Coho salmon dependence on intermittent streams

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In February 2006, the US Supreme Court heard cases that may affect whether intermittent streams are jurisdictional waters under the Clean Water Act. In June 2006, however, the cases were remanded to the circuit court, leaving the status of intermittent streams uncertain once again. The presence of commercial species, such as coho salmon (*Oncorhynchus kisutch*), can be an important consideration when determining jurisdiction. These salmon spawn in the upper portions of Oregon coastal stream networks, where intermittent streams are common. In our study of a coastal Oregon watershed, we found that intermittent streams were an important source of coho salmon smolts. Residual pools in intermittent streams provided a means by which juvenile coho could survive during dry periods; smolts that overwintered in intermittent streams were larger than those from perennial streams. Movement of juvenile coho into intermittent tributaries from the mainstem was another way in which the fish exploited the habitat and illustrates the importance of maintaining accessibility for entire stream networks. Loss of intermittent stream habitat would have a negative effect on coho salmon populations in coastal drainages, including downstream navigable waters.

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Intermittent streams only flow during part of the year and are often under-appreciated as aquatic resources. In the western US, over 65% of total stream length is intermittent (Stoddard *et al.* 2005). Whether intermittent streams are included under the jurisdiction of the Clean Water Act (CWA) is not clear. Under the CWA, the definition of "waters of the United States" is vague, leading to substantial debate in the courts and federal agencies about the geographic scope of the statute (Downing *et al.* 2003). Until recently, regulatory interpretations were fairly broad, but a 2001 US Supreme Court ruling (*Solid Waste Agency of Northern Cook County v US Army Corps of Engineers*, 531 US 159 [2001]) re-emphasized the importance of a water body's navigability and its "significant nexus" with navigable waters. In June 2006, the Court issued decisions in two additional cases (*United States v John Rapanos and June Carabell v United States Army Corps of Engineers and United States Environmental Protection Agency*, slip op, 547 US ___ [2006]) that concerned the jurisdictional status of non-navigable waters. An issue that remains unresolved is whether a tributary to a navigable waterbody must be perennial to be included, or whether it can be intermittent. Research documenting the impact of intermittent streams on interstate or foreign commerce in navigable waters, in particular, could influence whether such systems are protected under the CWA.

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Pacific salmon are extremely important to the ecosystems and economies of the Pacific Northwest and support valuable commercial and recreational fisheries. Salmon populations have experienced major declines and local extinctions, due in part to loss of freshwater habitat (Lichatowich 1999; CENR 2000). Coastal coho salmon (*Oncorhynchus kisutch*), which use headwater areas where intermittent streams are common, have experienced declines similar to other Pacific salmon and have been the focus of major restoration efforts (Oregon Watershed Enhancement Board 2005). The potential importance of intermittent streams to coho and other salmonids has been documented (Everest 1973; Erman and Hawthorne 1976; Kralik and Sowerwine 1977; Cederholm and Scarlett 1982; Brown and Hartman 1988), but quantitative data are limited.

Coho salmon commonly have an 18-month freshwater life cycle. Adult coho return from the ocean in late fall, when streamflows increase, and spawn in the upper portions of coastal stream networks. Coho fry emerge in late winter and remain in these streams through the summer and winter before migrating (as smolts) to the ocean the following spring. Juvenile survival during winter flood events is one of the most important factors controlling smolt production (Nickelson *et al.* 1992). High streamflows can physically displace or fatally injure fish unable to find suitable, low-velocity refugia. Larger smolts tend to have higher ocean survival rates (Holtby *et al.* 1990). Thus, both the number and size of smolts affect the size and biomass of adult populations.

In this paper, we quantify the contributions of intermittent streams to coho salmon production in an Oregon coastal watershed. Specifically, we provide estimates of

