Creek (California), which achieved the desired effect of increasing abundance of juvenile salmonids, and particularly steelhead parr. More recently, Espinosa and Lee (1991) reported high use by juvenile fish in boulder structures, root wads, and log weir pools placed in Lolo Creek, Idaho (average spring freshet, 14 m^3/sec). Steelhead parr were present in boulder sites in densities very similar to that found at the Keogh River, or about 10 parr/100 m^2, and structures in Idaho included chinook underyearlings at very high density (65.3/100 m^2 of treated habitat). Manuals of fish habitat improvement in the U.S. suggest the technique of boulder cluster addition has become standard practise (Seehorn, 1985; Flosi and Reynolds, 1991). However, «cookbook» approaches must be avoided, and we encourage the type of evaluation presented here (i.e., an adaptive approach with site re-visitation several years after placement) and as described by Frissell and Nawa (1992) so that we may learn more about which technique is most applicable under various conditions of discharge and sediment load. In-stream habitat improvement techniques cannot proceed successfully without consideration of watershed processes affected by land use and an overall ecosystem approach to fish enhancement.

Although additional recreational opportunities may develop from the enhancement of fish populations by artificial methods (i.e., hatcheries), it can be shown to be more cost effective and arguably more desirable to augment production of wild salmonids by the more natural methods of habitat enhancement. Hatchery production may develop or augment fisheries in previously non-utilized sites, in severely depleted stocks where immediate re-building is desired, and in large urban centres. However, wild populations should be managed by habitat protection and habitat improvement as the primary strategic objectives. We have demonstrated habitat improvement successes (e.g., boulder clusters in hydraulically suitable areas, debris catchers along margins of large rivers) and failures (boulder structures in large coastal streams with high bedload movement) and encourage further testing and evaluation. There are numerous opportunities to apply, refine, and evaluate habitat improvement methods, including opportunities to synergistically combine techniques such as habitat creation and nutrient augmentation, for maximum recreational fishery benefits.

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References

ADAMS, M.A., and I.W. WHYTE. 1990. Fish habitat enhancement: a manual for freshwater, estuarine, and marine habitats. Dept. Fish. Oc. Can. DFO 4474: 330 p.

BJORNN, T.C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Idaho Coop. Fish and Wild. Res. Unit Final Rep. Proj. F-49-R: 57 p.

BOWLBY, J.N., and J.C. ROFF. 1986. Trout biomass relationships in southern Ontario streams. Trans. Am. Fish. Soc. 115: 503-514.

BUSTARD, D.R., and D.W. NARVER. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32: 667-680.

CHADWICK, E.M.P. 1985. The influence of spawning stock on production and yield of Atlantic salmon, *Salmo salar* L., in Canadian rivers. Aquacult. Fish. Manage. 1: 111-119

CHAPMAN, D.W. 1966. Food and space as regulators of salmonid populations in streams. Am. Naturalist 100: 345-357.

CHAPMAN, D.W., and T.C. BJORNN. 1969. Distribution of salmonids in streams with special reference to food and feeding, p. 153-176. *In* T.G. Northcote [ed.]. Salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C.

CUNJAK, R.A., and G. POWER. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Can. J. Fish. Aquat. Sci. 43: 1970-1981.

ELLIOTT, J.M. 1989. The critical period concept for juvenile survival and its relevance for population regulation in young sea trout, *Salmo trutta*. J. Fish. Biol. (Suppl. A): 91-98.

ESPINOSA, F.A., and K.M. LEE. 1991. Natural propagation and habitat improvement Idaho: Lolo Creek and Upper Lochsa Clearwater National Forest. Ann. Rep. U.S. Dept. Energy Bonneville Power Admin. Div. Fish and Wildl., Project n° 84-6: 103 p.

EVEREST, F.H., and D.W. CHAPMAN. 1972. Habitat selection and spatial interaction of juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Board Can. 29: 91-100.

FACCHIN, A., and P.A. SLANEY. 1977. Management implications of substrate utilization during summer by juvenile steelhead trout (*Salmo gairdneri*) in the South Alouette River. Prov. B.C. Fish. Tech. Circ. n^o 32: 19 p.

FAUSCH, K.D., HAWKES, C.L., and M.G. PARSONS. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. Gen. Tech. Rep. PNW-GTR-213. Portland, OR: U.S. Dept. Agric., Forest Serv., Pac. Northw. Res. Station, 52 p.

FLOSI, G., and F.L. REYNOLDS. 1991. California salmonid stream habitat restoration manual. Calif. Dept. Fish and Game.

FRISSELL, C.A., and R.K. NAWA. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. North Am. J. Fish. Manage. 12: 182-197.

GRIFFITH, R.P. 1982. An evaluation of 1981 boulder placements aimed at enhancing rearing habitat of juvenile salmonids in small streams. Prov. B.C. Fish. Br. unpublished manuscript, Victoria, B.C. 23 p.

GRIFFITH, R.P. 1991a. West Kettle River, 1991: the identification of habitat improvement opportunities for trout of catchable size. Okanagan Region Wildlife Heritage Fund Society and Prov. B.C. Fisheries, Penticton, B.C. 26 p.

GRIFFITH, R.P. 1991b. The installation of structures to create complex debris habitat for trout in the West Kettle River. Okanagan Region Wildlife Heritage Fund Society and Prov. B.C. Fisheries, Penticton, B.C. 23 p.

HARTMAN, G.F. 1965. The role of behaviour in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 22: 1035-1081.

