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Contemporary Methods for Capturing Juvenile Salmonids in the Marine Environment

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ABSTRACT

Anadromous salmonids play vital roles in marine and freshwater ecosystems. The most abundant of these fishes—Pacific salmon (*Oncorhynchus* spp.)—are integral to coastal ecosystems and communities across the North Pacific Rim, but numerous populations are experiencing dramatic declines, particularly towards the south of their range. Although many declines have been linked to poor marine survival, the early marine life phase of salmon has historically been difficult to study because of challenges in capturing juvenile salmon once they leave freshwater. Recent advancements in capture methods, refined over decades of research, have greatly expanded our understanding of juvenile Pacific salmon life history. Here, we synthesise and review the literature on the five main capture techniques for juvenile Pacific salmon in the marine environment: beach seine, miniature purse seine, conventional purse seine, microtroll, and rope trawl. We compare gear, selectivity, cost, and fish welfare considerations across methods. Along with demonstrated utility in Pacific salmon research, these methods also have broad—and in some cases unexplored—applicability for studying other salmonids and nearshore marine fishes globally, including invasive populations and Atlantic salmon.

1 | Introduction

Salmonids are critically important for natural ecosystems and human societies across the northern ocean basins, with Pacific salmon (*Oncorhynchus* spp.) comprising the most abundant group of salmonids in marine waters globally. The migrations of these foundational species link marine, freshwater, and terrestrial food webs (Walsh et al. 2020), and their presence can determine the health of entire ecosystems (Cederholm et al. 1999). Economically, they support commercial and recreational fisheries worth billions of dollars annually (FAO 2024), providing livelihoods for many coastal communities, both Indigenous and non-Indigenous. Culturally, salmon have profound significance for Indigenous peoples, having supported sustenance, trade, ceremony, and identity for millennia (Atlas et al. 2021; Earth Economics 2021). These relationships and ways of life are at risk, however, as Pacific salmon experience widespread declines in the southern half of their range (Pacific Salmon Foundation 2024; Katz et al. 2013; Price et al. 2017), threatening not only salmon themselves but also the ecosystems and human communities that depend on them. Poor marine survival has frequently been identified as a primary driver of many of these declines (Beamish 2022; Walters et al. 2019; Welch et al. 2021), but the marine lives of salmon have historically been difficult to study.

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The first year of marine life for Pacific salmon is characterised by multiple stressors and high mortality rates (Quinn 2018; Welch et al. 2011). Upon entering the ocean as juveniles, Pacific salmon must quickly adjust to saltwater, (Björnsson et al. 2011; McCormick and Saunders 1987) while competing with millions of conspecifics for limited food (Beamish et al. 2010), resisting infection by pathogens and parasites (Bass et al. 2022), and avoiding a gauntlet of predators (Phillips et al. 2021; Sherker et al. 2021) and anthropogenic stressors (e.g., pollution (O'Neill and West 2009)). As they contend with these stressors, many juvenile salmon simultaneously travel hundreds to thousands of kilometres along the coast, from their natal rivers to the high seas (Groot and Margolis 1991). Others spend extended periods in estuaries or coastal basins after entering the ocean, rearing in these habitats for their first summer or longer (Chalifour et al. 2021; Trudel et al. 2009). Some authors have argued that this early marine period may be a critical life history phase that determines cohort survival (e.g., Beamish and Mahnken 2001) while others suggest that it is merely one of several important phases (e.g., Welch et al. 2013). Regardless, relative to subsequent life-history phases, the brief early marine period accounts for a large proportion of lifetime mortality (Welch et al. 2011, 2013).

Once juvenile salmon leave the physical constraints of a stream or river, they become more difficult to study. Historically, the early marine phase of the salmon life history was considered a "black box," its contents hidden from observation, largely because the principal methods used to capture these fish—rope trawl and purse seine—were only affordable to large-scale research programs (e.g., Beamish et al. 2007; Helle et al. 2007; Orsi et al. 1997; Thompson and Neville 2024). Over the past 20 years, however, the development of new capture techniques and the rise in popularity of others have led to a surge of research targeting salmonids' early marine life phase. Indeed, over 85% of all studies on the early marine phase of Pacific salmon have been published since the turn of the century.[1]

Despite the rapidly increasing study of anadromous salmonids in their early marine phase, there remains no resource that describes and compares the various collection techniques now available to researchers studying these fishes. The abundance of Pacific salmon has allowed for trial-and-error development of capture methods that would not have been possible elsewhere, and these techniques may well be useful for studying salmonids in other oceans as well.

One of these techniques (microtroll) was recently developed, and another (miniature purse seine) has been reintroduced with expanded utility after decades of minimal use. Here, we summarise the five main methods currently used to capture Pacific salmon during their first year in the marine environment beyond the estuary: (1) beach seine, (2) miniature purse seine, (3) conventional purse seine, (4) microtroll, and (5) rope trawl (Figure 1). For each method, we describe the physical equipment and deployment technique, and compare methods with regard to historical usage, selectivity, cost, and fish welfare considerations. As seven researchers who have used, developed, or advanced the methods described here, we present this synthesis largely on the basis of our collective expert knowledge. For the new or less-used methods (i.e., miniature purse seine and microtroll), the literature we present is exhaustive or exhaustive for the modern era, whereas for others, it draws on key papers for that method's development. In all cases, we checked for missing literature with spot-checks in Web of Science using the method names alongside "juvenile salmon*" and "marine" or "ocean".

2 | Beach Seine

2.1 | Overview and History

Beach seining is the primary technique used to catch small (< 10 cm) young-of-year salmon in the very nearshore marine environment (i.e., the intertidal-subtidal fringe). For pink, chum (*O. keta*), and ocean-type Chinook (*O. tshawytscha*), all of which migrate directly to the ocean without spending a year in freshwater after hatching, it is the most reliable capture method during their first weeks in saltwater, before the fish grow larger and move further from shore. Beach seines are deployed from shore or from a vessel and retrieved from shore, sitting vertically in the water with a "float line" or "cork line" on the top edge of the net and a weighted "lead line" on the bottom (Figure 2). The seine nets themselves are fairly inexpensive (roughly \$2000–\$6000 CAD) and relatively simple to operate, since the most common marine deployment methods require at most a small powerboat or rowboat and 2–4 people.

Although juvenile salmon have long been incidentally caught by beach seines in broad surveys of marine fishes (e.g., DeLacy and English 1954), it took some time before beach seines were regularly used to target juvenile salmon specifically. In estuaries, juvenile salmon were targeted by boat-deployed beach seines in the 1960s (e.g., in the Port Angeles estuary in 1964 by Ziebell et al. (1970) and the Columbia River estuary in 1966 by (Durkin 1985)), with the technique becoming relatively common by the early 1970s (e.g., Dunford 1975; Levy 1977; Sims and Johnsen 1974). In fully marine waters, juvenile Pacific salmon were regularly caught in beach-seine surveys of the nearshore environment throughout the 1970s, especially in Alaska (Barton 1978; Harris and Hartt 1977). One beach-seine catch of out-migrating pink salmon (*O. gorbuscha*) in Alert Bay, BC was reported in 1955 (Margolis and Adams 1956) but it was not until 20 years later that research programs began using beach seines in earnest to *target* juvenile salmon. By the late 1970s, juvenile pink, chum, and Chinook salmon were targeted in the nearshore marine environment from Puget Sound, Washington (Cordell et al. 1980) through British Columbia (BC) (Healey 1980) to Prince William Sound, Alaska (Cooney et al. 1978). Since then, beach seines have become the standard method for studying young-of-year salmon in littoral habitats.

