Developing a Foundation for Fish Migration Barrier Removals in California's Largest Undammed River: an Application of FISH*Pass* in the Smith River

Prepared for the CA Fish Passage Forum

By Ross Taylor and Associates

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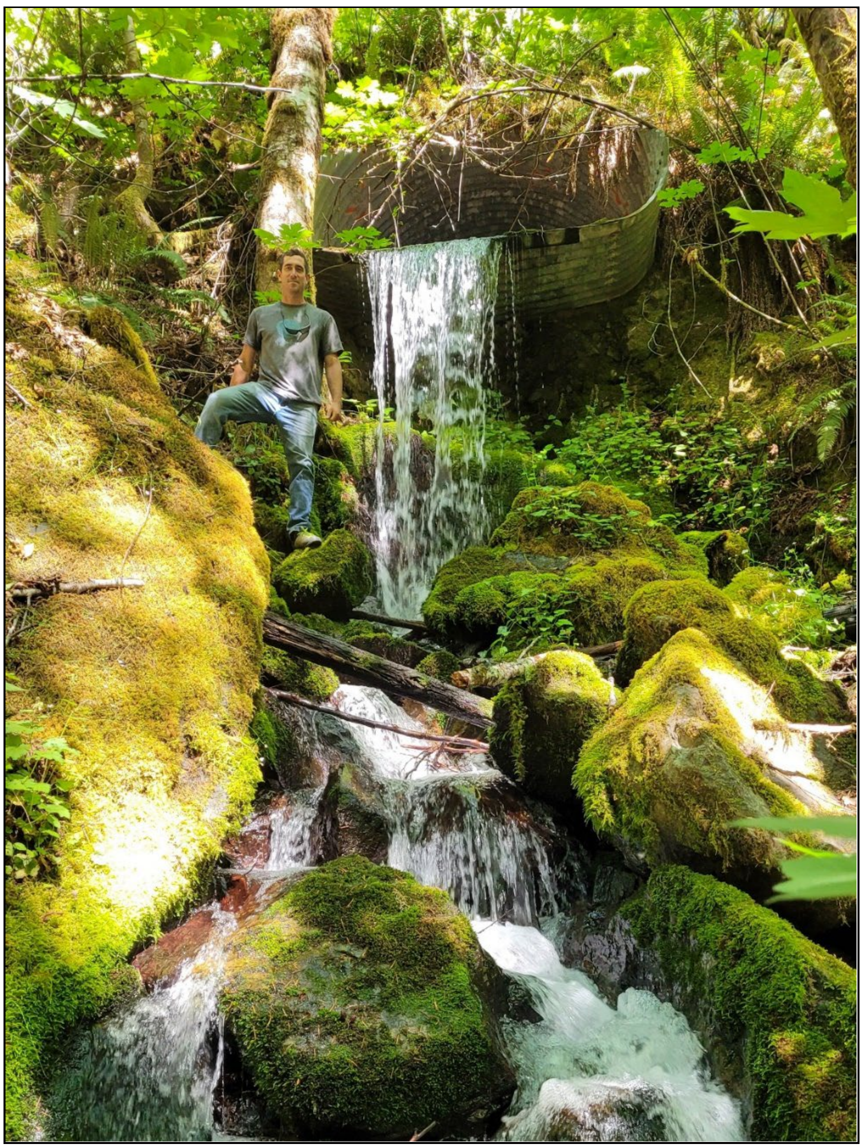

Impassable culvert on a tributary to Knopti Creek, Middle Fork Smith River

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Introduction:

The California Fish Passage Forum has invested considerable time and resources in the development of FISH*Pass*, a decision support tool that uses an optimization model (OptiPass™) to assist in identifying and prioritizing the treatment of migration barriers. FISH*Pass* uses barrier information from the California Passage Assessment Database (PAD); the model also accounts for spatial layout of the barriers in the stream/road network, cumulative barrier passability, potential upstream habitat, and optionally, estimated treatment costs.

This project leverages the effort invested in FISH*Pass* and applies it to a real-world example to develop an optimized list of barrier removals in one of California's most important watersheds for the conservation of wild anadromous fish, the Smith River. The Smith River was selected for testing FISH*Pass* because it's a relatively large watershed with several hundred potential barriers that are owned or maintained by a relatively small number of entities, which made gaining access more manageable. We also felt that the number of sites with unknown passage status within the PAD was a manageable amount to field verify.

The primary objective of this project was to apply FISH*Pass* in the Smith River using updated data resulting in a list of priority barriers to remediate in the watershed at variable levels of effort. Several reports and recovery plans state that the identification and treatment of anthropogenic migration barriers within the Smith River watershed is a high-priority restoration action (Voight and Waldvogel 2002; CDFW 2004; SRA 2018). Beyond this primary objective, this project also provided the opportunity to learn more about FISH*Pass* and gain insights on how to improve the model's functionality and utility. Additional benefits of this project included an assessment of FISH*Pass* model performance, updates to input data by ground-truthing PAD records; which will potentially identify approaches to strengthen the FISH*Pass* application for future use within the Smith River as well as other drainages in California.