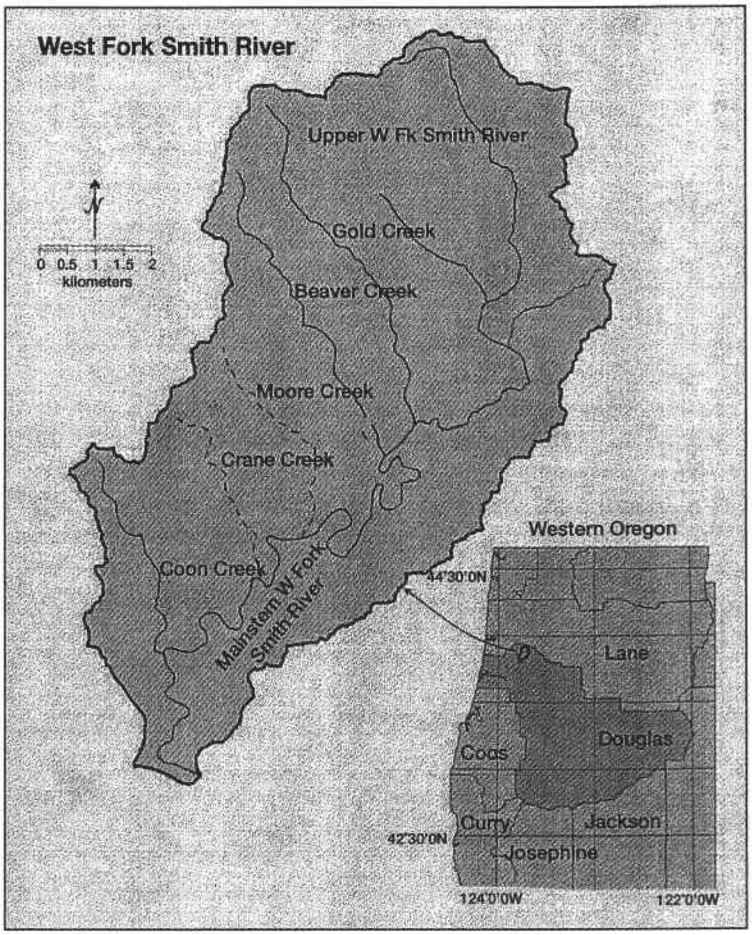

Figure 1. West Fork Smith River watershed and stream network. Intermittent streams are shown with dashed lines.

the (1) proportion of spawning that occurred in intermittent streams, (2) movement of juveniles into intermittent streams, (3) juvenile survival in intermittent and perennial streams during winter, and (4) relative size of smolts produced from intermittent and perennial streams. This effort is part of a larger study that is examining how coho use habitat in the whole stream network of an Oregon coastal watershed during their freshwater life cycle (Ebersole *et al.* in press).

Methods

Since 2002, we have studied survival and movement of juvenile coho salmon in the stream network of the West Fork Smith River (WFSR), a 67 km^2 forested drainage in coastal Oregon (Figure 1). The watershed supports a wild coho salmon population, and produced an average of 24 000 coho salmon smolts per year during 2002–2005 (Jepson *et al.* 2006). The stream network consists of a mainstem and six major tributaries (Figure 1). Two tributaries, Moore Creek and Crane Creek, have intermittent flow during many summers and represent 9% of the total stream network.

Douglas County has measured streamflow continuously on the mainstem WFSR, near the mouth, since 1981. During 2003–2005, we periodically measured streamflow in tributary streams using Swoffer flowmeters (Swoffer Instruments, Seattle, WA) mounted on wading rods (Gordon *et al.* 1992). We compared mainstem and tributary streamflows to establish mainstem threshold values below which intermittent tributaries ceased to flow. We also deployed an array of Onset Stowaway Tidbit (Onset Computer Corporation, Bourne, MA) temperature data loggers in 43 pools in the WFSR stream network (Cairns *et al.* 2005), and made recordings at 30-minute intervals.

Adult coho salmon spawner abundance was calculated from surveys conducted by Oregon Department of Fish and Wildlife (ODFW) personnel, using established field survey protocols (ODFW 2005). Area under the curve estimates were obtained from repeated ODFW surveys throughout the spawning period, and were converted to estimates of abundance assuming a 75% observation probability (Jacobs 2002). Because estimates of observation and associated variance are not available at the stream level (Jacobs 2002), we developed confidence intervals for the estimate of adult coho spawners using intermittent streams. A confidence interval was constructed using the difference between the spawner estimate and the actual number of coho observed during stream surveys to create upper and lower bounds for each stream. This confidence interval corresponds to an assumed range of observation probabilities from 50% to 100%.

