Klamath Dam Removal Drawdown Scenario 8: Potential Impacts of Suspended Sediments on Focal Fish Species with and without Mechanical Sediment Removal

Final Technical Memorandum

Prepared for
CDM
2295 Gateway Oaks, Suite 240
Sacramento CA, 95833

Prepared by
Stillwater Sciences
2855 Telegraph Ave. Suite 400
Berkeley, CA 94705

April 2011

Stillwater Sciences

Suggested citation:

Stillwater Sciences. 2011. Klamath Dam removal Drawdown Scenario 8: Potential impacts of suspended sediments on focal fish species with and without mechanical sediment removal. Final Technical Memorandum. Prepared by Stillwater Sciences, Berkeley for CDM, Sacramento, California.

Table of Contents

Tables

Figures

Appendices

1 INTRODUCTION

The U.S. Department of the Interior (DOI), as the National Environmental Policy Act (NEPA) lead agency, and the California Department of Fish and Game (DFG), as the California Environmental Quality Act (CEQA) lead agency, are currently developing an Environmental Impact Statement/ Environmental Impact Report (EIS/EIR) for the Klamath Hydroelectric Settlement Agreement (KHSA) and the Klamath Basin Restoration Agreement (KBRA). The EIS/EIR will evaluate the environmental and social effects of a set of alternatives that may include removing all or portions of J.C. Boyle, Copco 1 and 2, and Iron Gate dams on the Klamath River, which would provide volitional fish passage to aid in restoring salmonid fisheries.

Sediment transport modeling of the impacts of dam removal on suspended sediments in the lower Klamath River indicates high short-term loads immediately downstream of Iron Gate Dam under the Proposed Action (Greimann et al. 2010, Stillwater Sciences 2008), where the latter is defined as the full removal of all four dams. The potential effects of the Proposed Action on suspended sediment concentrations (SSC) downstream of the dams may be partially mitigated by physical removal of sediment from the reservoirs prior to dam deconstruction. Sediment removal would potentially decrease erosion of the existing reservoir sediment deposits following dam removal and correspondingly decrease the magnitude of suspended fine sediments transported downstream to the lower Klamath River. In support of the EIS/EIR evaluation of dam removal effects on downstream water quality and key fish species, this technical memorandum documents modeling results for a potential sediment removal mitigation measure, including a comparison of model results based on two similar, but not identical, reservoir drawdown scenarios. Details of the Proposed Action and multiple reservoir drawdown scenarios, as well as the approach to mechanical sediment removal from the reservoirs, will be documented elsewhere by the Bureau of Reclamation (USBR) and CDM. Only information relevant to the comparison of the two sediment removal drawdown scenarios for SSC model results and anticipated impacts to focal fish species are summarized below.

2 SEDIMENT REMOVAL ESTIMATES

Reservoir drawdown Scenario 8, as defined in Greimann et al. (2010), involves a three-phase drawdown for Copco 1 Reservoir: at 1 ft/day between 1 and 13 November 2019 to draw the pool level to 2593.5 ft from the normal pool level of 2606 ft, at 1.84 ft/day between 1 January 2020 and 4 February 2020, and at 2.25 ft/day starting on 5 February 2020 until the reservoir level reaches the natural level; a single-phase drawdown for Iron Gate Reservoir at 3 ft/day beginning on 1 January 2020; and drawdown of J.C. Boyle Reservoir at 13 ft on 1 January 2020 and another 10 ft on 16 January 2020. A variation of drawdown Scenario 8 reduces Iron Gate Reservoir drawdown rate to 1.7 ft/day to allow for increased mechanical sediment removal from the reservoir during the drawdown period. For the purposes of this technical memorandum, this variation is referred to as the "Scenario 8 – Slow Drawdown". There would be no change in drawdown commencement date or rate for J.C. Boyle and Copco 1 reservoirs for the Scenario 8 – Slow Drawdown.

The estimated volume of sediment that can be mechanically removed from each reservoir prior to and during Scenario 8 and Scenario 8 – Slow Drawdown was provided by CDM (Sami Nall, pers. comm., 27 January 2011 and 1 February 2011) (Table 1).

Table 1. Sediment that can be removed before and during reservoir drawdown.