Methodology:

First steps included reviewing existing PAD data for the Smith River and conducting field reconnaissance of locations listed as either "unassessed" or "status unknown" and identifying potential barriers that were not included in the PAD. At some existing PAD locations, no obvious barrier or structure existed, and these sites were recommended for removal from the PAD. A qualitative, first-pass level of passability was made at each site during the field reconnaissance to provide scores to enter into FISH*Pass*. Site visits also allowed cursory evaluations of upstream habitat and to evaluate the modeled layer of potential anadromous habitat which is used in FISH*Pass* ("Baseline Fish Habitat" layer). Ross Taylor and Associates

(RTA) worked closely with Damon Goodman (Cal Trout) in conducting the site visits in June and August of 2021. Prior to conducting these site visits, the Smith River's PAD data were filtered to remove all crossings on non-fish bearing channels; primarily these were small cross-drainage pipes on Highway 199. For site visit purposes, we also filtered-out natural features such as cascades and waterfalls, to pare down the list of sites to visit to human-made structures, however during the course of our site visits several natural features were incidentally examined. In the field, we used the Fish Passage Forum's Fish Passage Incidental Report Application (Fish Passage Incidental Report - Version 3). This Esri Survey123 application was used to electronically enter survey data on a tablet while in the field. The application was also linked to a georeferenced map that allowed us to view PAD data while in the field and to collect GPS location data for sites not included in the PAD. A one-day trip was made to the Smith River watershed on June 4, 2021 to field-test the electronic Fish Passage Incidental Report form and solidify our field methodology. Subsequent site visits were conducted by Taylor and Goodman on June 28-30, 2021 and August 25-27, 2021.

Once the site visits were completed, the data collected were used to either: remove a PAD record from our site list (if no structure was present), enter the type of crossing encountered (for passage status unknown or unassessed sites), provide a qualitative barrier status (for passage status unknown or unassessed sites), and/or add a new site to our site list (with a temporary PAD ID# for the FISH*Pass* test). At this point, site data from other sources were reviewed to ensure these locations were properly entered into the PAD and our site list; most of these sites were recently assessed for fish passage by the Smith River Alliance (SRA 2018).

For each site to be run through the FISH*Pass* test, the following information was included in the spreadsheet: PAD ID#, passability score, cost estimate, PAD ID# of the next downstream crossing, and length of potential habitat available immediately upstream of each barrier. Passability scores in FISH*Pass* default to 0.0 for total barrier, 0.5 for partial/temporal and 1.0 for not a barrier. Partial/temporal scores were also modified when FishXing assessment results were available, with the idea to test model sensitivity by comparing FISH*Pass* results between partial/temporal sites scored as 0.5 versus scores fine-tuned with FishXing results. Sites with FishXing analyses included Del Norte County-maintained sites and State Parks sites assessed by RTA, CalTrans-maintained sites assessed by Humboldt State University, and County and private sites within the Smith River Plains assessed by the Smith River Alliance (SRA).

For anadromous salmonids, users of FishXing typically assess passage for three age-classes: juvenile fish (age-0 and age-1), resident-sized trout and adult salmon and steelhead. For the California Department of Fish and Wildlife's Restoration Manual, total passability scores for assessing passage at road crossings included FishXing results for each of the three age-classes of anadromous salmonids (Taylor and Love 2003). For the CDFW Restoration Manual, scoring for each age class was based on 20% increments of the FishXing results, as follows. Score of 0 = meets passage criteria on >80% of the range of migration flows; score of 1 = meets 79-60% of passage criteria; score of 2 = meets 59-40% of passage criteria; score of 3 = meets 39-20% of passage criteria, score of 4 = meets passage criteria on <19% of the range of migration flows. Please note that for the CDFW passability scoring, a higher number means less passage; whereas for FISH*Pass* scoring, a lower number means less passage.

A similar, by age class, approach was also applied to the FISH*Pass* test in the following manner:

- Partition the FISH*Pass* unimpeded passage total score of 1.0 amongst three age classes of anadromous salmonids. Adults = 0.4, resident trout = 0.3 and juveniles = 0.3.
- For adults, passage scores: 0.4 = meets >75% passage criteria; 0.3 = meets 74-50% passage criteria; 0.2 = meets 49-25% passage criteria; 0.1 = meets <25% passage criteria.
- For resident trout-size, passage scores: 0.3 = meets >80% passage criteria; 0.25= meets 79-60% passage criteria; 0.2 = meets 59-40% passage criteria; 0.15 = meets 39-20% passage criteria; 0.1 = meets <20% passage criteria.
- For juvenile salmonids, partial passage scores: 0.3 = meets >80% passage criteria; 0.25= meets 79-60% passage criteria; 0.2 = meets 59-40% passage criteria; 0.15 = meets 39-20% passage criteria; 0.1 = meets <20% passage criteria.

On 2/28/22, Taylor and Goodman met with Brett Holycross (PSMFC) to review the Smith River passage data and discuss a range of test run scenarios to consider. These scenarios included:

- Run FISH*Pass* using coarse passability scores of 0.0, 0.5 and 1.0.
- Run FISH*Pass* using passability scores based on FishXing results. Compare these results to the previous run to evaluate model sensitivity. Depending on the sensitivity analysis of passability scoring, select the appropriate data set to use for the next two scenarios.
- Run FISH*Pass* using the current 2021-2022 status of all sites, which included **17** remediated sites.
- Run FISH*Pass* with barrier status as if no recent (post-1998) sites were remediated. Compare these results with how barrier remediation actually occurred. Were high-priority sites property identified by other ranking or project-selection processes?
- Run FISH*Pass* from the publicly accessible version of the model, which employs online PAD data that does not reflect the clean-up effort completed by Taylor and Goodman in 2021. The results of these runs were then compared to runs completed using the cleaned-up site list from Taylor and Goodman's 2021 field assessments.