Coho salmon juveniles were individually tagged from August to October each year, with 11 mm passive integrated transponder (PIT) tags (PIT Tag Steering Committee 1999). We collected coho for tagging by seining (Ebersole *et al.* in press); fish were recaptured as they left the watershed using a rotary screw trap that was operated continuously (February through June, except for brief periods during extremely large hydrologic events), with a trap efficiency of 33–39% (Jepson *et al.* 2006). Each fish was measured for fork length (distance from tip of snout to indentation in caudal fin) at time of tagging and at time of recapture at the smolt trap. From August to October 2003, we PIT tagged an average of 328 coho salmon (range = 94 to 469) in each of eight reaches located in the upper and lower sections of Crane, Moore, Beaver, and Gold Creeks, and at ten reaches within the mainstem. Each tributary reach was 800 m long and each mainstem reach was 400 m long. In total, 3977 coho salmon were tagged in the mainstem, 1214 were tagged in the perennial tributaries, and 400 were tagged in the intermittent tributaries. During August to October 2004, we established 30 PIT-tagging reaches, spaced systematically across the WFSR stream network. Each reach was 300 m long. We tagged an average of 149 coho salmon (range = 86 to 185) within each reach, tagging a total of 3012 coho salmon in the mainstem, 2010 coho salmon in the perennial tributaries, and 1156 coho salmon in the intermittent tributaries.

We estimated overwinter survival for each tagged group per reach by dividing the number of fish recovered at the rotary screw trap by the number released, after correcting for trap efficiency and the proportion scanned for PIT tags. Variance estimates for overwinter survival were derived using a bootstrap method (a technique for estimating the sampling distribution of an estimator by resampling with replacement from the original sample; Thedinga *et al.* 1994).

Movement of PIT-tagged coho salmon between the mainstem and four tributaries (two perennial: Beaver and Gold, and two intermittent: Moore and Crane) was monitored using stationary PIT-tag monitoring stations positioned in the tributary near the junction with the mainstem West Fork Smith River. All four antennae were in operation for the winters of 2003–2004 and 2004–2005. Each monitoring station consisted of a Destron-Fearing (South St Paul, MN) FS1001 transceiver powered by deep-cycle batteries. A rectangular antenna (3.3 m x 1.2 m) was positioned in the stream and bracketed with weir panels to capture all but the highest streamflows. PIT-tagged fish passing through the antenna field were recorded (PIT-tag identification number, date, and time) continuously on a laptop computer attached to the transceiver. Coho salmon smolts PIT tagged during the autumns of 2003 and 2004 were classified according to the recapture history (where they were located within the stream network during the overwinter period) as (1) mainstem, (2) perennial tributary, or (3) intermittent tributary habitat users.

We used analysis of covariance (ANCOVA; Gotelli and Ellison 2004) to compare the length of PIT-tagged coho salmon smolts recaptured at the smolt trap that used mainstem, perennial tributary, or intermittent tributary stream habitats. We used the year of PIT tagging as a categorical variable to account for between-year variations and coho salmon length at the time of PIT tagging as a covariate to control for variability in initial fish length. Date of recapture at the smolt trap was also included as a covariate, because juvenile coho salmon grow rapidly in the spring, and smolts that out-migrate later in the spring tend to be larger. A model of the two covariates and two factors and all interactions for the ANCOVA were fit using the mixed procedure (PROC MIXED) in SAS 9.1 (SAS Institute; Carey, NC). Model fit, structure, and assumptions were visually assessed using diagnostic plots of predicted values and residuals.

Table 1. Estimated number of days with no open channel streamflow for two intermittent streams

	Summer		
Stream	*2002*	*2003*	*2004*
Moore Creek	65	38	0
Crane Creek	47	21	0

Results

We were able to use streamflow data from the summer of 2003 to establish mainstem streamflow thresholds below which streamflow ceased at the mouth of the intermittent tributaries (Moore Creek and Crane Creek). Using these thresholds, we estimated that one or both intermittent tributaries experienced periods with no flow during approximately 14 of the 24 years of streamflow record, with 6 years having no streamflow in intermittent streams for periods of 15 to 87 days. During our study, two summers (2002 and 2003) had extended periods with no streamflow in the intermittent streams, but during the summer of 2004 streamflow did not cease at any time (Table 1).

