Strategies for Restoring and Developing Fish Habitats in the Strait of Georgia–Puget Sound Inland Sea, Northeast Pacific Ocean

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Rehabilitation and development of fish habitats are potential techniques for achieving sustainable development in coastal seas. Recent projects in the Strait of Georgia and Puget Sound to examine this possibility have conducted trials or experiments with sedge marshes (*Carex lyngbyei*) (26 sites) and eelgrass beds (*Zostera marina*) (14 sites). Some studies have been appropriate for examining the potential compensation of wetland losses from industrial developments, but many were experimental and small scale. Larger scale projects and longer term monitoring are needed to confirm that the policy goals of no net loss or net gain in fish habitat can be met using these techniques.

I. INTRODUCTION

Estuarine marshes and eelgrass beds are recognized as important fish habitats in the coastal waters of the northeast Pacific Ocean. The dominant vascular plants in these ecosystems are Lyngbyei's sedge (*Carex lyngbyei*) and eelgrass (*Zostera marina*). As well as providing one of the bases of the food web supporting juvenile salmon (e.g., Simenstad and Wissmar, 1985) vascular plants provide structure to the ecosystem (Levings, 1986) and possibly refuge from predation. Pacific herring (*Clupea harengus pallasii*) also spawn on eelgrass. Fish communities are more diverse in eelgrass beds relative to unvegetated areas. Harbour facilities, industrial activities, and log storage have affected these ecosystems in the Strait of Georgia and Puget Sound. The ports of Vancouver and Seattle, for example, have radically changed natural substrates. In particular estuaries shore habitats are significantly modified - in the North Arm of the Fraser River estuary, only 58% of the shoreline is currently considered high quality fish habitat (Williams and Colquhoun, 1987). Proposals for new developments in many areas of the Strait and the Sound currently require intensive evaluation and management of the nearshore areas to maintain productive fish habitat. Industrial development is concentrated in estuaries in these regions because of the availability of flat land at river mouth deltas.

In this paper I describe some of the recent projects that have been conducted in support of habitat management policies to restore and develop sedge marshes and eelgrass beds and hence contribute to sustained development. As pointed out by Bradshaw (1988), restoration is probably an unrealistic goal for habitat managers, and an objective of rehabilitation is more suitable since it is unlikely that exact re-creation of the original ecosystem is possible. Development of habitat has also been considered in certain projects in order to compensate for the losses, but in most instances should be viewed as replacement (Bradshaw, 1988). The issue of compensation ratios, that is the ratio of the area of the restored or developed habitat to that of the lost area, has some major scientific problems. There is a trend toward comparing functional or ecological values, but these are difficult to quantify. I conclude the paper with some recommendations for future research.

The research projects I describe have been stimulated by policy to manage fish habitat under guidelines issued by the Canadian Department of Fisheries and Oceans (DFO) and the U.S. Federal Clean Water Act (Section 404). The overall objective of the DFO policy is to achieve a net gain in the productive capacity for

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fisheries resources through three goals: fish habitat conservation, fish habitat restoration, and fish habitat development (DFO, 1986). Under Section 404 of the U.S. Federal Clean Water Act and state removal-fill laws, rehabilitation, replacement, or creation (collectively known as mitigation in the U.S.) can be proposed when loss of wetland vegetation is likely. Both these policies provide a framework for planning and are in line with the initiatives of sustained development to promote anticipation and prevention of environmental damage (WCED, 1987).

II. REHABILITATION

A. Estuarine Marshes

1. Strait of Georgia (Fig. 1)

The first project to rehabilitate sedge habitats in this area was undertaken in the Fraser River estuary in 1979, when an attempt was made to restore marshes that had been destroyed by construction of jetties. About 700 rhizome cores were taken from an existing marsh and replanted in the area of interest (Pomeroy et al., 1981). Since then, habitat managers have arranged at least 24 additional transplants of sedges and other estuarine marsh plants in the Fraser estuary. There have also been four projects in the Strait of Georgia where marshes previously isolated by dykes or fill and therefore not available as estuarine fish habitat have been reconnected by constructing passages through the dykes (e.g., Englishman River estuary, Tutty et al., 1983). Since 1980, three sand islands have been created in the Fraser River estuary from dredged material (Wiley, 1984) and sedge transplants were attempted on one of them.