- For each of these described scenarios, FISH*Pass* runs were made in a stepwise progression by setting the number of sites in the Fixed Limit input as one site, two sites, three sites, five sites, seven sites, 10 sites, 15 sites, 20 sites and 25 sites.

Cost estimates assigned to each PAD site were derived from post-construction project data collected and updated by the PSMFC and the Fish Passage Forum. While these values may not accurately portray total project costs (planning, engineering, permitting, monitoring), these values provided a relative spread of costs to assign to various barrier types and various road types. Please note that channel width was originally employed, but generated inconsistent results, whereas road type provided more consistency to cost estimates. The cost estimates used for the Smith River test of FISHPass were the following:

1. Modification of an existing fish passage facility = $82,000.
2. Treatment of an unpaved road = $291,000.
3. Treatment of a paved road = $613,975.
4. Treatment of a tide gate = $256,250.
5. Treatment of a dam = $110,000 per vertical foot of dam height.

Prior to conducting test runs of FISH*Pass*, the following GIS methods were employed with the site data. Brett Holycross (PSMFC) performed these GIS analyses with the revised PAD dataset for the Smith River.

<u>Hydrography:</u> The public version of FISH*Pass* uses a Baseline Fish Habitat (BFH) layer at a 1:100,000 scale hydrography. For the FISH*Pass* test, a decision was made to push the Baseline Fish Habitat product out to a higher-resolution hydrography. NHDPlus High-Resolution (NHDPlus-HR, Source: USGS) flowlines for the focus area were copied into a new dataset, and were supplemented with additional flowlines to capture additional stream reaches, as necessary, to capture known barriers and potential habitat. Those streams for which there were data for BFH (1:100,000 scale) were coded as such (using a combination of proximity analysis, and visual QA/QC), and other NHDPlus-HR streams with modeled streamflow above the calibrated minimum flows for the Smith subbasin were considered for inclusion in the potential habitat layer. The flowlines were modified to create a consistent downstream flow direction, and were developed into an ArcGIS “tracing network” for subsequent analysis steps. Holycross also manually added stream sections beyond the higher resolution product to capture more salmonid habitat, partially associated with new the PAD sites generated from the 2021 ground-truthing site visits. The result of these efforts to update the Baseline Fish Habitat layer and high-resolution hydrography was an increase of potential anadromous salmonid habitat in the Smith River from approximately 400 miles to 450 miles.

Barriers: All barriers within the scope of the project were snapped to the Hydrography, and attributed with a stream ID and a measurement field. New barrier records from the field surveys were assigned temporary PAD_IDs for subsequent processing steps. Visual QA/QC were performed on the snapped barrier locations, and adjustments were made, as necessary, to accurately depict the stream/potential habitat network and barriers impacting it.

The barriers were run through a series of geoprocessing steps using ModelBuilder (Esri, ArcGIS Pro 2.8), in order to create attributes required by the OptiPass/FISH*Pass* analysis. The first attribute relates to the quantity of potential habitat available immediately upstream of each barrier in the tracing network ("Upstream Miles"). Each barrier is attributed with only the length of the immediate upstream network (in miles), until another barrier is reached, or until the end of the tracing network. The second attribute developed for each barrier through these geoprocessing steps is the ID of the nearest downstream barrier ("DS_ID"), if present.

Once the site data were fully processed, the next step was to execute the test runs in the statistical computing and graphics program, R. We had to use R instead of FISH*Pass* to execute the test runs because R allowed us to independently make the required revisions to the PAD data generated from our Smith River site visits. The test runs were made by Goodman and results were shared via Excel spreadsheet files. An important distinction of the results generated by R and by FISH*Pass* must be clarified. When the same input data were used, both applications generated the same lists of PAD sites for the runs made in the stepwise progression of number of sites (as previously mentioned on page 4). However, the R application's results only reported and summarized upstream habitat gains, and were unable to produce the cumulative passability metric generated by FISH*Pass*, even though R was computing this metric in the background while running the scenarios. The cumulative passability metric accounts for all likely habitat gains in a channel network, including the potential effects of untreated sites when one or more other sites are treated. Figure 1 is an example of how FISH*Pass* solved for maximum cumulative passability in Tillas Slough and Delilah Creek in the lower Smith River. Again, regardless of R's inability to report cumulative passability, test run results in both R and Fish*Pass* selected the same list of barriers from the PAD. Thus, comparing site selection was the best available metric for this test of FISH*Pass* in the Smith River. If desired for future applications in other watersheds, R could be re-programmed to report cumulative passability, which was unfortunately outside the scope of our project.