2.2 | Gear Description

Beach-seine design is often dependent on the size and species of salmon being targeted by the study. The most common type of beach seine has three sections: a middle section, called the "bunt", which has fine mesh size and usually a dark colour, and two outside sections (the "tow" ends or "wings"), which have coarser mesh and sometimes a lighter colour (Figure 2). A popular alternative design incorporates only two sections:

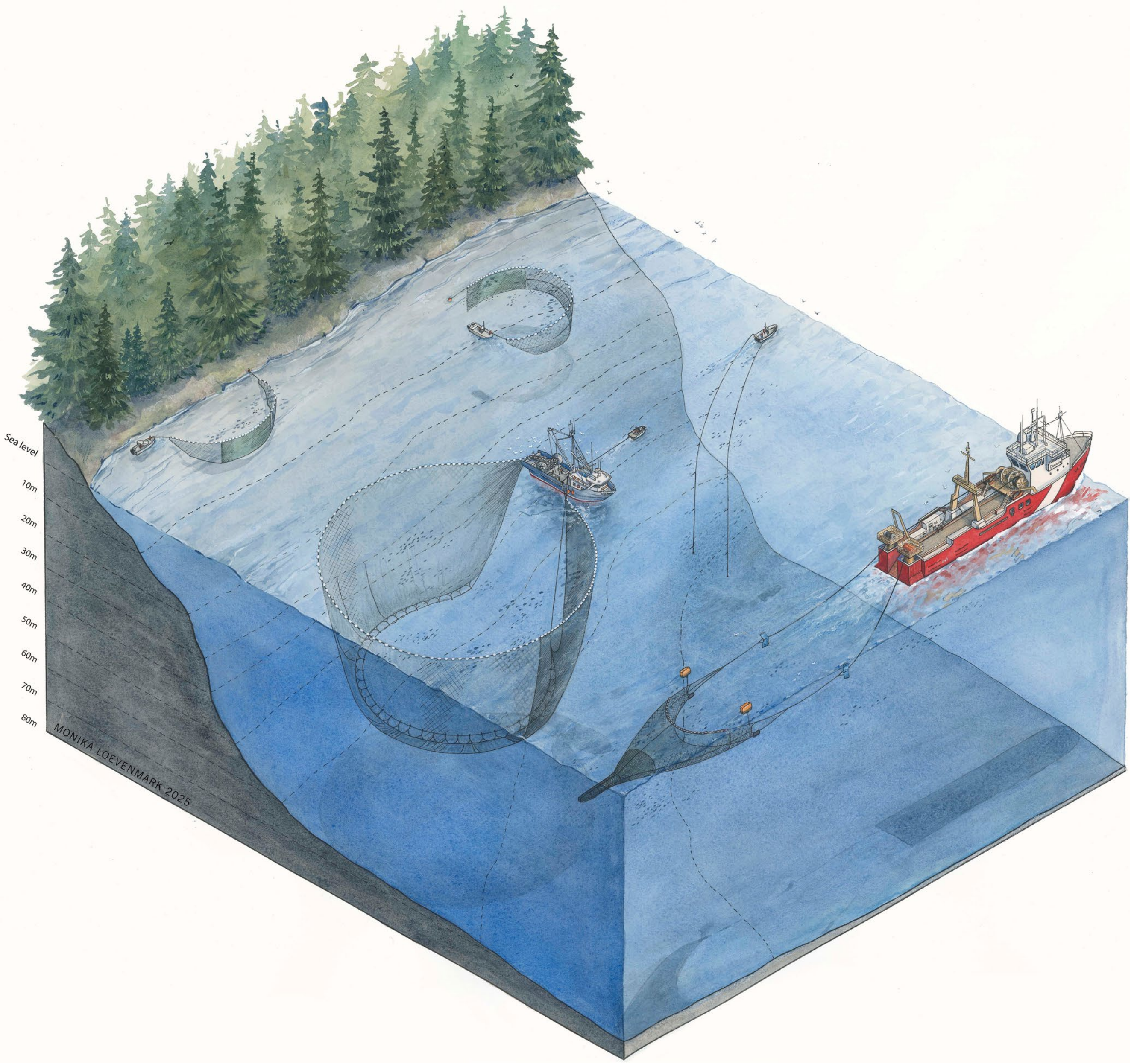

FIGURE 1 | Typical deployment for the five main contemporary methods for capturing juvenile salmon in the marine environment: Beach seine (top left), miniature purse seine (top middle), conventional purse seine (bottom left), microtroll (top right), and rope trawl (bottom right). Illustration by Monika Loevenmark.

a bunt and a single tow end, which allows for a different deployment strategy (see Supporting Information) that can be advantageous when targeting larger, more offshore fish. Exact dimensions vary, but three-section (Peacock 2018) (Figure 2) and two-section beach seines (Atkinson et al. 2024) currently employed by a pair of major juvenile-salmon monitoring programs in BC are both 40 and 46 m long and 2.5 m deep with 15 m bunts. A knotless-mesh size of 0.4–0.7 cm for the bunt (all mesh sizes reported in stretched form, as is standard) is ideal for work with juvenile salmon under 6 cm fork length; too much larger and it is possible for the smallest (3–4 cm) salmon to become trapped in the net, in a similar manner as in a gillnet. Mesh sizes up to 1 cm can be used when exclusively targeting fish >6 cm (Atkinson et al. 2024). Using coarser mesh in the wings (e.g., 0.8–1.6 cm) saves on material, space, weight, and hauling resistance, and having a lighter wing colouration (often white) can serve as an aversive visual cue that directs fish towards the less visible bunt, which is often dark green or black. Lead-line weights are highly variable, but tend to be between 0.1 and 0.6 $\mathrm{kg\,m^{-1}}$, depending on the size of the net. An extra ‘bridle’ line, extending from each end of the lead line to the corresponding tow line is needed to retrieve the net. The floats of the bunt are generally more closely spaced than those on the tow end to better support the net and prevent fish escaping between the floats.

Beach seines targeting juvenile salmon are most commonly deployed using the “round haul” method, in which one end of the net is held on shore while the other is set in a wide U-shape from a boat or, in shallow habitats, by waders. Careful hauling to maintain contact between the lead line and seabed is important

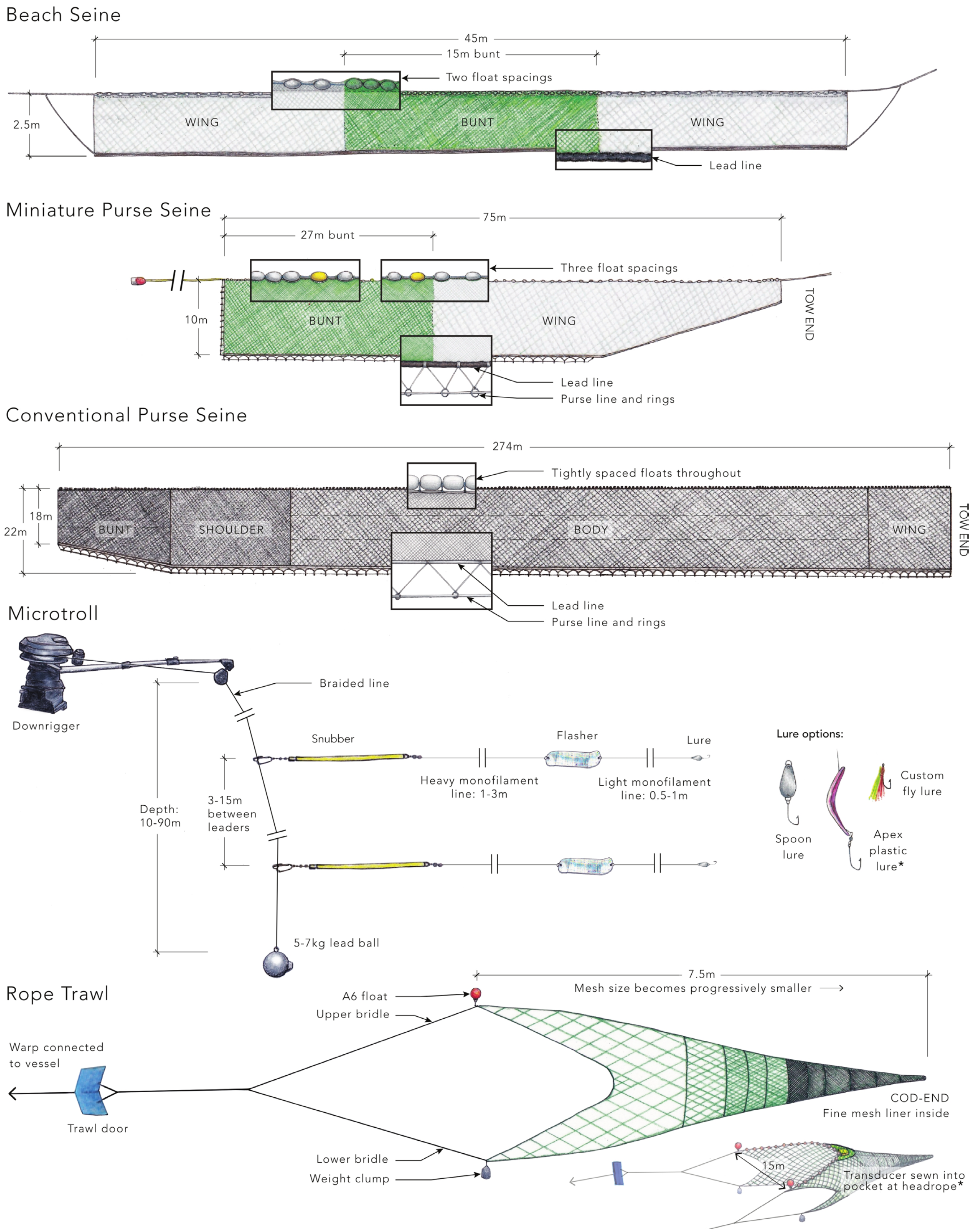

FIGURE 2 | Gear for the five main methods of capturing juvenile salmon in the marine environment. Dimensions are given for a common version of each method, but for four net-based capture methods, there is ample variation. Not all lines are shown on the conventional purse seine because of space restrictions. A flasher is not used with the Apex lure because of drag and erratic action. Some transducers require a wire connected to the vessel. Illustration by Monika Loevenmark.