During periods with no streamflow, residual pools (Figure 2) were present in Moore and Crane Creeks for a considerable period of time after streamflow had ceased. Water temperature data in intermittent and perennial

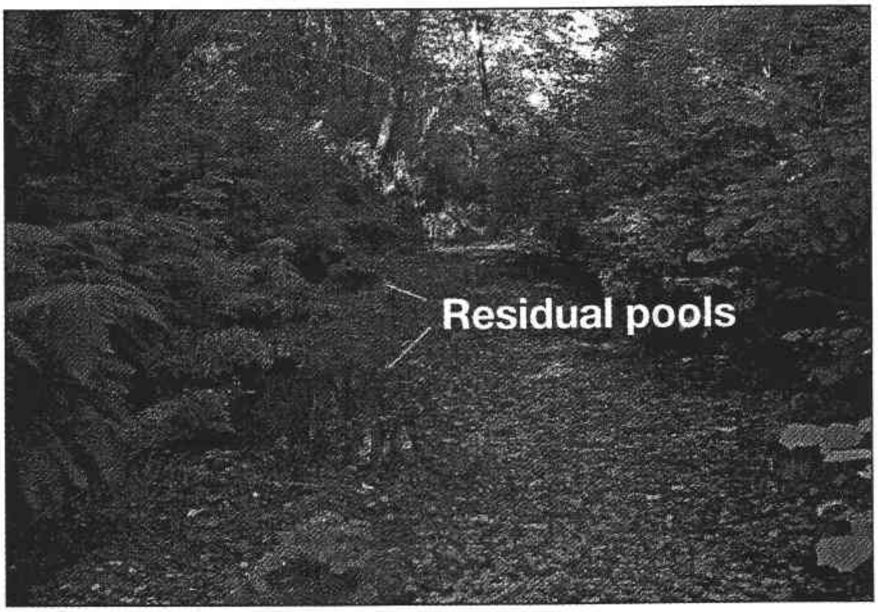

Figure 2. Residual pools during a dry summer in a West Fork Smith River intermittent tributary stream.

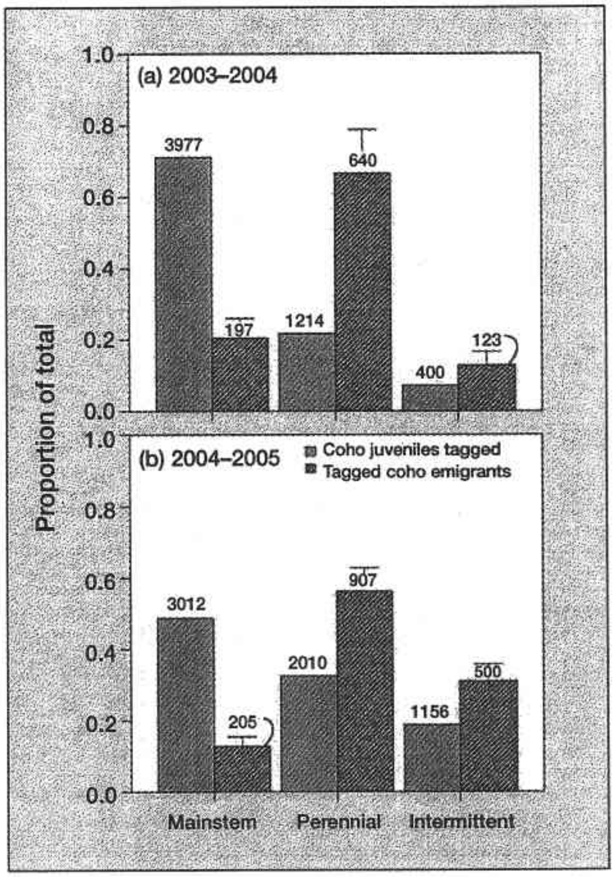

Figure 3. *Proportion of juvenile coho tagged during the fall in mainstem, perennial tributaries, and intermittent tributaries, and the estimated proportion of the same tagged coho emigrating from the West Fork Smith River (based on recaptures at the smolt trap) that were classified as mainstem users, perennial tributary users, or intermittent tributary users. (a) Coho tagged in fall 2003 and captured in smolt trap in spring 2004; (b) coho tagged in fall 2004 and captured in smolt trap in spring 2005. The number of coho comprising the bars are shown above the bars. The standard error of the tagged coho smolt emigrants are shown as whiskers above the bars. Coho smolts that were located during the overwinter period exclusively in mainstem habitats were classified as* mainstem users; *smolts that were originally tagged in or located at some time during the over-winter period in the perennial tributaries were classified as* perennial tributary users; *and smolts that were originally tagged in or located at some time during the over-winter period in the intermittent tributaries were classified as* intermittent tributary users.

streams confirm the presence of residual pools. Diel water temperature patterns were consistent in upper and lower Gold Creek throughout the course of the summer of 2003 and are indicative of perennial streamflow. In contrast, water temperature patterns in Moore Creek show moderately fluctuating temperatures followed by widely fluctuating temperatures, indicative of a dry channel in the lower stretches during that period. We observed cool, constant temperatures, indicative of a residual pool sustained by groundwater, at an upper Moore Creek site from early July into September.