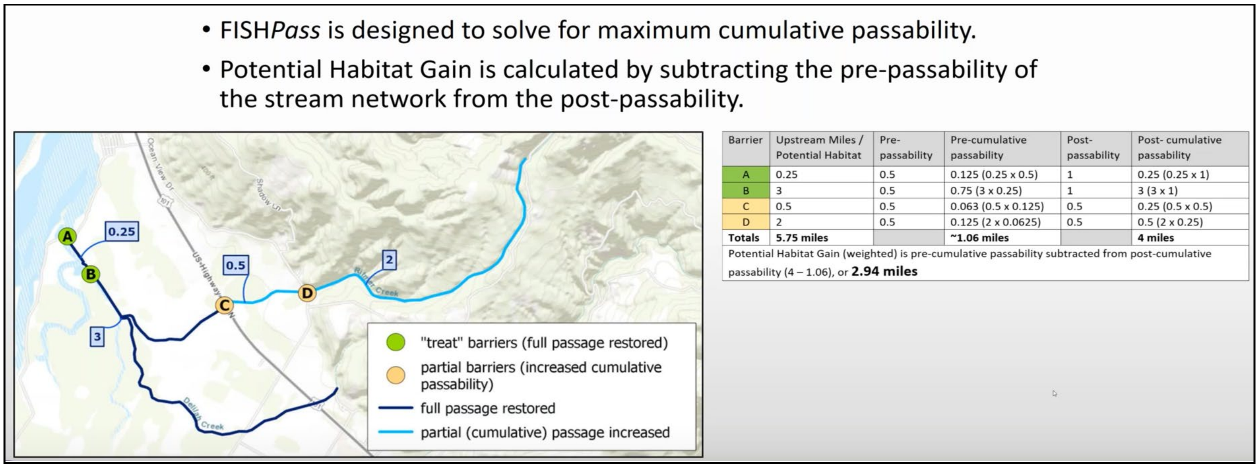

Figure 1. Graphic example of a Fish*Pass* computation of cumulative passability.

Results – Smith River Site Visits

In seven days of field work during the summer of 2021, Taylor and Goodman conducted site visits at 82 locations throughout the Smith River watershed. Forty-one sites had PAD ID numbers and were identified as either "unassessed" or "passage status unknown". An additional 41 locations, not identified in the PAD, were inspected that had some type of human-made structure. Site visits were generally conducted from upstream to downstream, starting in the tributaries of Griffin and Knopti creeks near the Oregon border. The South Fork of the Smith River and its tributaries included inspection of numerous sites within the Hurdygurdy Creek sub-basin.

Assistance with site visits was provided by the Smith River Alliance (SRA), California State Parks, U.S. Forest Service, and the Tolowa Dee-ni' Nation/Smith River Rancheria. Access to private property in the Smith River Plains and to California State Parks was facilitated by Marisa Parish, who is employed by both SRA and State Parks. We also coordinated with Matt House at Green Diamond Resource Company to access their holdings within the Smith River, primarily within the Rowdy Creek and Peacock Creek drainages.

Of the 41 locations identified within the PAD as either "unassessed" or "passage status unknown", our field reconnaissance surveys determined:

- At 20 locations, bridges were observed that provided unimpeded fish passage.
- At eight locations, no human-made structure that would constitute a stream crossing or an impediment to fish passage was observed. We recommend that the status of these is updated in the PAD database; these were PAD ID #'s: #720865, #720866, #720996, #720999, #721002, #721404, #721599, #761561.
- At five locations, natural features were investigated that the PAD had flagged as needing passage assessments. At two locations, no passage constraints were observed

(#721398, #721404). We recommend that the status of these two locations is updated in the PAD. At the remaining three locations we observed a delta fan and two cascades/boulder jumbles that may be partial or temporal migration barriers, depending on flow levels.

- At two locations, the PAD had identified unassessed dams. We found a decommissioned dam on Monkey Creek (#721153) with no fish passage issues and on Hurdygurdy Creek (#721606) there was no structure or remains of a dam found. We recommend that the status of site #721606 is updated in the PAD.
- At five locations, culverts were observed. At #736717, this site on a tributary to Nickerson Creek was replaced in 2020 and provides passage. Sites #761539, #765252, #765253, and #765254 were all considered partial barriers and should be surveyed and evaluated with FishXing.
- Finally, one location (#720928) was identified in the PAD as an unassessed diversion on Rock Creek. At this location, we found a screened diversion intake pipe with a hand-placed rock weir diverting the streamflow towards the intake. We qualitatively assessed this site as providing partial passage.

During the Smith River field work, we also discovered 41 stream crossings that did not have any type of PAD record. For our FISH*Pass* test project, these sites were given temporary, six-digit PAD numbers, #800000 through #800040. Our field reconnaissance surveys determined:

- At 22 locations, there were bridges and 21 of these were considered to provide unimpeded fish passage. At one site, Savoy Creek/Rowdy Creek Road (#800015) , steep, rip-rapped banks severely constricted channel width and was considered a partial barrier. This site was on Green Diamond property.
- At 14 locations, culverts were observed. Eleven of these sites were in the Mill Creek watershed, all on roads managed by California State Parks, including seven sites within the Mill Creek campground. Of the 11 State Park sites, four were considered complete barriers, six were considered partial/temporal barriers, and one was considered passable. California State Parks is tentatively scheduled to conduct site surveys and FishXing analyses at these sites during the fall of 2022. The three remaining culverts were on U.S. Forest Service roads , two were complete barriers on Knopti Creek Road (FS18N07), but had limited upstream habitat. The third culvert was on FS17N38 in Hurdygurdy Creek and had failed; this site was considered passable.
- Three sites on FS17N38 had failing Humboldt-style crossings on unnamed tributaries in the headwaters of Hurdygurdy Creek. One of these sites was considered a partial barrier and the other two were considered passable. These tributaries had limited upstream habitat for salmonids; however, fish were observed during the site visit.
- One site on FS17N38 had a ford crossing and was considered passable.

- One site on Savoy Creek Road (Green Diamond property) was at the end of the actively used road and the culvert had been removed. This site was considered to be passable.