Klamath Project Reservoir	Before drawdown (yd^3)	During drawdown (yd^3)	Total (yd^3)
J.C. Boyle	335,600	219,800	555,400
Copco 1	176,700	1,277,100	1,453,800
Iron Gate: Scenario 8	106,000	733,100	839,100
Iron Gate: Scenario 8 – Slow Drawdown	106,000	1,354,000	1,460,000

3 SEDIMENT TRANSPORT MODELING APPROACH

We applied the USBR SRH-1D model (Huang et al. 2010) to conduct the sediment transport modeling and compare downstream SSC under the two considered drawdown scenarios with sediment removal as a mitigation measure. Time series data of discharge and reservoir surface elevations were provided by USBR and used as SRH-1D model input without modification. Existing surveyed cross sections provided by USBR were modified to reflect pre-drawdown and during-drawdown mechanical sediment removal.

Mechanical removal of the reservoir sediment deposits in each reservoir is assumed to be restricted to a "dredging slot" of constant width along the river thalweg. Sediment that is initially outside of the dredging slot would slide into the dredging slot during excavation and would be picked up by the dredge, forming a 1:10 (vertical: horizontal) bank slope outside of the dredging slot. Sediment within the dredging slot would be removed by the dredge, leaving a constant residual sediment deposit above pre-dam topography in each reservoir. For J.C. Boyle Reservoir, the designed dredging volume of sediment (see Table 1) cannot be achieved using a dredging slot width less than 1,000 ft; however, due to the relatively small volume of sediment in this reservoir, the assumption for dredging width in J.C. Boyle Reservoir has a minimal effect on the overall modeling results Thus, the width of the dredging slot in J.C. Boyle Reservoir is assumed to be 1,000 ft (or the width of the deposit, if it is narrower than 1,000 ft) such that the residual sediment thickness following dredging is 0.42 ft. For Copco 1 and Iron Gate reservoirs, the width of the dredging slot is assumed to be 100 ft. The residual thickness of the deposit remaining within the dredging slot after sediment removal in Copco 1 Reservoir would be 4.45 ft. For Iron Gate Reservoir, the residual thickness of the sediment deposit remaining after sediment removal would be 2.42 ft for the Scenario 8 drawdown and 1.96 ft for the Scenario 8 – Slow Drawdown. The volume of sediment removed by dredging in each reservoir implemented in the SRH-1D modeling is within 0.5% of the volume provided in Table 1. Figure 1 is a cross section in Iron Gate Reservoir, showing pre-dam, current, and post-dredging cross sections.

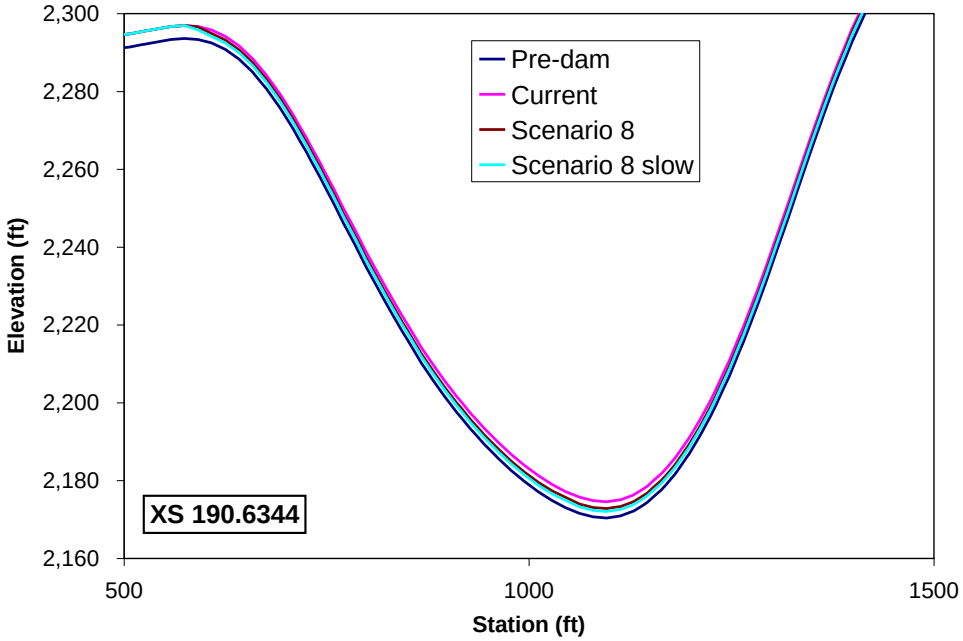

Figure 1. Cross section XS190.6344 in Iron Gate Reservoir, showing cross-sections for pre-dam, current, and post-sediment removal conditions for the Proposed Action under Scenario 8 with Dredging and Scenario 8 □□Slow Drawdown with Dredging.