HILBORN, R. 1993. Controlling Johnny Salmonseed. The Osprey (1993) n^o 17: 2 p.

HOUSE, R.A., and P.L. BOEHME. 1985. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North Am. J. Fish. Manage. 6: 38-46.

HUNT, R.L. 1969. Effects of habitat alteration on production, standing crop and yield of Brook trout in Lawrence Creek, Wisconsin, p. 281-312. *In* T.G. Northcote [ed.]. Salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C.

HUNT, R.L. 1976. A long term evaluation of trout habitat development and its relation to improving management-related research. Trans. Am. Fish. Soc. 195: 361-364.

IRVINE, J.R., and B.R. WARD. 1989. Patterns of timing and size of wild coho smolts (*Oncorhynchus kisutch*) migrating from the Keogh River watershed on northern Vancouver Island. Can J. Fish. Aquat. Sci. 46: 1086-1094.

JOHNSTON, N.T., PERRIN, C.J., SLANEY, P.A., and B.R. WARD. 1990. Increased juvenile salmonid growth by stream fertilization. Can. J. Fish. Aquat. Sci. 47: 862-872.

LIRETTE, M.G., HOOTON, R.S., and V.A. LEWYNSKY. 1987. Preliminary steelhead production capability estimates for selected Vancouver Island streams. Prov. B.C. Fish. Tech. Circ. n^o 74: 23 p.

PEARLSTONE, D.S.M. 1976. Management implications of summer habitat characteristics of juvenile steelhead trout (*Salmo gairdneri*) in the Big Qualicum River. Prov. B.C. Fish. Manage. Rep. n^o 67: 13 p.

PTOLEMY, R.A. 1977. Responses of a coastal sea-run cutthroat trout (*Salmo clarki clarki Richardson*) and coho salmon (*Oncorhynchus kisutch*) to habitat development in Colquitz Creek, Vancouver Island. Prov. B.C. Fish. Br. unpublished manuscript, Victoria, B.C.

REEVES, G.H., and T.D. ROELOFS. 1982. Influence of forest and rangeland management on anadromous fish habitat in western North America. 13. Rehabilitating and enhancing stream habitat: 2. Field applications. USDA Forest Serv. Gen. Tech. Rep. PNW-140: 36 p.

SAUNDERS, J.W., and M.W. SMITH. 1962. Physical alteration of stream habitat to improve trout production. Trans. Am. Fish. Soc. 91: 185-188.

SEBER, G.A.F., and E.D. LeCREN. 1967. Estimating population parameters from catches large relative to the population. J. Anim. Ecol. 36: 631-643.

SEEHORN, M.E. 1985. Fish habitat improvment handbook. U.S. Dept. Agricult. For. Serv. Tech. Publ. R8-TP 7: 21 p.

SHETTER, D.S., CLARK, O.H., and A.S. HAZZARD. 1949. The effects of deflectors in a section of a Michigan stream. Trans. Am. Fish. Soc. 91: 185-188.

SHIRVELL, C.S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Can. J. Fish. Aquat. Sci. 47: 852-861.

SLANEY, P.A. 1986. An assessment of the rainbow trout (*Salmo gairdneri*) population of the upper Nechako River and the effects of a sports fishery closure. Prov. B.C. Fish. Man. Rep. n^o 89: 37p.

SLANEY, P.A., RUBLEE, W.O., PERRIN, C.J., and H. GOLDBERG. In prep. Debris structure placements and whole-river fertilization for salmonids in a large regulated stream in British Columbia. Bull. Mar. Sci.

SLANEY, P.A., and B.R. WARD. 1992. Experimental fertilization of nutrient deficient streams in British Columbia, p. 128-141. *In* G. Shooner et S. Asselin [éd.]. Le développement du Saumon atlantique au Québec: connaître les règles du jeu pour réussir. Colloque international de la Fédération québécoise pour le saumon atlantique. Québec, décembre 1992. Collection *Salmo salar* n^o 1: 201 p.

TSCHAPLINSKI, P.F., and G.F. HARTMAN. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Can. J. Fish. Aquat. Sci. 40: 452-461.

TSUMURA, K., and B.R. WARD. 1987. A sling used for boulder placement in instream enhancement projects. North Am. J. Fish. Manage. 7: 456-457.

WARD, B.R., and P.A. SLANEY. 1979. Evaluation of in-stream enhancement structures for the production of juvenile steelhead trout and coho salmon in the Keogh River: Progress 1977 and 1978. Prov. B.C. Fish. Tech. Circ. n° 45: 47 p.

WARD, B.R., and P.A. SLANEY. 1981. Further evaluations of structures for the improvement of salmonid rearing habitat in coastal streams of British Columbia, p 99-108. *In* T. J. Hassler [ed.]. Proceedings: propagation, enhancement and rehabilitation of anadromous salmonid populations and habitat symposium, Humboldt State University, Arcata, Californie.

WARD, B.R., and P.A. SLANEY. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Can. J. Fish. Aquat. Sci. 45: 1110-1122.

WARD, B.R., and P.A. SLANEY. 1992 in press. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead (*Oncorhynchus mykiss*). Can. Spec. Publ. Fish. Aquat. Sci. 181.

WHITE, R.J. 1975. Trout population response to stream flow fluctuation and habitat management in Big Roche-a-Cri Creek, Wisconsin. Verh. Internat. Verein. Limnol. 19: 2469-2477.