<u>Results – Smith River Revised PAD Site List</u>

For the test of the FISH*Pass* model, we had a total of 197 PAD locations with some type of human-made structure. The 197 sites were owned/managed by Cal Trans, California State Parks, U.S. Forest Service, Del Norte County, Green Diamond Resource Company, Tolowa Dee-ni' Nation, Alexandre Family Farm, Reservation Ranch, and other private landowners. Of these 197 locations, 126 sites were identified as "not a barrier" and currently provided fish passage (this included 17 remediated sites). The remaining 71 sites were classified as either temporal, partial or total barriers, or as unknown (due to lack of access to private property). For the test of FISH*Pass*, the seven sites classified as "unknown passage status" were given a partial passage score of 0.5. These 71 sites were the focus of the FISH*Pass* tests.

The 17 sites where remediation efforts have occurred were:

1. PAD #705649 – Unnamed tributary to East Fork Mill Creek.
2. PAD #705873 – Clarks Creek on Walker Road.
3. PAD #705874 – Peacock Creek on Tan Oak Drive.
4. PAD #707134 – Dominie Creek on Highway 101.
5. PAD #707135 – Ritmer Creek on Highway 101.
6. PAD #707142 – Little Mill Creek on Highway 197.
7. PAD #707143 – Sultan Creek on Highway 197.
8. PAD #713195 – Griffin Creek on Oregon Mountain Road.
9. PAD #720982 – Peacock Creek on Highway 101.
10. PAD #721315 – Unnamed tributary to East Fork Mill Creek.
11. PAD #721402 – Hamilton Creek on Picnic Road.
12. PAD #722112 – Cedar Creek on Douglas Park Drive.
13. PAD #732426 – Yontocket Slough on Pala Road.
14. PAD #736715 – Unnamed tributary to Nickerson Creek on Howland Hill Road.
15. PAD #736716 – Unnamed tributary to Nickerson Creek on Howland Hill Road.
16. PAD #737662 – Tyron Creek at Tyron Creek Slough
17. PAD #765526 – Hurdygurdy Creek on South Fork Road.

<u>Results – FISH*Pass* Runs with Coarse Passability Scores versus FishXing results</u>

For the Smith River, 24 of the 71 sites (or 34% of the sites) had full FishXing passage evaluations. The FISH*Pass* runs using coarse passability scores versus passability scores generated from FishXing were quite similar, as depicted by the number of miles of upstream habitat that would be opened-up (Table 1). Five of the nine test runs resulted in the same amount of opened-up habitat (Table 1). A possible reason for the similar results was the relatively small number of sites with FishXing analysis information, because even in running this scenario, 66% of the sites with coarse passability scores were still used within the FishXing test run.

The 24 sites with FishXing scores included 18 sites with passability scores lower than 0.5, thus the FishXing analyses determined that these sites were more severe barriers than the coarse score of 0.5. These 18 sites included five sites with passability scores of 0.1, three sites with passability scores of 0.2, three sites with passability scores of 0.3, and seven sites with passability scores of 0.4. The remaining six sites had FishXing scores higher than 0.5, meaning they were less severe barriers than the coarse score of 0.5. These sites included two sites with passability scores of 0.7 and sites with scores of 075, 0.8, 0.85, and 0.9.

The final scenario to evaluate the sensitivity of FishXing passability scores with the Smith River data was setting all sites that lacked a FishXing evaluation as “no barrier” with scores of 1.0 and then conducting two FISH*Pass* runs with the remaining 24 sites – one run with coarse scores of 0.5 and one run with the FishXing values. These final two runs produced the same results as the previous coarse versus FishXing with all 71 sites included (Table 1).

O’Hanley (2011) discussed that an additional benefit of an optimization model approach (such as FISH*Pass*) was its low input data requirements, with no attempt to incorporate the variable effects that barriers have on fish passability (by species or age-class). He contended that quantitative passage evaluation data were expensive to collect and most watersheds lacked these comprehensive data sets (O’Hanley 2011). While these are valid statements, comprehensive passage evaluations with hydraulic models such as FishXing provide passability information tailored to specific fish species and age-classes of interest, as well as identification of the types of issues impeding or preventing passage that, in turn, often assist in designing appropriate treatments. In addition, submission of proposals to major restoration funding sources in California typically require the results of a FishXing analysis to better understand the severity of the barrier and the site-specific issues creating the migration barrier.

At this point, our recommendation is to use FishXing data when available, yet coarse scores should still produce reasonable results (even when combined with limited FishXing data). Further analyses using FishXing may be warranted, but are beyond the scope of this Smith River test project. Ideally, selecting a watershed or sub-basin with comprehensive fish passage assessments and FishXing evaluations completed for all of the crossings. For example, RTA conducted a comprehensive assessment of the Corte Madera Creek watershed in Marin County and all sites were evaluated with FishXing. The influences of FishXing passability scores may also be different in a watershed with a higher density of crossings and/or a more complex channel network, thus a watershed such as the Russian River may provide better insights to FishXing's utility in improving FISH*Pass* analyses.

Finally, in a real-world application of FISH*Pass*, the availability of FishXing scores for closer review may assist during the process of selecting sites for remediation. For example, let's say a 10-site FISH*Pass* run was made and this group of sites consisted of a number of sites with partial passability, a 0.5 score in FISH*Pass*. At the individual site level, this partial passability in FishXing could range from complete adult passage/partial juvenile passage to very little adult passage/no juvenile passage. If potential habitat gains were similar, FishXing analyses would likely steer you towards selecting the more severe barrier(s), whereas this important nuance would be missed by a straight, coarse scores only, FISH*Pass* analysis.