Intermittent tributaries were used by coho salmon in several ways. During 2002–2004, 11% (confidence interval [CI] = 8 to 14%) to 21% (CI = 16 to 26%) of the adult coho salmon spawned in the two intermittent streams. The total number of spawners in the West Fork Smith were 3451, 3728, and 994 in 2002, 2003, and 2004, respectively. We detected 833 (460 in Moore Creek and 373 in Crane Creek) coho juveniles originally PIT tagged in the mainstem at one or more of the intermittent tributary antennas during the winters of 2003–2004 and 2004–2005. Most mainstem-tagged juvenile coho salmon entered the intermittent tributaries during high streamflows in the fall months. Juvenile coho that had been tagged in or used intermittent and perennial tributary streams comprised a higher proportion of the smolts that were recaptured at the smolt trap during the subsequent smolt migration period than coho that had remained in the mainstem (Figure 3). Overwinter survival of coho salmon PIT tagged in intermittent streams during the winters of 2002 through 2005 was similar to survival rates in perennial tributaries, but higher than mainstem survival rates in all years (Table 2).

After accounting for variation in the length at tagging and smolt migration timing, our statistical analysis showed a significant difference in the length of coho smolts that used perennial (mainstem and tributary) and intermittent tributary habitats ($F_{2,861} = 9.06$, $P = 0.0001$) during 2004 and 2005. Significant interaction terms complicated direct interpretation of the model, so we evaluated differences in smolt length at lower, middle, and upper values of the covariates used in the model for all habitat user classes and cohort years resulting in a total of 54 comparisons. Statistical significance of the differences was set at a P value < 0.0009 (0.05/54 pairwise tests).

Coho smolts that used intermittent tributaries were larger than coho smolts that used perennial tributary habitats during both 2004 and 2005 (Figure 4). This difference was statistically significant throughout the smolt migration period in 2004, but only during the middle portion of the 2005 smolt migration. Coho smolts that used intermittent tributary habitats were larger than coho that used the mainstem during 2004 (Figure 4). This difference was statistically significant for the middle and end of the migration period. On the other hand, coho smolts that had used intermittent tributary streams were significantly smaller than coho

Table 2. Estimated overwinter survival (%) of PIT-tagged juvenile coho salmon in the West Fork Smith River drainage by stream type

Stream type	*2002-03*	Winter *2003-04*	*2004-05*
Intermittent streams	13	21	41
Perennial streams	12	25	38
Mainstem	9	14	14

smolts that had used mainstem habitats through the early and middle portions of smolt migration during 2005.

Discussion

Although intermittent streams experience periods with no streamflow, they provide valuable habitat for juvenile coho salmon. In the WFSR network, Moore and Crane Creeks provided both spawning and rearing habitat for coho salmon. Even during years in which the streams had extended periods with no streamflow, they accounted for an important component of the coho smolts leaving the WFSR watershed (Figure 3). In addition, overwinter survival rates for juvenile coho originally tagged in the intermittent streams were higher than survival rates in mainstem habitats and equivalent to survival in perennial streams (Table 2). How can intermittent streams produce coho smolts even though the streams have extended periods with no streamflow?

One reason is that if periods without streamflow are not too long, residual pools (see Figure 2) can sustain juvenile coho until streamflow resumes with autumn rains. May and Lee (2004) found that in Oregon coastal streams, gravel-bed pools sustained by hyporheic flow were able to carry over coho juveniles during the summer, but the pools experienced a decrease in juvenile coho abundance of 36% because of fish mortality caused by pool drying.

We observed numerous residual pools in Moore Creek and Crane Creek during late summer periods, when no streamflow occurred at the mouth of the streams. Water temperature patterns in the pools were consistent with two types of pools in Oregon coastal streams identified by May and Lee (2004), which may have the potential to maintain water during periods with no streamflow. One pool type is comprised of gravel pools with bedrock contact for which hyporheic flow is the primary source of water during dry periods. Lower Moore Creek was a location that featured this type of pool; in this case, the pool dried out during late summer, as evidenced by the wide fluctuations of temperature, typical of air temperature fluctuations. Bedrock pools that received no surface flow from upstream but are recharged by groundwater from fractured bedrock represents another class of pools. These have relatively low water temperatures and little diurnal fluctuation.