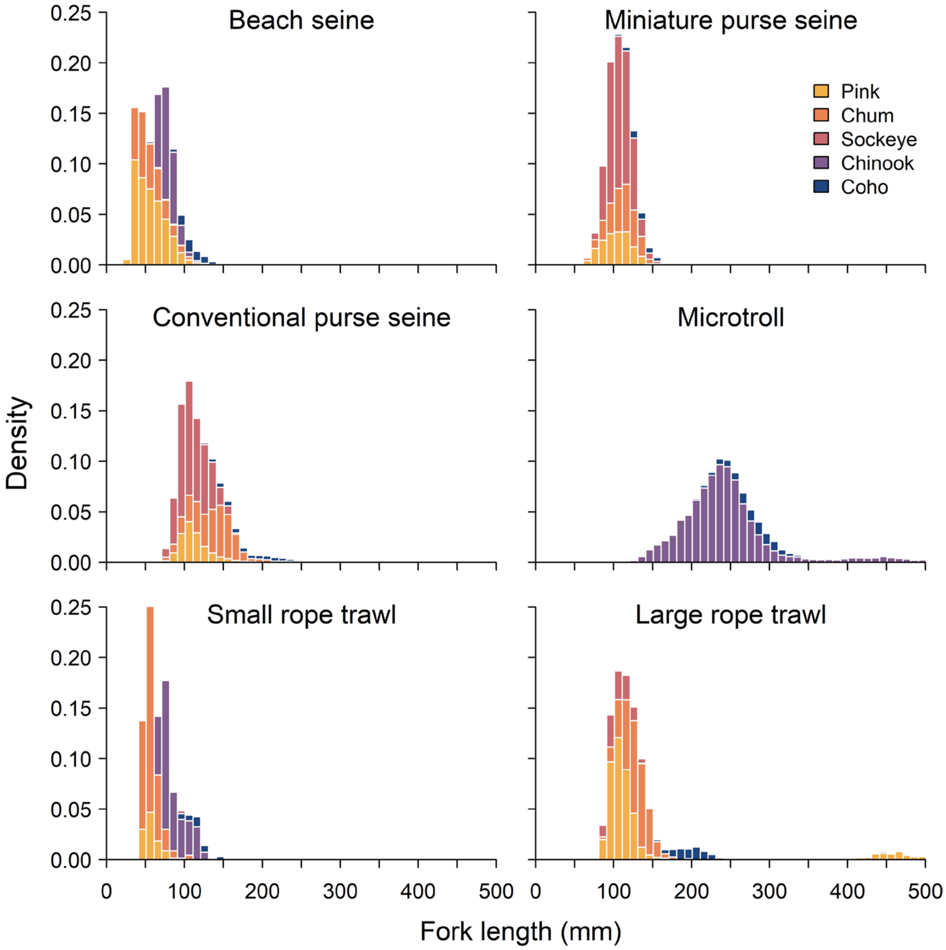

FIGURE 3 | Fork-length frequencies of salmon collected using the five main methods currently used to capture marine-phase juvenile Pacific salmon. All fish were caught in the Salish Sea, British Columbia (Peacock 2018; Atkinson et al. 2024; Peacock et al. 2016; B. T. Johnson 2022; Rousseau et al. 2020; Duguid 2020). Species compositions are not directly comparable because of sampling differences across time and space (Table S1), but length frequencies are reasonably representative given the strengths and constraints of the various capture methods. Approximately 0.9% of microtroll observations and 1.0% of rope-trawl observations are greater than the *x*-axis limit, to a maximum of 750 mm (microtroll) and 1022 mm (rope trawl).

for ensuring capture, and modified nets with a single wing allow larger deployments without increasing crew size. See Supporting Information for detailed deployment descriptions.

2.3 | Other Considerations

A beach seine can only fish to the depth of the net (Figure 1), which is usually 1.5–4 m, so in locations with deeper water, it can hang freely in the water column until it is hauled closer to shore, resulting in the possibility of deeper-swimming fish escaping underneath. Juvenile salmon tend to move further from shore and into deeper water as they grow (Macdonald et al. 1987; Patanasatienkul et al. 2013), making them inaccessible to beach seines. Combined, these limitations explain the size- and stage-selectivity of beach seines (Figure 3).

Beach seining for early marine salmon is normally an active affair. Typically, visual confirmation of fish presence prior to setting the net and subsequent targeting of those fish provide the highest CPUE. Marine-phase salmon of the size targetable by beach seine can usually be seen underwater or by their surface activity (raindrop-like “dimpling” or leaping). Although blind sets with beach seines are regularly used for general fish surveys (e.g., Barton 1978; Johnson 2003), they are often much less successful at catching large salmon schools because of the beach seine's small capture area. There are exceptions, of course; blind sets can be successful if juvenile salmon abundance is very high or in specific locations where juvenile salmon are known to aggregate (e.g., Bartlett 2019). Blind sets also allow for standardised catch per unit effort (CPUE) measures. If a current is present, blind fishing success can be increased by holding the net open to the current for a few minutes by hand or with an anchor (Beamer et al. 2005).

In good conditions and with proper gear, beach seining appears to have minimal direct effects on juvenile salmon survival. For example, observed mortalities in the net have comprised only 0.13% of the estimated number of fish caught in the long-term beach seining program conducted by Salmon Coast Field Station (Peacock et al. 2016). Since most mortality during beach seining occurs when waves or currents collapse the pocket formed by the net or push it against the shore, being prepared to release fish quickly is important and care must be taken to avoid trapping fish between folds of the net, which increases abrasion and can strand fish out of the water. When targeting visible salmon schools with beach seines, bycatch rates also tend to be moderate, but are highly variable (e.g., < 1% (Peacock et al. 2016))—most sets (i.e., deployments) will capture a few non-target species (e.g., threespine stickleback (*Gasterosteus aculeatus*) or shiner perch (*Cymatogaster aggregata*)) but occasionally an entire school of non-salmonids can be accidentally captured (e.g., Pacific sand lance (*Ammodytes hexapterus*) or Pacific herring (*Clupea pallasii*); Peacock 2018), which can lead to stressed salmon and/or long processing times.

3 | Miniature Purse Seine

3.1 | Overview and History

Miniature purse seines allow for the capture of juvenile salmon (roughly 7–15 cm; Figure 3) in all but the shallowest coastal marine habitats, including small inlets that conventional purse seines and rope trawls (see below) are unable to access. Like beach seines, miniature purse seines sit vertically in the water using a float line and a lead line (Figure 1), but instead of being pulled onto shore, they are retrieved in water and cinched or "pursed" like a drawstring bag. The nets themselves are moderately expensive ($7000–$10,000 CAD) and require at least one small (usually at least 6–8 m) powerboat and 3–4 people to operate.