4 SEDIMENT TRANSPORT MODELING RESULTS

Forty-eight model runs were undertaken for Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging. For each model run, it was assumed that hydrologic conditions during dam removal would be identical to the recorded hydrological conditions during these years. Results of the model runs have been provided to USBR and other scientists working on the EIS/EIR analyses as Excel spreadsheets. In order to evaluate the effectiveness of sediment removal as a potential mitigation measure, SSC immediately downstream of Iron Gate Dam for Scenario 8 Drawdown with Dredging and Scenario 8 – Slow Drawdown with Dredging are presented in Figures 2 through 4, for three typical "water year types": a median year that assumes dam removal occurs in a year identical to water year (WY) 1976 (Figure 2), a wet year that assumes dam removal occurs in a year identical to WY 1984 (Figure 3), and a dry year that assumes dam removal occurs in a year identical to WY 2001 (Figure 4), along with model results for Scenario 8 Drawdown (Proposed Action) (i.e., without sediment removal) provided by USBR from prior model runs.

A comparison of simulated SSC immediately downstream of Iron Gate Dam (Figures 2 through 4), indicates that dredging reduces SSC downstream of the dam. In the median year simulation shown in Figure 2, for example, the maximum SSC at Iron Gate Dam is reduced to approximately 5,000 mg/L from 12,000 mg/L if dredging is used, and it is further reduced to 3,000 mg/L as a result of the removal of an additional 600,000 cubic yards of sediment from Iron Gate Reservoir under the Scenario 8 – Slow Drawdown with Dredging. The Scenario 8 – Slow Drawdown with Dredging exhibits a secondary peak in SSC in March and early April of 2020 for the typical median year and dry year (Figures 2 and 4). The secondary peak is due to the fact that the slow drawdown scenario does not allow Iron Gate to empty before the spring runoff. The impact of SSC on focal fish species given Scenario 8 Drawdown with and without dredging is summarized in Section 5.

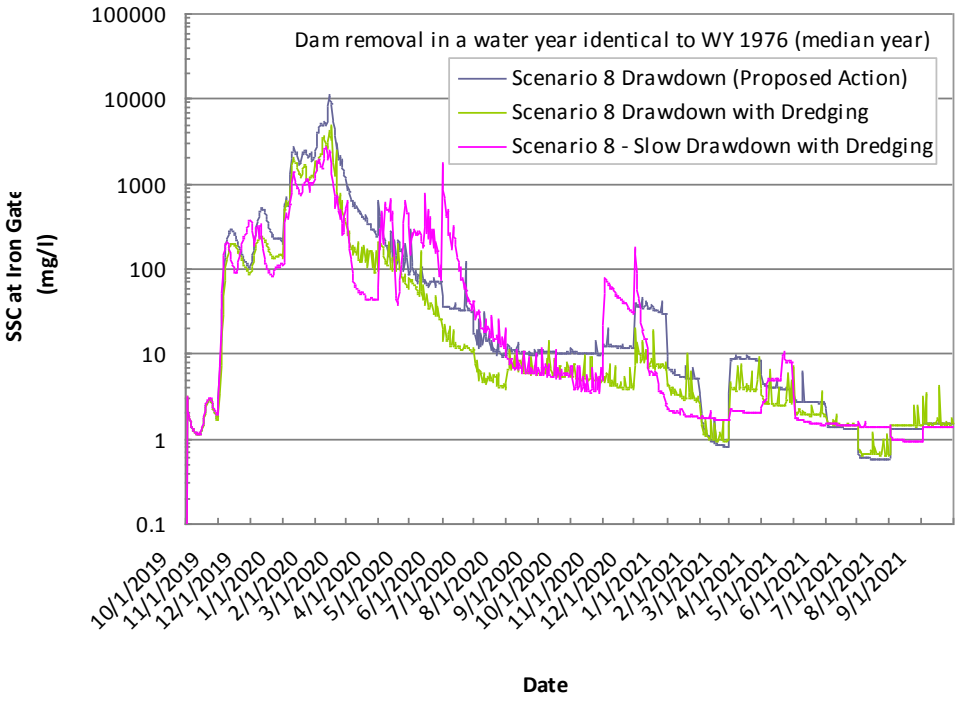

Figure 2. Modeled suspended sediment concentration (SSC) at Iron Gate Dam (RM 190.1) if dam removal occurs in a median year identical to WY 1976.