Table 1. Results of coarse passability scores versus FishXing passability scores.

Number of Sites	Number of Miles of Upstream Habitat using Coarse Passability Scores	Number of Miles of Upstream Habitat using available FishXing Passability Scores
1	13.8	13.8
2	15.9	15.9
3	17.3	17.4
5	18.5	18.7
7	21.0	20.7
10	22.1	22.6
15	24.8	24.8
20	26.5	26.5
25	27.0	27.0

Results – FISH*Pass* Runs with current PAD data versus Pre-remediation

For the Smith River test of FISH*Pass*, the 17 sites that were assessed, prioritized and remediated prior to the development of FISH*Pass* were subjected to test runs as if not yet treated. Most of these sites were identified for remediation in stream crossing inventories and passage assessments completed the U.S. Forest Service, Del Norte County Department of Transportation, Cal Trans and California State Parks between 2001 and 2009. For their individual road networks, these entities utilized the scoring and ranking methods described in the CDFW Restoration Manual to select priority barriers for remediation (Taylor and Love 2003). The stepwise FISH*Pass* runs of 1, 2, 3, 5, 7, 10, 15, 20 and 25 sites resulted in variable numbers of the remediated sites being selected by FISH*Pass* (Table 2). When FISH*Pass* was run to select the top ten sites for remediation, seven of the previously remediated sites were selected, which suggests that the previous ranking, prioritization, project-selection processes performed fairly well (Table 2). These seven sites were located on Clarks Creek, North Fork

Diamond Creek, Unnamed tributary to East Fork Mill Creek, Hamilton Creek, Cedar Creek, Yontocket Slough, and Hurdygurdy Creek. These seven sites accounted for opening-up a total of 30.2 miles of upstream habitat.

The top, pre-remediated site selected was PAD #765526, a U.S. Forest Service crossing on lower Hurdygurdy Creek that was replaced with a bridge, which had 18.4 miles of upstream habitat. The dam structure at the Rowdy Creek Hatchery (PAD #721887) is currently the top site for remediation, with 13.8 miles of available upstream habitat. Remediation of the hatchery's dam has been the focus of planning and engineering efforts for at least the past eight years.

For the 25-site FISH*Pass* run, three of the previously remediated sites were not selected. These sites included a culvert on upper Griffin Creek at Oregon Mountain Road that Del Norte County DOT replaced as a storm-damage project in 2013. Although only 1,400 feet of viable fish habitat was present above this crossing, this site was considered a high-priority for treatment based on the culvert's poor condition and its extremely limited stormflow capacity with >6,000 cubic yards of fill within the crossing (RTA 2006). At the time of treatment, the inlet was completely plugged with sediment and flow was seeping under the culvert, actively eroding the fill prism. Thus, treatment of the Griffin Creek at Oregon Mountain Road crossing addressed multiple objectives, primarily the avoidance of a catastrophic introduction of sediment to high-quality spawning habitat, with restoring fish and amphibian passage to the relatively limited upstream habitat as a secondary project objective. The other two sites not selected in the 25-site FISH*Pass* run were unnamed tributaries to Nickerson Creek on Howland Hill Road within California State Parks property. These two crossings had undersized and poor conditioned culverts that impeded fish passage due to perched outlets. Although these two sites were not selected by our FISH*Pass* runs, both sites were ranked as medium-to-high priority treatment locations in the California State Park's assessment report (RTA 2009). California State Parks worked with Pacific Coast Fish, Wildlife & Wetlands Restoration Association to replace these structures in 2015 with properly-sized culverts designed for passage of resident trout and juvenile salmonids. California State Parks treated these two Nickerson Creek sites after treating their two highest priority sites on Hamilton Creek and Cedar Creek; Hamilton Creek was selected in the 5-site FISH*Pass* run and Cedar Creek was selected in the 7-site FISH*Pass* run.

Results – FISH*Pass* Runs with Publicly available PAD Data versus 2021 Revised PAD Data

This comparison reflects differences between executing FISH*Pass* runs with the current/publicly available data on the PAD and the data revised from our 2021 ground-truthing efforts. For the 10-site runs, the publicly available PAD data selected sites that had 16.4 miles of potential upstream salmonid habitat (Table 3). In contrast, the 10-site FISH*Pass* run with the revised PAD data selected sites that totaled 22.1 miles of potential upstream salmonid habitat (Table 3). The differences in potential upstream habitat gains were both a function of different sites being selected, as well as the higher resolution hydrography utilized with the revised PAD data to define BFH. Only four sites from the FISH*Pass* run with the publicly available (and inaccurate) PAD data were included in the 2021 revised run's results (Table 3). These sites were Rowdy Creek Hatchery Dam, Griffin Creek Hwy 199, Rock Creek Highway 197, and Tillas Slough #1 (Table 3).

Table 2. Previously remediated sites selected by FISH*Pass*.