Small-scale purse seining for juvenile salmon and other fish emerged as a method in the 1960s and 1970s, in parallel with the development of industrial-scale purse seining for commercial adult salmon fisheries. Typically used as a method to target larger juvenile salmon that had moved offshore beyond the reach of a beach seine, miniature purse seines were first deployed for catching salmon in California (Hunter et al. 1966), Oregon (Durkin and Park 1967), and Washington (Johnsen and Sims 1973). During this period, the exact methods varied, with a few examples of nets set and hand-hauled off a single boat (e.g., Hunter et al. 1966) and relatively more examples of conventional but miniaturised purse seining, in which small nets were set using two boats and hauled aboard by winch (e.g., Durkin and Park 1967; Johnsen and Sims 1973). The developing method was also occasionally described as a 'bag seine,' referring to the net design having a finer mesh 'bag' with coarser mesh wings on either side (e.g., Reimers 1971). Early use of the miniature purse seine method primarily targeted coho (*O. kisutch*), Chinook, and/or steelhead (*O. mykiss*) salmon in estuaries (e.g., Healey 1980; Johnsen and Sims 1973; Meyer et al. 1981), but there are also examples of purse seining for pink and chum (e.g., Bravender and Van 1997; Feist et al. 1991). The past two decades have seen the re-emergence of miniature purse seine nets as a method to capture all species of juvenile salmon in the marine environment, largely because of the re-development and implementation of the technique, and sharing of expertise, by a BC fisher named J. Eriksson.

3.2 | Gear Description

To our knowledge, all but one of the miniature purse seines currently targeting marine-phase juvenile salmon are of the same design and operate exclusively in coastal BC (Carr-Harris et al. 2018; Godwin et al. 2018; Hunt et al. 2018, M. Bartlett, unpublished data). These nets are 73 m long and 9 m deep, divided into two sections: a 27 m bunt with 1.3 cm knotless mesh and a 46 m tow end with 7.6 cm knotless mesh (Figure 2). The float line of the bunt has a higher density of floats than the tow end, to ensure that fish cannot escape on the surface between floats. The one known, currently operational exception to this design is a 60 m long net with roughly the same ratio of bunt to tow end and otherwise the same specifications (J. Eriksson pers. comm. Routledge and Morton 2023). At least two smaller purse seines have also been used recently to target juvenile salmon in shallower areas—one in the Skeena estuary (with minimal success; C. Sharpe pers. comm) and one in the mouth of the Fraser River (Chalifour et al. 2021)—but the fish being captured were fry or smolts in fresh or estuarine waters rather than post-smolts migrating along the coast.

Miniature purse seines require skillful handling and are physically demanding to operate, with deployment typically involving a powerboat reversing in a wide arc around target fish to form a 'J' shape before cinching the purse line to close the bottom. Recent or conceived adaptations, such as two-vessel operations (Carr-Harris et al. 2018), hydraulic haulers (Sharpe et al. 2019), and design modifications (e.g., net colour and size) highlight ongoing opportunities to optimise capture efficiency under varying field conditions. See Supporting Information for detailed deployment descriptions.

3.3 | Other Considerations

Like beach seines, miniature purse seines only fish to the depth of the net (commonly ~9 m), which can prevent the capture of larger juvenile salmon, such as over-winter residents or larger migrants traveling deeper in the water column (Figure 3). Miniature purse seine nets have a larger mesh size than beach seines and cannot touch the ocean floor without risking damage or loss, so they rarely capture the small, young-of-year salmon targeted by marine beach seines. Exemplifying this, the 5th percentile of fish lengths in the Hakai Institute's miniature purse-seine dataset (B. T. Johnson 2022) (Figure 3) is equal to the 90th percentile in Salmon Coast Field Station's beach-seine dataset (Peacock et al. 2016). The size distributions and species ratios of fish captured by miniature purse seines do not always match up with those caught by conventional purse seines in the same region (B. Johnson, pers. comm.; Figure 3), as larger individuals are less likely to be in the nearshore waters that miniature purse seines are particularly well-suited to fish.

Of the five capture methods described here, miniature purse seining probably results in the lowest rates of incidental mortality and bycatch, alongside beach seining in good conditions. Although no mortality estimates for miniature purse seining have been published, to our knowledge, mortality risk is thought to be minimal as fish are allowed to swim freely throughout and can easily be released at any time. Like beach seining, most mortality by this capture method occurs from inadvertently collapsed nets (e.g., because of waves or current), so care must be taken in the same manner. Net collapse happens less frequently with miniature purse seines than beach seines, however, because purse seines are not brought in against the shore, it is easier to make adjustments that minimise the effects of currents and waves when on a boat than on shore, and the fish captured tend to be larger and more resilient when net collapses do occur (S. Godwin, pers. obs.). One major exception is when large numbers of jellyfish are caught as bycatch—this can cause mass salmon mortalities, as jellyfish fracture when they rub against the mesh and fish in the catch, fouling the water. With an experienced crew capable of distinguishing salmon schools from those of other nearshore fishes, miniature purse seining operations also have very low bycatch rates when fishing visible schools of fish, with bycatch typically limited to a couple of non-target fish per set. If a salmon school is misidentified or if setting 'blind', however, bycatch rates can be high (e.g., a school of 5000 Pacific herring in a single net (B. T. Johnson 2022)). Of the other ~344,000 fish captured by miniature purse seine in the same monitoring program between 2015 and 2022, only ~2100 (~0.6%) were non-salmonids (B. T. Johnson 2022).

4 | Conventional Purse Seine

4.1 | Overview and History

Conventional purse seines have been deployed to capture adult Pacific salmon in commercial fisheries for over a century, and are now commonly used to capture juvenile salmon as well. For juvenile research, these nets are deployed from commercial fishing vessels to capture post-smolts mostly 8–20 cm in length, but they are also able to capture larger salmon swimming in deeper, offshore waters (Figure 3). Unlike miniature purse seines, the conventional purse seine requires a large commercial fishing vessel (~20 m in length), a secondary vessel ("power skiff"), and hydraulic hauling equipment. A skilled fishing crew of 4–5 is needed to operate the vessel and work the net, as well as 2–5 biological staff members for data collection and fish handling, sometimes with overlap. The nets are quite expensive ($50,000–$80,000 CAD), and the operation of the vessel is relatively costly ($4000–$8000 CAD per day, not including biological staff). The net depth and vessel size required for this method limits access to nearshore habitats, so conventional purse seines are sometimes deployed as one of multiple net types in a given study (Fisheries and Oceans Canada 1990; Jones et al. 2006; Tanasichuk et al. 2014). On the other hand, they offer a much greater capture area, in terms of netted volume of water, than beach seines and miniature purse seines.

Juvenile salmon have been targeted using conventional purse seine nets in nearshore waters since at least the 1950s (Beamish et al. 2003; Neave 1953). Conventional purse seining was one of the first methods used to capture and study juvenile salmon in a marine setting in the northeast Pacific, with the first documented deployments taking place in BC in 1955 (Fisheries Research Board of Canada 1956). Since then, conventional purse seines have been used throughout coastal waters in the North Pacific basin, including the Inside Passage, BC, in the 1960s and 1970s (Argue and Heizer 1971), coastal Hokkaido, Japan, since the 1960s (Mayama and Ishida 2003), the Columbia River estuary and plume during the 1970s and 1980s (Dawley et al. 1985), and Barkley Sound, BC, intermittently since the 1980s (Fisheries and Oceans Canada 1990).

4.2 | Gear Description

A conventional purse seine setup consists of a very large net with a complex array of large lines and attachment points to aid in retrieval and net handling. Its mesh panels include a small vertically tapered bunt that is at the leading (i.e., first deployed) end of the net, a shoulder and main body that are of equal depth, and a vertically tapering wing at the trailing/tow end (i.e., last deployed; Figure 2). Purse rings are affixed to the lead line and are strung through with a purse line that is used to cinch the net upon retrieval. A running line is attached to the bunt end of the net and purse line, allowing for the bunt to be secured to the midline of the vessel and the purse line cinched as the net is retrieved. A tow line is hooked to the wing of the net and used to tow the net once it has been deployed over the stern. The tow line is strung through a block on the boom, moving the tow point from the stern to the midline of the vessel. The net is stored on a large hydraulically actuated drum that is used for net deployment and retrieval.