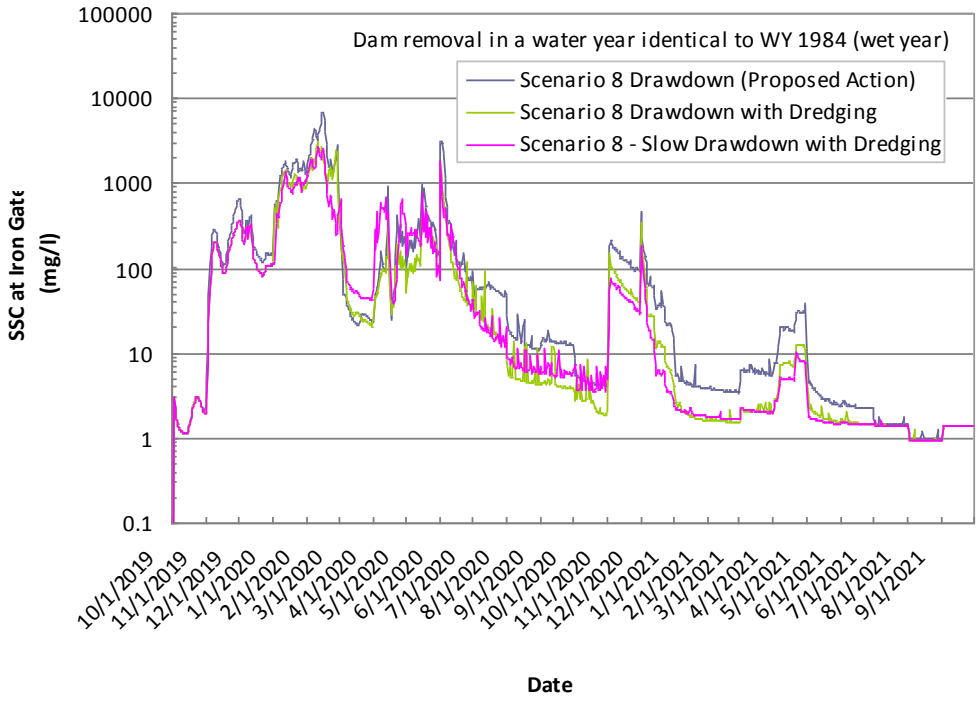

Figure 3. Modeled suspended sediment concentration (SSC) at Iron Gate Dam (RM 190.1) if dam removal occurs in a wet year identical to WY 1984.

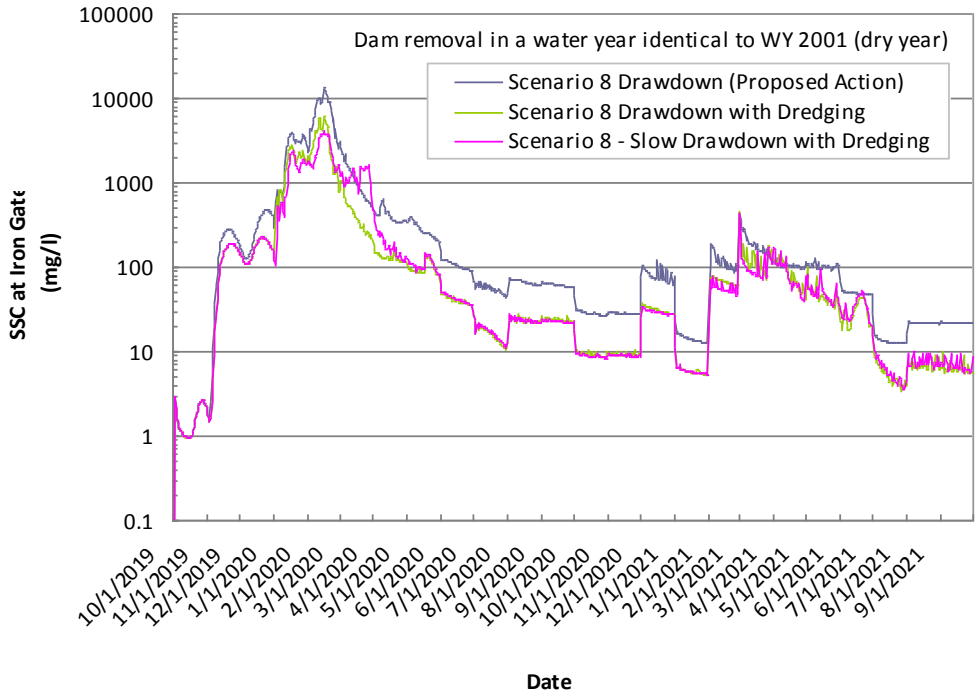

Figure 4. Modeled suspended sediment concentration (SSC) at Iron Gate Dam (RM 190.1) if dam removal occurs in a dry year identical to WY 2001.