The largest estuarine rehabilitation project in the Strait of Georgia was conducted at the Campbell River estuary. In 1981 a forest company wanted to build a log sorting area which required dredging in the estuary. Since much of the intertidal zone of the estuary had been used for log storage since about 1904, the habitats were considerably degraded from the deposition of organic debris and impact from logs grounding at low tide. The company gave up their lease for log storage and helped rehabilitate this part of the estuary. In November 1981 mats of plant material were salvaged from the area to be dredged and stored in the intertidal zone. Four artificial islands (3.7 ha) were then built from dredged gravel and graded to the proper elevation. Embayments were developed to maximize the perimeter of the islands for shoreline use by juvenile salmonids. The intertidal islands were built to specifications outlined by DFO biologists working in collaboration with engineers from the forest company. Wood debris was also removed from the area. In March 1982 the stored plant material was cut up and approximately 27000 cores were planted on the islands. The procedures are fully described in Brownlee et al. (1984).

An extensive research and monitoring program, summarized by Levings and Macdonald (1991), was conducted between 1982 and 1986 to determine if the manmade islands were successfully colonized by plant and invertebrate communities and fish. The project resulted in a net gain of approximately 18.8 ha of fish habitat. After 5 years, production by the plants as measured by peak biomass (approximately 305 g m^{-3}) was about the same as that contributed by natural plant communities in the estuary prior to the rehabilitation. By 1986 the sedge on the islands was contributing approximately 9600 kg dry weight per year of potential detrital material. Invertebrate communities in the sand and mud zone in the lower elevations colonized faster than in the marsh zone approximately 1 m higher. Fish food organisms produced in the former area were mainly crustaceans and oligochaetes. Dipteran insects (Chironomidae) and sabellid polychaetes (*Manayunkia aestuarina*) dominated in the planted marsh and by 1986 their abundance was similar to densities in reference areas. Total invertebrate biomass, however, was less than that at a reference area, possibly due to sediment differences. By the fifth year of monitoring, catches of wild juvenile salmon, especially chinook, were more abundant in the manmade islands than in reference areas.

2. Puget Sound (Fig. 1)

Cooper (1987) provided an overview of 16 estuarine habitat mitigation projects in the State of

Washington. Two of the 16 projects were marsh transplants, two were eelgrass transplants, and the remainder were substrate or shoreline modifications that did not involve vascular plants. One of the projects was a major rehabilitation program conducted in 1985 and 1986 at the Puyallup River estuary (Thom et al., 1987). This wetland was built as compensation for a natural area needed for expansion of container storage landing space in the Port of Tacoma (Fig. 1). Approximately 2.2 ha of intertidal wetland were developed from a sanitary landfill adjacent to the estuary. The area was graded to intertidal elevations and planted with 48800 shoots of sedge, obtained from a nursery in Oregon and from the Big Beef Creek estuary on the west side of Puget Sound. The habitat was provided with channels and a central basin (Fig. 1) to create a low tide refuge for juvenile salmon.

Results of monitoring showed that juvenile salmon and a variety of other fish were present within a few months after water was introduced to the wetland (Shreffler et al., 1988). Epibenthic and planktonic organisms used as fish food were also found. In a cooperative study at this site in May 1989, it was found that detritus from cattails (*Typha* spp.) appeared to be an important habitat for emergence of dipteran insects (Chironomidae) that can be used as food by salmon (mean 16 adult chironomids m^{-2} day^{-1} in sedge, 214 in cattails, and 2 on mudflats). Studies of the duration of residence of juvenile chinook salmon in the rehabilitated wetland 2 years after construction showed that fish used the wetland for up to 38 days (Shreffler, 1989) which was comparable to salmon in natural habitats. This rehabilitated habitat therefore appeared to be fulfilling many of the functions of natural areas after 3 years. However sedimentation rates have recently increased in the wetland so the habitat is still undergoing changes.

B. Eelgrass

Compared to sedge marshes, the rehabilitation of eelgrass beds seems to be more difficult and no major pilot project has been conducted. In the Strait of Georgia, experiments or trials with eelgrass have been conducted at four locations (Fig. 1). Results of these transplants are not available in the open literature and monitoring has not been intensive. In the Fraser River estuary, transplants have examined competition between *Z. marina* and an introduced eelgrass plant (*Z. japonica*) (Nomme, 1989). Rehabilitation with *Z. japonica* may be more successful as the plant reproduces using seeds. However, this species occurs higher in the intertidal zone than *Z. marina* and as *Z. japonica* is an annual may be less productive.