Net dimensions have varied across surveys, with different lengths, depths, and mesh sizes (e.g., 179 m × 16 m with 3.2 cm body mesh and 1.9 cm bunt mesh (Tanasichuk et al. 2014), 206 m × 11 m with 1–2 cm mesh (Dawley et al. 1985), and 200 m × 20 m with 2.5 cm mesh (Boldt and Haldorson 2004)). One modern net, designed and manufactured in 2024 specifically for juvenile Chinook salmon capture, is 274 m long and 22 m deep in the main body and shoulder, tapering to 18 m in the wing and bunt (Figure 2; B. Volgig pers. comm.). This net, like most others, has a coarser main body and wing mesh (9 cm), than shoulder mesh (2 cm), and bunt mesh (1 cm), and uses a 0.5 m deep strip of coarse (~2 cm) mesh to attach the floats to the bunt mesh. Unlike purse seines used to capture adult salmon, which are larger and less surface-oriented than juveniles, the floats of these nets are tightly spaced (~5 cm between floats) along the entire length of the net to minimise escapes.

Conventional purse seining involves deploying the net from the starboard side of a seiner positioned parallel to shore, with a power skiff holding the bunt end in place as the larger vessel encircles the fish in a U-shaped set. Retrieval entails closing the net while coordinating the skiff and seiner movements, hauling the purse line to secure the catch, and brailing fish from the shoaled bunt. See Supporting Information for detailed deployment descriptions.

4.3 | Other Considerations

The conventional purse seine net is commonly used to target relatively large post-smolt salmon, but its depth allows it to also catch jacks and even some adult salmon. Given its typical mesh size, it is not effective for capturing small juveniles (< ~7 cm). Conventional purse seines can be fished shallower than their depth, and be retrieved safely even after bottom contact because of their sturdy builds and mechanical means of retrieval, but this is avoided when possible to prevent destroying benthic habitats and capture of benthic non-target species.

Conventional purse seine nets can have high bycatch rates and relatively poor selectivity compared with some of the other juvenile salmon capture methods. Large schools of juvenile Pacific herring, juvenile northern anchovy (*Engraulis mordax*), and other small pelagic fishes are often intercepted during sets targeting juvenile salmon (Government of Canada 2020; Tanasichuk et al. 2008; M. Bartlett, unpublished data), as are adult Pacific salmon, spiny dogfish (*Squalus acanthias*), and jellyfish (*Scyphozoa* spp.). In 2024, for example, a single set targeting juvenile salmon in Barkley Sound, BC, captured 85 adult Chinook Salmon, 88 dogfish, and thousands of jellyfish (Fisheries and Oceans Canada, unpublished data).

Although mortality and bycatch rates of juvenile salmon captured by conventional purse seines remain unreported in the literature, to our knowledge, they are likely the second highest of the five capture methods, behind only rope trawl. Importantly, mortality rates are highly variable and dependent on conditions, bycatch, and processing protocols (e.g., how fish are brailed). In general, mortality is minimised when the net is kept deep enough to allow swimming space while fish are being removed from the bunt. During sets with very high catches this requires keeping more of the bunt in the water and demands much more time to retrieve the target species from the net than on a typical set. Although juvenile salmon can often be released alive in a similar manner to that of a miniature purse seine operation, large catches of non-target species in a conventional purse seine can increase stress and mortality of captured salmon (Fisheries and Oceans Canada, unpublished data). As in miniature purse seining, jellyfish are a strong indicator of high salmon mortality in conventional purse seines (Broadhurst et al. 2008). When juvenile salmon are intercepted amongst schools of other fishes, the net is often shoaled up so the juvenile salmon can be brailed from the catches by dipnet. This shoaling increases crowding in the net and can cause larger fish to thrash. Indeed, juvenile salmon caught along with considerable bycatch often show signs of physical trauma, including loss of mucous and scales, discolouration, bloodied eyes, and/or gills fouled with sediment (Patterson et al. 2017; Raby et al. 2015, M. Bartlett pers. obs.).

5 | Microtroll

5.1 | Overview and History

Systematic hook-and-line sampling via towing of small fishing gear, or ‘microtrolling,’ is a recently developed method for capturing piscivorous juvenile salmon through their first year in the ocean (~14–50 cm; Figure 3). Microtrolling uses very small hooks, lures, and attractors (flashers) deployed at multiple depths to catch juvenile coho and Chinook salmon in a broader range of pelagic habitats than most other capture methods (Figure 1). This capture method is very accessible for researchers, as it uses economical gear (~$2000–$3000 CAD for a full set-up) and small vessels (5 m boats have been used, but smaller would be possible).

Hook-and-line gear has been used in commercial salmon fisheries since at least the beginning of the 20th century. The advent of power gurdies in 1918 (Milne 1964) marked the origin of specialised fishing vessels (trollers) capable of deploying gear at multiple depths simultaneously. Orsi (1987) pioneered the use of small lures deployed from a commercial troller for research on juvenile Chinook and coho salmon. This approach was subsequently used to investigate juvenile salmon habitat use (Orsi and Wertheimer 1995) and distribution (Orsi and Jaenicke 1996) in Southeast Alaska. The use of recreational downriggers to deploy multiple small lures from a small vessel to sample juvenile salmon was first employed in the Southern Gulf Islands of the Salish Sea (Duguid and Juanes 2017). Over the following years, the technique was refined through a number of studies investigating the movement (Rechisky et al. 2019), survival (Pellett et al. 2019), habitat use (Duguid et al. 2021; Smith et al. 2024), and trophic ecology (Duguid 2020; Beauchamp 2020) of subadult Chinook. Microtrolling is now the primary capture method for ongoing large-scale projects to investigate overwinter ecology and survival of juvenile Chinook salmon on the West Coast of Vancouver Island, BC (Fisheries and Oceans Canada's “Follow the Fish” Program) and in the Strait of Georgia, BC (Pacific Salmon Foundation and BC Conservation Foundation's “Bottlenecks to Survival” Program; Atkinson et al. 2024).

5.2 | Gear Description

The primary equipment for microtrolling is one or more downriggers to deploy and retrieve the weights required to lower small lures (with hooks) to the desired depth (Figure 2). Although the use of a single downrigger is possible, reduced manoeuvrability because of uneven drag makes the use of two downriggers (one on either side of the vessel) preferable. Electric downriggers designed for recreational fishing for adult salmon (e.g., 1106 Depthpower, Scotty Manufacturing, Sidney, Canada) have typically been employed, but manual downriggers could also be used as a cheaper (but more physically demanding) option. Because of heavy wear from repeated gear deployments, spooling the downriggers with a durable (e.g., 114 kg test) braided microfilament line offers advantages over steel cable, which is prone to fraying and kinking. Weights consist of 5–7 kg lead downrigger balls. Heavier balls enable deeper deployments, reduce the line angle caused by drag, and allow for greater numbers of hooks but are slower to retrieve and put more strain on downriggers.

Microtroll terminal gear consists of “leaders” that are attached to the downrigger cable using stainless steel line snaps at 3–15 m intervals. Each leader consists of a 1–3 m section of heavy monofilament line (18–68 kg breaking strain) and a shorter 0.5–1 m section of lighter monofilament line (2.4–9.1 kg breaking strain) connected to the lure (Rodgers et al. 2022). Most recent microtroll work (e.g., Smith et al. 2024) employs small (14 cm) flashers between the heavy and light monofilament leader sections to attract fish and increase catch rates, as well as a shock-absorbing ‘snubber’ between the heavy monofilament section and the snap used to connect the leader to the downrigger cable. Snubbers may be constructed of marine-grade bungee cord or of surgical tubing with a braided line core to prevent overextension, or purchased (e.g., 30 cm chartreuse Luhr Jensen Great Lakes Snubber (Rapala, Helsinki, Finland)). Lures used for microtrolling have included 2 cm custom-made “flies,” 2.5 cm Apex Trout Killer plastic lures (Hot Spot, Lacombe, Canada), and 2–2.5 cm ‘spoons’ [e.g., Mini G (Gibbs Fishing, Delta, Canada)]. Where nonlethal sampling is desirable (e.g., in tagging studies) original hooks are typically replaced with smaller hooks (e.g., size 10 open-eye siwash hook (Gamakatsu, Tacoma, USA) or size 10–12 caddis fly-tying hooks (Mustad, Gjøvik, Norway)). To maintain sharpness, hooks should be regularly replaced.

Microtroll deployment involves attaching multiple leaders to a downrigger cable as it is lowered, with gear depth and spacing adjusted to target fish across depths and/or to assess catch efficiency or selectivity. Effective operation requires maintaining appropriate gear speed, which can vary with current strength, leader depth, and fish size, and is often gauged from the downrigger cable angle rather than vessel speed alone. See Supporting Information for detailed deployment descriptions.