Number of Sites in each Fish*Pass* Run	Number of Previously Remediated Sites Selected by FISH*Pass*
1	1
2	1
3	2
5	4
7	6
10	7
15	10
20	13
25	14

The 10-site run made with the publicly available PAD data included two sites on U.S. Forest Service roads that have been remediated. The 20-site run made with publicly available PAD data included three sites on U.S. Forest Service roads and one Cal Trans site that have been remediated. These discrepancies between the publicly available PAD data and the revised data were a product of the daunting task of continuously keeping the PAD records up-to-date and the reliance on having various entities diligently self-reporting updated passage assessment and site remediation data to the PAD manager. In addition to maintenance of PAD records, updating the BFH layer and snapping PAD records to the BFH layer are processes in need of continual updating.

Conversely, the 10-site run made with the revised data included two sites that were not in the PAD and were encountered during Taylor and Goodman's 2021 site visits and given temporary PAD ID #'s. The 20-site run with the revised data included five sites that were not in the PAD, that were given temporary PAD ID#'s. The identification and inclusion of these sites (out of 41 sites missing in the PAD) was only possible because effort and budget were allocated to ground-truthing and updating the PAD records for the Smith River.

Table 3. Top ten sites selected by FISH*Pass* for publicly available PAD data versus revised data. Shaded sites were selected in both runs of FISH*Pass*.

Top Ten Sites selected by FISH*Pass* from publicly available data	Top Ten Sites selected by FISH*Pass* from data set revised by the 2021 site visits
#721877 – Rowdy Creek Hatchery Dam	#721877 – Rowdy Creek Hatchery Dam
#707900 – North Fork Diamond Creek	#707137 – Griffin Creek Highway 199
#707137 – Griffin Creek Hwy 199	#707144 – Rock Creek Highway 197
#707144 – Rock Creek Hwy 197	#759946 – Tillas Slough #1 – tide gate
#707868 – High Plateau Creek	#707139 – Clark's Creek – Hwy 199
#759946 – Tillas Slough #1 – tide gate	#720556 - Sultan Creek – dam
#759947 – Tillas Slough #2 – tide gate	#721902 – Dominie Creek – hatchery intake
#765238 – Tillas Slough #3 – culvert	#721903 – Dominie Creek – dam/weir
#765219 – Morrison Creek #1 – culvert	#800023 - Unnamed trib. to Knopti Creek
#721148 – Morrison Creek #3 – culverts	#800039 - Unnamed trib. to Hurdygurdy Ck
Total miles upstream habitat = 16.4	**Total miles upstream habitat = 22.1**

Discussion and Recommendations

As presented in the Introduction, choosing the Smith River as the watershed to test FISH*Pass* in was based on several factors, including what we assumed was a manageable number of sites to field-inspect and gain access to, as well as having no more than several hundred PAD records to review and work with. In retrospect, testing FISH*Pass* in either a larger watershed or in a similar-sized watershed with a higher number of road crossings and potential barriers may have been more prudent. Also, with a total of 17 sites already remediated in the Smith River, there's relatively few high-priority barriers left to treat. In all of our test runs, the outstanding barriers to fix were associated with the Rowdy Creek Fish Hatchery, with the primary dam/weir at the hatchery (#721887) having the largest weighted habitat gain of 7.4 miles (cumulative passability) or a total potential of 13.8 miles upstream (Table 1). PAD ID's #721902 and #721903 are on Dominie Creek and are also structures associated with the Rowdy Creek Fish Hatchery.

The biggest take-home from testing Fish*Pass* in the Smith River watershed was the importance of having accurate PAD and BFH data; because like most modeling applications, the quality and accuracy of the input data often has a profound influence on the quality of the results. Our ability to allocate effort towards ground-truthing sites defined as "unassessed" or passage status "unknown" lead to more robust analyses. The time spent ground-truthing also lead to the discovery of sites within the Smith River watershed that were missing from the PAD. We expect that any major watershed would have similar issues, and possibly, the bigger the watershed and/or higher densities of road/stream intersections would result in more erroneous or missing data points. Watersheds with large tracts of private property (such as timber, rangeland, or vineyards) may also likely result in higher numbers of unassessed and/or unknown passage status sites. Our ground-truthing efforts in the Smith River suggest that a thorough clean-up of the PAD and updating the BFH layer are warranted prior to conducting FISH*Pass* runs for the purpose of identifying and prioritizing the treatment of migration barriers in California.

Project cost analyses in FISH*Pass* may have limited utility when considering how most watershed restoration funding sources operate. Typically, one has a list of sites (or one high-priority site) from a stream crossing inventory and passage assessment already selected for treatment and then they seek funds for designing, permitting and implementing their fish passage project(s). Rarely does one obtain a large amount of funds and then as a second step, runs analyses to determine how best to spend this chunk of money on one or more barrier remediation projects. Cost information could be used in FISH*Pass* to estimate how much money is needed to effectively treat an entire watershed or a biologically important sub-basin; however, cost estimates are also notoriously difficult to accurately categorize simply by road surface type, project type and/or size. Factors that also influence project costs include: geographic area, site location (as in how remote a site is), site ownership (private versus county versus state), completing work in-house versus contracting work out, presence of utilities within project area, amounts of road-fill volume, degree of difficulty of water management and streamflow bypass, levels of traffic control and/or bypass required, etc. Also, annual inflation of at least 2.5% and recent supply-chain shortages should be taken into account when assigning updated costs to FISH*Pass* runs. A query of recently completed or funded projects in northern California depict the wide variability associated with fish passage remediation:

- Parks Creek/Shasta River – culvert replacement on private ranch road - $350,000.
- Kenny Creek/South Fork Eel River - culvert replacement on private road – $730,000.
- Rohner Creek/Eel River – 12th Street culvert retrofit - $750,000.
- Strong's Creek/Eel River – South Fortuna Blvd. culvert retrofit - $850,000.
- Gulch C/Noyo River – two crossings replaced, one arch culvert on RR and one pre-fab bridge on private timber road w/grade-control - $1,230,000.
- Hotelling Gulch/Salmon River – culvert replaced with bridge w/grade-control – $2,100,000.
- Cedar Creek/South Fork Eel River – removal of a remnant dam, approximately eight feet tall - $2,300,000 or $287,500 per vertical foot. Total cost breakdown - $1.9 million for implementation and $400K for permits, design and engineering.
- Noyo River/Skunk Train RR – open-bottom arch culvert w/grade-control - $2,549,000.
- Little Lost Man Creek/Highway 101 (two traffic lanes) – box culvert replaced with a bridge - $9,230,000.

The most appropriate utility of FISH*Pass* may be for project funding/review committees in the selection of projects to implement, since in many cases various barrier owners are competing for limited funds and are typically focused solely on their infrastructure. FISH*Pass* analyses also have the potential to facilitate a more holistic approach to barrier remediation and encourage various entities to cooperate in scheduling and designing their barrier remediations. For example, on Durphy Creek/South Fork Eel River, California State Parks has two migration barriers they're interested in fixing. However, these two crossings are located downstream and upstream of a barrier on Highway 101. All three sites need remediation to truly have a positive biological effect in opening-up the two miles of upstream habitat. In addition, the three sites are in close enough proximity to each other that any treatment at one site will likely cause channel adjustments that could negatively affect the passability and structural integrity of the other sites. FISH*Pass* could be powerful tool in identifying similar situations where comprehensive barrier remediation requires coordination and cooperation amongst various stakeholders.

The development of OptiPass™ and FISH*Pass* were efforts to improve on previously developed score-and-rank methods for identifying sites for fish passage remediation, with the goal to be the standard prioritization tool used to select high-priority projects in California. O'Hanley (2011) was frank in his low opinion of score-and-rank methodologies, "*In most cases, prioritization methods have focused predominately on restoring access to upstream spawning grounds of migratory (diadromous) fish and have usually employed overly simple scoring-and-ranking type procedures. Scoring-and-ranking, as used by Taylor and Love (2003), Kocovsky et al. (2009), and WDFW (2009), has been shown to produce ineffective and inefficient solutions as a consequence of ignoring the cumulative, non-additive impacts that barriers have on fish passage success."* Interestingly, our test of FISH*Pass* in the Smith River demonstrated that the CDFW Restoration Manual's score-and-rank methods selected 70% of the top ten (pre-remediated) sites identified by FISH*Pass*. Several of these supposedly "ineffective and inefficient solutions" remediated total barriers that opened-up miles of high-quality habitat that were immediately recolonized by coho salmon, Chinook salmon, steelhead, coastal cutthroat trout, and Pacific lamprey. CDFW's score-and-rank methods also incorporate culvert hydraulic sizing and condition, species diversity and ESA-listing status, and detailed FishXing passability analyses; all of which FISH*Pass* fails to address or incorporate. Section IX of the CDFW Restoration Manual also prefaces that the results generated from FishXing analyses and its barrier ranking methods are simply tools to assist in site selection, and that in the reality, other factors frequently influence site/project selection (Taylor and Love 2003). These additional factors are outside the realm of both FISH*Pass* and CDFW's score-and-rank methodology. These factors include: presence of fish species of interest, pre-project biological monitoring, other project objectives (sediment reduction, road failure, storm damage repair), access opportunity, culvert upgrades in conjunction with other road maintenance or repair, timing and sequencing with adjacent fish passage projects, and/or in conjunction with other types of watershed restoration projects.

Although the test of FISH*Pass* in the Smith River did not specifically have a task or methodology for examining the Baseline Fish Habitat GIS layer's characterization of potential salmonid habitat, based on our site visits we can qualitatively state what we observed in the field supported the BFH layer's characterizations. At all 82 sites we inspected, we made cursory observations of channel slopes and widths, potential fish habitat and looked for the presence of salmonids. Many of the sites we visited were in headwater areas, near the upper limits of fish-bearing lines depicted by the BFH layer. For example, we spent a day in the headwaters of Hurdygurdy Creek where wetted channel widths were three to five feet and slopes were approaching 8-10%. The BFH layer predicted that these upper channels were potentially fish-bearing and we observed juvenile and likely resident trout in all of these channels. Conversely, we examined several road crossings on tributaries to Knopti Creek and Griffin Creek that were considered non-fish-bearing in the BFH layer due to excessively steep slopes and our field observations supported these characterizations. We also field-verified a number of natural features considered total barriers, where the BFH layer ended, such as PAD #720554, an impassable waterfall with a 25-foot drop located on the Middle Fork of the Smith River, just upstream of its confluence with Knopti Creek (Figure 2).

In conclusion, FISH*Pass* is an effective tool for assisting in the identification and prioritization of barriers for remediation, however the previously mentioned factors should always be considered in final site selection and scheduling of projects. Detailed FishXing analyses have the potential to assist FISH*Pass* in final site selection and scheduling of projects. Having accurate and updated PAD records and BFH layers are critical for all future applications of FISH*Pass* in California.

Figure 2. Waterfall (PAD #720554) on Middle Fork of the Smith River, photo taken on 6/28/21.

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