Thom (1990) reviewed ten eelgrass transplant projects in Puget Sound (Fig. 1). The area of the trials ranged from 0.1 to 0.8 ha and were conducted for experimental and compensation purposes. This author concluded that about 50% of the projects were successful, but as most of the transplants were monitored for <2 years, long term data were not available. A pilot project was recommended to develop techniques to rehabilitate eelgrass habitats on a larger scale (e.g., >0.4ha) in Puget Sound.

III. FISH HABITAT DEVELOPMENT

The only way that aquatic habitat in coastal areas can be created or developed in the strict sense is by lowering the elevation of supratidal areas. Any other technique is actually habitat replacement, which is not acceptable under the policies described above as most regulatory agencies require "like for like" exchanges of habitat. Some of the difficulty may be overcome by assuming that rehabilitation of areas degraded previous to a certain time represents a net gain in habitat. Breaching of dykes to connect previously flooded areas with coastal waters can be particularly successful if this method is adopted. Another possibility is to create a bank of developed habitat which can be used as credit in future compensation projects.

Unless terrestrial or supratidal areas are lowered to intertidal elevations, new marsh and eelgrass habitat to compensate for that lost due to industrial development can only be developed by planting vegetation on previously barren sediment (e.g., sand or mud flats, which occur in the low intertidal) or in riparian vegetation (e.g., willows, *Salix* spp., which occur in the high intertidal). Replacement of sand flats may require the placing of fill material to bring the intertidal zone to an appropriate elevation. This filling can result in loss of shallow water "living space" which can be important in small estuaries where considerable water volume may have already been lost due to industry by filling or water pollution. Creation of intertidal islands at the Campbell River estuary was only justified because a dam on the river had stopped natural sedimentation in the estuary. In large estuaries such as the Fraser River estuary, sand islands up to 2 ha have been developed (Fig. 1) by disposal of dredged material onto intertidal sandbanks. Preliminary data indicate one of these are providing some of the functions of natural fish habitat.

IV. COMPENSATION RATIOS

Fish habitat managers in the Strait of Georgia and Puget Sound are using rating schemes to give quantitative values to habitat components. This rating is done on a case-by-case basis and the values are still under development. Current thinking is that functional values of the habitats such as food supply, refuge from predation, and structuring of the habitat should also be considered as well as simple areal measurements. However, because of the difficulties and expenses involved in quantifying function, application has been limited. At present, to compensate for loss of sedge marshes and eelgrass a 2:1 ratio (compensatory area: lost area) based on areal measurements is usually required by habitat managers. Compensation ratios are thought to provide a "safety factor" in habitat rehabilitation and development projects because of the risk involved and the scientific uncertainties that the developed habitats will provide equal structure, function, and productivity as those lost (Gatton, 1983). Some fish habitat managers accept compensation ratios of 1:1 for sand and mud flats as well as riparian areas, based on the assumption that these areas begin to function as fish habitats faster than marshes or eelgrass beds.

V. CONCLUSIONS AND RECOMMENDATIONS FOR RESEARCH

Fish habitat rehabilitation and development in enclosed coastal seas is a relatively new branch of biotechnology that clearly requires further research. It is not yet proven technology, but shows good potential as a strategy for fish habitat management. A pressing need at this time is for more information on the relative functional values of habitats such as sand and mud flats, algae beds, and riparian areas. There is very little information on the feasibility of rehabilitating these habitats, which no doubt have significant but unappreciated functions in our coastal ecosystems. There are many reports on the apparently successful application of vegetation rehabilitation in locations other than the northeast Pacific (Fonseca et al., 1988), but doubts remain (Zedler, 1988). Many of the problems encountered in using this strategy are procedural rather than scientific (Cooper, 1987; Kunz et al., 1988). Comprehensive management plans for coastal seas are required for long term planning and to improve communication between researchers, managers, industrial interests, and the general public.

Under sustained development, the goals of no net loss or net gain in fish habitat might therefore be achieved by rehabilitation and development of marsh and eelgrass ecosystems. However, pilot scale projects with long term monitoring programs are required to provide data to verify that the manmade systems are performing the functions of natural habitats. In the northeast Pacific, where coastal habitats are relatively undisturbed and nearshore ecology is poorly documented, most scientists are advising caution and full protection of important plant communities. Nevertheless, there appears to be strong support for rehabilitation as a strategy to recover fish habitat destroyed by man's activities.