5.3 | Other Considerations

Microtrolling is highly selective against the more planktivorous species of juvenile salmon, because the movement and speed of microtroll lures generally imitate that of small fish. Juvenile Chinook and coho salmon are more piscivorous than pink, chum, and sockeye (*O. nerka*) (Thompson and Neville 2024), and have been the focus of microtroll studies to date. Microtroll programs conducted in the same region as rope-trawl surveys with large catches of pink and chum have instead caught 99.5% Chinook and coho (Atkinson et al. 2024). Despite the occasional good catch of pink salmon during reconnaissance microtrolling elsewhere, potentially because of exceptionally high densities of this species or regional differences in behaviour, microtrolling seems by far most suitable for Chinook and coho salmon research, and potential catchability biases should be considered even for these species.

Terminal gear likely influences the size selectivity of microtrolling in several ways. Both Chinook and coho salmon experience an ontogenetic shift to a piscivorous diet (Brodeur 1991; Duffy et al. 2010). The small zooplankton, insects, and other prey consumed prior to this transition are difficult or impossible to imitate with microtroll gear, likely leading to some degree of bias against smaller fish. After qualitatively comparing data from overlapping purse-seine, rope-trawl, and microtroll collections, Duguid and Juanes (2017) suggested that the fork length at which Chinook salmon became fully vulnerable to microtroll gear was likely between 12 and 15 cm. The small microtrolling lures likely also select against larger salmon (Orsi 1987), and the small hooks, split rings, and leaders are vulnerable to breaking or bending when larger fish are hooked. Lure size and colour may also influence catchability at certain sizes. All studies employing microtrolling should consider target fish size when selecting the type and size of terminal gear and determining target fishing depths and vessel speed. The implications of potential unavoidable and unmeasurable biases to study design should also be considered.

Depth considerations are paramount for microtrolling. Although it is possible to microtroll very close to shore if the bathymetry is steep, it cannot be conducted in very shallow (i.e., < 10 m) water, limiting access to salmon that are still utilising littoral habitats. Salmon near the surface may also be averse to the deployment vessel and be less catchable than salmon that encounter the gear at depth. In some cases, for example, when abundant coho are present at the surface, depth-specific CPUE estimates may not be very accurate, as fish can be hooked during gear deployment or retrieval. Deployment of small, in-line cameras could facilitate accurate assessment of the depth at which fish encounter the gear. Despite these minor limitations, microtrolling allows simultaneous sampling across a broader range of depths (i.e., from the surface to at least 90 m) than any other gear type.

Microtrolling offers the potential for nonlethal sampling with a strong chance of minimal harm to captured fish, which is important for tagging studies or where sampled fish are of conservation concern. In a small-scale 24-h holding experiment, Duguid and Juanes (Duguid and Juanes 2017) reported only a single short-term mortality out of 66 Chinook salmon caught by microtrolling during their first ocean summer. Another study found that 15% of captured salmon died “early” after being captured by a microtroll, but these fish were also subjected to additional invasive handling procedures, including surgical tagging (Rechisky et al. 2019). The occurrence of fish that die or need to be euthanised because of sustained bleeding from a hook injury or other causes has been below 4% in all years of microtrolling conducted by University of Victoria researchers since 2014 ($n > 4000$; W. Duguid, unpublished data). The most important mortality mitigation measures in microtrolling are: (1) maintaining short set times (i.e., less than 10 min, including deployment and retrieval) to minimise fish stress, and (2) using small hooks, as these reduce the incidence of eye-hooking—the primary serious injury observed (Hinch et al. 2024). An additional benefit of microtrolling is the very low incidence of bycatch. Collectively, Duguid and Juanes (2017), Duguid et al. (2021), and Atkinson et al. (2024) reported a bycatch rate of 0.6%.

6 | Rope Trawl

6.1 | Overview and History

Like purse seines and trolling gear, trawl nets have long been employed in commercial fisheries, and trawls are now commonly used to capture juvenile salmon in the ocean. A trawl net can be towed anywhere from the ocean surface to the ocean floor, depending on the target species, although rope trawls are not designed for bottom contact and are less robust than bottom trawls. Trawl net design and configuration can vary drastically, and different rope trawls can access different habitats and therefore target different species and life stages of Pacific salmon. For example, a small trawl net deployed in the Strait of Georgia, BC, caught mainly 40–120 mm pink, chum, and Chinook while a large trawl deployed just to the north, in Johnstone and Queen Charlotte Straits, caught largely 80–150 mm pink, chum, and sockeye as well as coho up to 230 mm (Figure 3). Because of their complexity and size, trawl nets are expensive and require large vessels and crews. A smaller set-up involves a ~20 m vessel, and the net and doors (described below) cost \$35,000–\$45,000 CAD, plus at least \$5–15 k in sensors (but \$50,000–\$100,000 for real-time measurements). They also require 3–4 people to operate the vessel, 2–3 crew to work the net, and 2–3 biological staff, often with some overlap in the non-biological jobs. Larger set-ups, on the other hand, use a 40–60 m vessel and cost

$140,000–$180,000 CAD for the net and doors, plus $100,000–$200,000 for sensors. These operations typically involve a crew of 5–15 to operate the vessel, 4–6 people to work the net, and 4–6 biological staff, with little overlap.

Rope trawls were first used to capture marine-phase juvenile Pacific salmon in the 1980s by Russian researchers (Karpenko et al. 2004; Radchenko and Mathisen 2004). The Canadian federal fisheries department began fishing with a twin beam trawl in 1990 (Hargreaves and Hungar 1990), but moved to a rope trawl by the mid-1990s because it is not restricted to surface waters, allowing it to fish deeper species like coho and Chinook, and it can be towed faster, allowing for a greater size range to be captured (Beamish et al. 2003). United States fisheries departments also moved to rope trawls at roughly the same time (e.g., Orsi et al. 1997). Since then, rope trawls have been a preferred capture method by federal agencies in Canada and the United States (Freshwater et al. 2024; Thompson et al. 2024) as they can be used even in rough seas and can estimate the absolute abundance of salmon by accounting for the volume of water swept during sampling (Beamish et al. 2003, 2000; Brodeur et al. 2003).

6.2 | Gear Description

Although rope trawl design varies, the general pattern is consistent (Figure 2). The first rope on each side of the net's tow end is called the "sweep", which splits into two or three rope bridles that are connected to a mesh panel wing. The wings connect to a series of successively smaller net funnels, each connected to the next, constructed of successively finer mesh, starting with wide knotless mesh to corral fish into the middle of the net and ending with the fine mesh of the "cod-end" (Anderson et al. 2021; Sala et al. 2019). A fine-mesh (6.5–24 mm) liner is usually placed inside the cod-end to retain juvenile salmon (Davis 2018).

The dimensions of trawl nets used to catch juvenile Pacific salmon are highly variable, with mouth openings ranging from as small as 4 m wide by 4 m deep (Trudel and Neville 2014) to as large as 50–60 m wide by 20 m deep (Davis 2018). Typically, trawls used in coastal waters of the Northeast Pacific Ocean have a mouth opening of 30–40 m wide by 15–20 m deep (Anderson et al. 2021; Fisher et al. 2007). Smaller trawls can be used to catch juveniles in shallow waters and close to shore, and even in rivers (Carr-Harris et al. 2015). Floats on the head rope of the net's opening keep the top of the net above the footrope during towing and help prevent fish escaping above the net (Sheehan et al. 2011). Additional floats can be added as needed (e.g., in rough sea conditions), and weights are also frequently attached to the footrope to help keep the net open vertically during trawling (Sheehan et al. 2011).

The components of trawl gear in front of the net itself are critical parts of the system. The sweeps connect to trawl doors, which hold the net open laterally during towing, and the doors are connected in turn to trawl "warps," the tow lines for the whole system. Trawl door material varies, ranging from steel-reinforced wood (cheaper and lighter) to high-performance steel (more expensive and heavier, but more configurable). Trawl warp material also varies (e.g., braided rope or steel cable). Onboard, trawlers require further equipment. A net drum reels the trawl net into and out of the water, and another pair of drums is usually used for the warps. Yet another drum may be required for cables to net-associated equipment (e.g., echosounder or sensors; see below). The trawl vessel also requires sufficient deck space to sort the catch, and usually a crane for net handling. A roller at the stern of the vessel facilitates the deployment and recovery of the trawl while minimising chafing.