The importance of residual or isolated pools in sustaining fish populations in intermittent streams has been documented in a wide range of settings. Closs and Lake (1996) found that *Galaxias olidus*, a small salmoniform fish, was able to survive in scattered small pools throughout the upper reaches of an intermittent stream in Australia. Pires *et al.* (1999) noted that isolated pools were important habitats for fishes in intermittent streams in Portugal. Labbe and Fausch (2000) reported that, during summer drought, permanent pools were important habitats for the Arkansas darter (*Etheostoma cragini*) in two intermittent streams in the Colorado plains.

Another reason that WFSR intermittent streams were able to produce coho smolts was that some coho tagged in the mainstem moved into intermittent tributaries when streamflow resumed in the fall. Once the intermittent tributaries resumed streamflow, coho that had survived in the residual pools or immigrated in the fall probably experienced lower densities and higher food resources compared to coho in perennial tributaries. We hypothesize that this provides higher survival and growth of coho that overwinter in intermittent streams via release of density dependence (Chapman 1966). Our observation that, following a particularly dry summer in 2003–2004, coho smolts from intermittent streams were considerably larger than smolts that used perennial habitats (Figure 4) is consistent with this hypothesis.

In conclusion, WFSR intermittent streams provided both valuable spawning and rearing habitat for coho salmon. Residual pools in intermittent streams provided one means by which juvenile coho could survive during dry periods. Movement of juvenile coho into intermittent tributaries from the mainstem was another way in which juvenile coho exploited intermittent stream habitat, and illustrates the

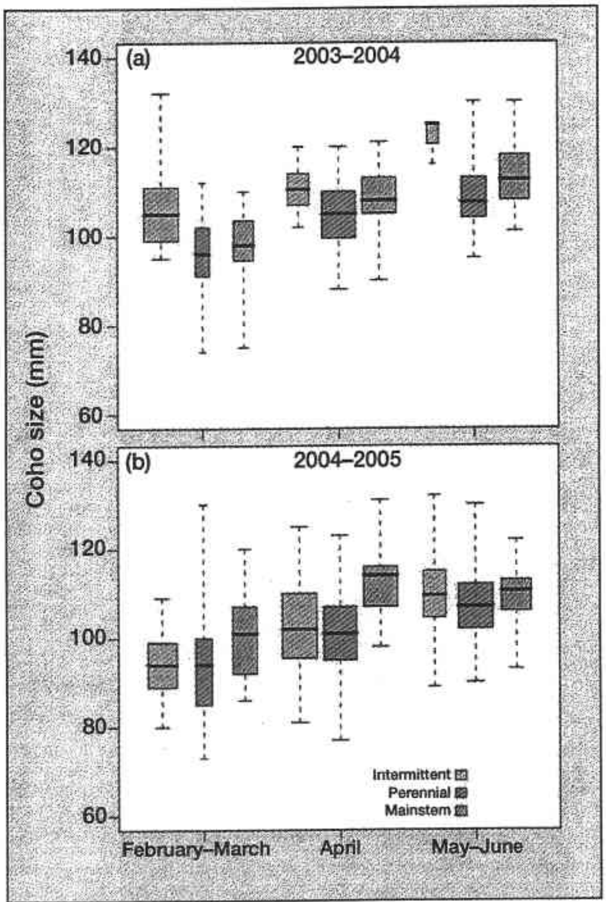

Figure 4. *(a) Date of capture and length of coho smolts originally tagged in 2003 and recaptured at the smolt trap in 2004, and (b) originally tagged in 2004 and recaptured in 2005. The width of the box is proportional to the number of coho used to generate the box.*

importance of maintaining accessibility of entire stream networks to coho. Under particularly dry conditions, smolts that overwintered in intermittent streams were larger than those from perennial streams. Low-gradient intermittent streams, such as those in the WFSR, are common in watersheds with sedimentary bedrock, which comprise the prime coho salmon habitat among Oregon coastal drainages. Our results demonstrate that loss of intermittent stream habitat would have a negative effect on coho salmon populations in coastal drainages, and in general, our study illustrates the important role that intermittent streams can play in maintaining the biological integrity of navigable waters. Research and methods that demonstrate these interconnections are critical in helping regulators and policy makers respond to recent US Supreme Court decisions.

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