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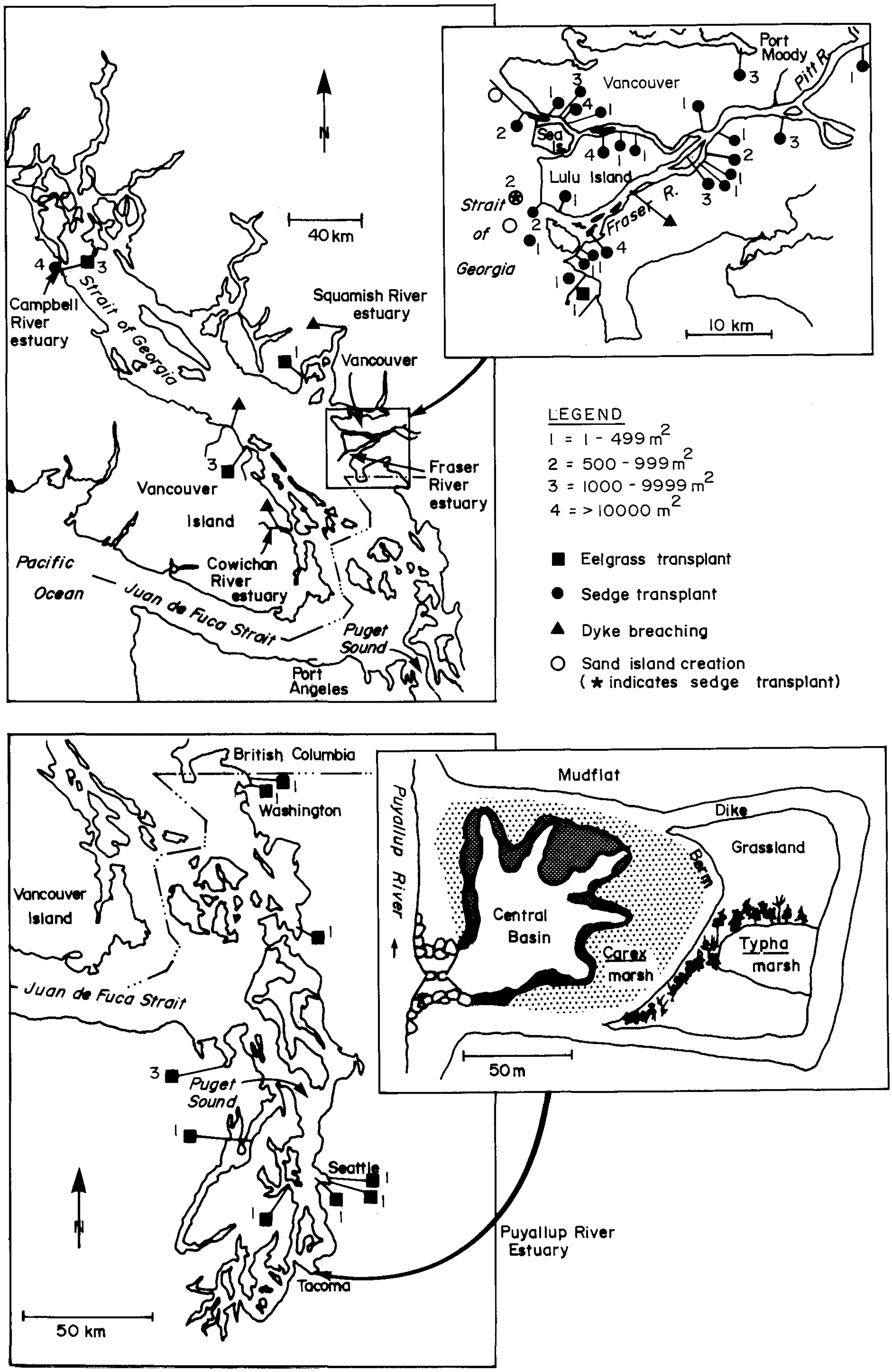

Figure 1. Maps of the Strait of Georgia (upper panel) and Puget Sound (lower panel) showing locations of sedge transplants (●), eelgrass transplants (■) and dyke breaching (▲). The locations of numerous small transplants of eelgrasss in Puget Sound described in Backman (1983) are not shown. Data from sources given in the paper. Lower right inset from Thom et al., 1987.