As trawling is expensive compared to other sampling methods, it is recommended to get advice on net design from an experienced fishing master or manufacturer prior to committing to purchasing a trawl net and associated instruments, to ensure that the net is designed effectively to catch the target species. Once a net has been purchased and put into use, design changes will likely impact the consistency of any resulting time series (Wainwright et al. 2019). Performance comparisons and inter-net calibration require considerable effort, as catches are often patchy (Bagley et al. 2015) and uncertainties will affect the detection of changes over time.

Deploying a rope trawl involves coordinated use of vessel cranes, warps, and trawl doors, with tow speed and warp length governing depth and catch efficiency. When targeting juvenile Pacific salmon surveys, rope trawls are towed in the upper 20 m of the water column at relatively high speeds. See Supporting Information for detailed deployment descriptions.

6.3 | Other Considerations

One of the main advantages of trawling is that it can be used to estimate the abundance of Pacific salmon (Beamish et al. 2000). This requires an estimate of the catchability coefficient (i.e., probability of catching a fish in the trawler's path), which is often assumed, as well as the sampled volume of water, calculated in its simplest form as the area of the deployed net's opening times tow distance. The opening can be measured using an attached echosounder, which can also monitor catch as fish swim into the net, or sensors (e.g., depth sensors on the head rope and footrope to calculate opening height; Sheehan et al. 2011). Instruments required to determine net dimensions add to the costs of trawl gear.

Trawling is flexible with respect to sampling conditions, but important constraints affect its suitability for certain sampling locations and target life stages. Trawl nets can be operated in rougher conditions than other juvenile salmon gear, including conventional purse seines (the other commercial-scale gear discussed here), although ocean conditions can nevertheless limit sampling days and influence survey designs. Trawl depth constraints, including the tendency of the trawl to sink before it is towed, can preclude trawling in many habitats where juveniles occur, particularly shortly after they enter the ocean. In a pelagic setting, however, trawling presents a flexible capture method as species' depth distributions can change seasonally as juveniles grow, particularly in the case of Chinook salmon, which tend to be deeper than most species during winter (Beamish et al. 2007; Trudel and Tucker 2013). Nets are rarely towed right at the surface because of waves and currents, though, and trawling does frequently miss juvenile steelhead, which, like juvenile Atlantic salmon (*Salmo salar*)—tend to occupy the top 2 m of the water column (English et al. 2023; Hayes and Kocik 2014).

Of the methods presented here, rope trawls generally result in the highest juvenile-salmon mortality and relatively large amounts of bycatch. Mortality data remain unreported in the literature, but mortalities can be mitigated to some extent by reducing tow times when catches are expected to be high; even then, however, surviving fish are often descaled. In the future, holding tanks may be attached to the cod-end of the net to keep the fish alive during trawling, provided that the number of fish caught does not exceed the volume of the tank (Sheehan et al. 2011; Holst and McDonald 2000; Lacroix and Knox 2005). Although a trawl net's lack of size selectivity, subject to habitat accessibility, can be beneficial when sampling Pacific salmon, it can also result in substantial, but variable, levels of bycatch (Orsi 2007). For example, in the > 3500 juvenile-salmon trawls by Fisheries and Oceans Canada between 2005 and 2014, 33% of trawls had no bycatch, 31% had between 1 and 10 bycatch fish, 20% had 11–99 bycatch fish, and 16% had 100 bycatch fish or more (Fisheries and Oceans Canada, unpublished data). An excluder device can also be added to the trawl net to minimise bycatch of mammals and large pelagic species, such as great white sharks (*Carcharodon carcharias*; Wainwright et al. 2019).

7 | Discussion

The five marine capture methods for juvenile salmon, described above, together form a modern suite of sampling tools for scientific investigation. Over recent decades, this toolkit has been honed to allow all five species of Pacific salmon and other anadromous salmonids to be targeted during their early marine phase, helping to open windows into the "black box" of early marine salmonid ecology. Further refinements and additions will undoubtedly be made, but the existing tools allow juvenile salmon to be studied as they leave freshwater (beach seine), move out into nearshore marine habitats (miniature purse seine, conventional purse seine, and microtroll), and then migrate towards feeding grounds in the open ocean (rope trawl). Together, this set of tools has facilitated surveys of juvenile salmonid migration timing, abundance, and distribution (e.g., Thompson and Neville 2024; Freshwater et al. 2024; Johnson et al. 2019); enabled tag deployment to study migration and survival (e.g., Pellett et al. 2019; Rechisky et al. 2020); allowed screening for pathogens and parasites, in some cases helping to identify the sources of exposure (e.g., Bass et al. 2024; Bateman et al. 2022; Krkosek et al. 2006); and provided insights into patterns of growth, survival, and recruitment (e.g., Bass et al. 2022; Duguid et al. 2021; Godwin et al. 2017; Peacock et al. 2013).

Although the five capture methods are complementary, offering the ability to sample juvenile salmon from their initial ocean entry through to the high seas, they are not interchangeable and it is important to understand their relevant differences and limitations. Each method is suited to particular habitats, life stages, and species, and each has pros and cons with respect to operation, biases, and costs (Table 1). By combining different gear types across different habitats and life-history stages, a research program can build a sampling plan that draws on the strengths of different techniques (e.g., Pellett et al. 2019), and still be able to conduct relevant work at various budget levels.

Clearly, the deployment complexity of the five methods differs greatly, as does the cost, with capture gear itself ranging from a few thousand dollars for a beach seine or microtroll gear to tens of thousands of dollars for a conventional purse seine or rope trawl (Table 1). Two of the methods (conventional purse seine and rope trawl) require commercial-style gear and substantial investment in equipment, staff, and training, and are often restricted to government research programs (e.g., Johnsen and Sims 1973; Tucker et al. 2012). The other three methods (beach seine, miniature purse seine, and microtroll), however, are compatible with lower-budget—though still rigorous—smaller-scale research programs, including one-off projects and graduate research (e.g., Godwin et al. 2018; Duguid and Juanes 2017; Krkosek et al. 2005).

As always, sampling methodology and study design need to be considered together. In addition to the practicalities of deployment, the five capture methods differ substantially both in terms of how they impact captured fish and how fish condition affects catchability. Four of the five methods—beach seine, miniature and conventional purse seine, and microtroll—can all be deployed nonlethally, given sufficient care and appropriate environmental conditions. Indeed, all four methods have been used to deploy passive integrated transponder (PIT) or acoustic tags in studies of survival or migration behaviour (Pellett et al. 2019; Rechisky et al. 2021). Rope trawling, on the other hand, as with many towed gear types (Broadhurst et al. 2006), generally incurs substantial (if not complete) mortalities for juvenile Pacific salmon, although this may change in the future with the use of a live box attached to the cod-end of the trawl (Holst and McDonald 2000; Lacroix and Knox 2005). Rope trawling can, however, be used to generate unbiased samples across a cohort that has already moved to open-water habitats, as the trawl can catch all the salmon in its path. The other pelagic, deeper-water capture method, microtrolling, cannot be used to generate a truly unbiased sample, since microtroll gear targets individuals above a minimum size that are willing to bite a lure, so capture rates confound effort, feeding activity, and life stage (Duguid and Juanes 2017). Thus, to study the disease ecology of deep-water juvenile Chinook salmon, for example, trawl sampling may be necessary to establish pathogen distributions (e.g., Bass et al. 2023) and stock-level correlates of survival (e.g., Bass et al. 2022) while microtrolling can be used to generate individual-level insight into survival or migration effects from pathogens present at the time of capture, for example, via nonlethal screening and tag deployment in released fish (Deeg et al. 2022; Stevenson et al. 2020; Vollset et al. 2021).

All of the juvenile salmon sampling methods described here can be used to generate indices of abundance, but because of the differences involved, data will not be directly comparable. All of the methods described here are habitat-specific, to an extent—for example, beach seines miss the largest individuals that have started to move offshore while rope trawls and purse seines will miss the smallest that are still littoral. Careful consideration must be given to the sampling design for estimating absolute abundance (in the case of rope trawling) or abundance indices for Pacific salmon. In particular, randomised stratified sampling

TABLE 1 | Comparison of five sampling methods for juvenile Pacific salmon in their early marine phase.

Method	Suitable marine habitat	Purchase cost (CAD)	Vessel requirements	Crew requirements	Susceptible species	Size selectivity	Fishing depth	Mortality risk	Bycatch risk	Unique advantages
Beach seine	Coastal inshore and nearshore marine environment	\$2000–\$6000 per net	Single small powerboat (4–8 m)	2–4 people	All species, but pink, chum, and ocean-type Chinook most likely given size selectivity	Mainly small young-of-year salmon (< 10 cm)	Dependent on net depth, ~0–4 m	Minimal in good conditions with proper handling, but high in poor conditions (e.g., strong currents or waves)	Moderate and highly variable, depending on location and season[a]	- Relatively cheap - easy to train non-expert field crew - the only shore-based method
Miniature purse seine	Coastal nearshore marine environment	\$7000-\$10,000 per net	Single powerboat (6–9 m) or powerboat and punt (4–6 m)	3–4 people	All species	Mainly smolts and small to mid-sized post-smolts (~7–15 cm)	Dependent on net depth, ~0–9 m	Low, with specific, rare exceptions (e.g., high jellyfish bycatch)	Low; usually occurs when mistakenly setting on non-salmonid schools[a]	- Relatively cheap - easy to train non-expert field crew - targets fish unable to be caught by other methods (because of depth and/or proximity to shore)
Conventional purse seine	Coastal nearshore and offshore marine environment	\$50,000-\$80,000 per net	Large commercial vessel (~20 m) and power skiff (5–8 m)	6–10 people	All species	Post-smolts (~8–20 cm)	Dependent on net depth, ~0–20 m	High, but variable depending on weather and bycatch	High; other fishes and jellyfish common	Large capture area

(Continues)

TABLE 1 | (Continued)

Method	Suitable marine habitat	Purchase cost (CAD)	Vessel requirements	Crew requirements	Susceptible species	Size selectivity	Fishing depth	Mortality risk	Bycatch risk	Unique advantages
Microtroll	Coastal nearshore marine environment	$2000-$3000 for full set-up	Single small powerboat (5–8 m)	2–3 people	Primarily Chinook and coho	Salmon in their first or second ocean year (~14–50 cm)	0 to at least 90 m	Low; hook injuries likely the most common cause	Very low; occasional non-piscivorous salmon species, but other fishes are rare	- Highly targeted - useful for live sampling & tag deployment - flexible depth range
Rope trawl	Coastal nearshore and offshore marine environment	Smaller: $35,000–$45,000, plus $5000–$100,000 (sensors) Larger: $140,000–$180,000, plus $100,000–$200,000 (sensors)	Smaller: Large vessel (~20 m) Larger: Very large vessel (40–60 m)	Smaller: 7–10 people Larger: 13–27 people	All species, but less effective at capturing surface-level fish (e.g., steelhead juveniles)	Highly variable depending on gear design and configuration	Flexible, near-surface to bottom	Very high, but avenues to reduce in the future	High	- Allows for estimates of abundance indices - adaptable to rough weather conditions - flexible depth range

[a] Bycatch risk for beach seine and miniature purse seine assumes juvenile salmon are being targeted by sight; otherwise (i.e., when ‘blind’ setting) bycatch risk is high.

designs will provide the most robust estimate of salmon abundance (Freshwater et al. 2024; Beamish et al. 2000) within the habitat that the given gear can fish (see discussions of depth and habitat constraints, above). Even in the case of long-term rope trawl surveys, however, model-based abundance estimates are required to ameliorate different sampling methodologies (Freshwater et al. 2024). The features and constraints of the various methods will inevitably factor into study design, but empirical comparisons and careful analysis are required to integrate information from across multiple gear types.

Whether comparing across gear types or considering a single gear type, captures must be interpreted within their ecological context. The example catch data we have used to illustrate the five juvenile salmon capture methods (Figure 3)—data chosen, in our expert opinions, from the most representative sources available to us—reveal this upon consideration. Although these data could be naively interpreted to suggest different species selectivity of the methods, species composition of the catches is typically more indicative 0of geography and salmonid migratory behaviour. For example, we present combined beach-seine data from two geographically distinct sampling programs; one captures almost exclusively pink and chum while the other catches mostly Chinook and coho.

The capture process is only one component of scientific studies on salmonids, and numerous other technologies can be paired with the five methods we have described to maximise the utility of captures. In addition to standard physical analyses, such as stomach-content (Godwin et al. 2018; Atcheson et al. 2012) and various otolith (Freshwater et al. 2015; Quindazzi et al. 2025) analyses, new technology is constantly being developed and deployed in concert with fish capture. We have already discussed tagging methods, including deployment of acoustic and PIT tags in live-sampled fish. These methods are now common in salmon research, and when paired with a range of capture technologies, they can be used to build a picture of fine-scale survival or movement patterns across salmonid life-history stages, from before ocean entry through eventual spawning (e.g., Pellett et al. 2019; Hinch et al. 2024). Molecular DNA- and RNA-based tools are also now widely deployed. We have already mentioned nonlethal pathogen screening and gene-expression assays (e.g., via the recently developed salmon Fit-Chip (Deeg et al. 2022)), but molecular approaches are also widely applied to lethal samples, and a core molecular tool—genetic stock identification—is now standard practice in salmonid work. In addition, environmental DNA (eDNA) is now a widely deployed tool, the full potential and constraints of which have yet to be realised. Approaches that combine eDNA sampling with fish capture can be used to improve the comprehensiveness of surveys (Chevrinais et al. 2025) and to yield insights into unsampled predator, prey, pathogen, and competitor communities (Deeg et al. 2023, 2025), extending the utility of vessel-based surveys. The lack of associated biological data is a key limitation for eDNA approaches, and outstanding questions remain, such as how age class, habitat use, and abundance of salmon contribute to presence/absence or quantitative eDNA results (Ramey et al. 2024; Rehill et al. 2024). As more novel techniques are developed and refined, they will be able to further complement capture-based approaches, and may be useful in integrating information across the various techniques we have discussed (e.g., by informing model-based approaches; Freshwater et al. 2024).

The five capture methods on which we have focused are not the only methods that could be—or have been—used to catch juvenile salmonids. Even within the categories of gear we have discussed, a wide range of variation is possible. In the case of trawl nets, for example, a diversity of configurations has been deployed to sample juvenile salmon. These configurations have ranged from small trawl nets, a few metres across, to large nets, dozens of metres across (Duguid et al. 2019). Net mesh sizes have varied widely, and some configurations have even used two vessels, rather than one, to tow a net (Rice et al. 2011). We do not claim to be comprehensive in our treatment, but rather present an overview of now commonly used capture techniques that together provide the ability to sample juvenile salmonids during early marine residence. The capture methods we have presented have all undergone substantial design changes over time, and in our experience are almost always modified whenever they are applied in a new setting. Such (re)design, development, and tailoring of capture methods will undoubtedly continue.

Beyond salmon on the Pacific coast of North America, information about these five capture methods may be useful for other species and settings. For example, details on these capture techniques may be helpful to researchers studying pink salmon invasions in the Arctic and in Europe (e.g., Sandlund et al. 2019). Although fishery-sourced sampling of Atlantic salmon in the ocean occurs (Teffer et al. 2020), outmigrating smolts can be difficult to capture (K. Vollset, pers. comm.), and the decades of experience catching pink salmon in the Pacific (e.g., Figure 3) are likely to be useful. Beyond the five species of Pacific salmon, some of the information we have presented may help inform efforts to capture other salmonids or nearshore marine fishes that have not received the same level of investment (either in terms of time or money) and for which capture techniques are less developed.

Overall, we have presented a description and discussion of five common, if not comprehensive, gear types for capturing juvenile Pacific salmon. Together, these methods have provided, and continue to provide, insight into the “black box” of salmonids' important early marine life history phase. Depending on the choice of gear, the set of capture methods provides options suited to multiple sampling scales, experience levels, and program budgets. On their own, and in concert with other existing and developing tools, the methods we have described and discussed offer a powerful package for research into the life-history, ecology, epidemiology, and fisheries management of Pacific salmon and beyond.

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Conflicts of Interest

S.C. Godwin is an Editor of Fish and Fisheries.

Data Availability Statement

The data and code for Figure 3 are available here.

Endnotes

[1] Web of Science Core Collection search on 2025-01-07 with search terms ((pacific AND salmon) OR Oncorhynchus) AND (early marine OR outmigrat* OR postsmolt OR post-smolt) NOT ("Atlantic salmon" OR "Salmo salar").

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** faf70039-sup-0001-DataS1.docx.