5 POTENTIAL IMPACTS OF SUSPENDED SEDIMENT CONCENTRATIONS ON FOCAL FISH SPECIES

Simulated SSC for the location immediately downstream of Iron Gate Dam (see Sections 3 and 4) were translated farther downstream in the Klamath River by USBR using the SRH-1D model for Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging. Consistent with analyses of SSC conducted for the development of the EIS/EIR (see Appendix E of the Administrative Draft EIS/EIR, February 28, 2011), these predicted concentrations were used to assess impacts to focal fish species based on life-history stage at multiple locations in the middle and lower river. Rather than conducting the analysis using wet, median, and dry water year types as described for the sediment transport modeling (Section 4), the fisheries impacts analysis is based on "most-likely" and "worst-case" suspended sediment release scenario. The most-likely condition is akin to the median model prediction, for which there is a 50% probability of modeled SCC concentrations and durations being equaled or exceeded during the year of facility removal (Greimann et al. 2010). For the worst-case suspended sediment release scenario, there is a 10% probability that modeled SCC concentrations and durations will be equaled or exceeded during the year of facility removal (see Appendix E of the EIS/EIR for additional detail).

SRH-1D modeling results indicate that although SSC for both Scenario 8 Drawdown with Dredging and Scenario 8 – Slow Drawdown with Dredging are lower than SSC under the Proposed Action, concentrations in the Klamath River downstream of Iron Gate Dam remain high for several months following dam removal such that there would be little to no benefit of dredging for most fish species and

life history stages considered (Tables 2 and 3, also Appendix A). Notable benefits would occur for some species and life-stages under both dredging scenarios; for the most-likely suspended sediment release scenario, a small proportion of Type III fall-run Chinook salmon outmigrants (Figure 5) and Type III spring-run Chinook salmon outmigrants (Figure 6) would experience less severe sublethal impacts if dredging was employed as compared to the Proposed Action. A larger proportion of coho salmon smolts outmigrating during early and late spring from tributaries to the Klamath River upstream of the Trinity River would also experience less severe sublethal impacts if dredging were undertaken prior to dam removal (Figure 7). More substantial benefits would occur for juvenile steelhead and Pacific lamprey ammocoetes rearing in the mainstem if dredging were used, as decreases in mortality would occur for these species and life-history stages (Figures 8-9). Under the worst-case suspended sediment release scenario, fewer benefits of dredging are anticipated. There would be reduced mortality for Type III fall-run Chinook salmon outmigrants (Figure 5) and for early-spring coho salmon outmigrants (Figure 7) compared with mortality under the Proposed Action. Reduced mortality would also occur for adult steelhead migrants and Pacific lamprey migrants, as well as for juvenile steelhead and Pacific lamprey ammocoetes rearing in the mainstem (Figure 8–9).

There are only slight differences in anticipated benefits between the dredging scenarios themselves; for the most-likely suspended sediment release scenario, the Scenario 8 – Slow Drawdown with Dredging would result in increased mortality for fall Chinook salmon smolts (Figure 5), reduced sublethal impacts on coho salmon winter rearing (Figure 7), winter steelhead (Figure 8) and Pacific lamprey adult migrants (Figure 9), and reduced sublethal impacts on green sturgeon juveniles (Figure 10) as compared to impacts for the Scenario 8 Drawdown with Dredging. No differences would occur for all other species and life stages considered (Appendix A). Under the worst-case suspended sediment release scenario, sediment removal for the Scenario 8 – Slow Drawdown with Dredging would result in reduced sublethal impacts on fall Chinook salmon smolts (Figure 5), reduced sublethal impacts on winter-rearing coho salmon juveniles (Figure 7), and reduced sublethal impacts to winter steelhead (Figure 8) and Pacific lamprey adult migrants (Figure 9). However, under the worst-case suspended sediment release scenario, sediment removal for Scenario 8 – Slow Drawdown with Dredging would result in increased sublethal impacts on spring Chinook salmon smolts (Figure 6), coho salmon smolts (Figure 7), summer steelhead adult migrants (Figure 8), winter steelhead adult run-backs, juvenile rearing for steelhead (Figure 8), and increased sublethal impacts on Pacific lamprey ammocoetes (Figure 9).

Table 2. Summary of key differences between anticipated impacts of high SCC under Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging and Scenario 8 ▫ Slow Drawdown with Dredging, for the "most-likely" suspended sediment release scenario (i.e., 50% exceedance probabilities).

Species/Run	Life history stage	Predicted benefit of Scenario 8 drawdown with dredging as compared to Scenario 8 drawdown (Proposed Action)	Predicted differences between Scenario 8 drawdown with dredging and Scenario 8 – slow drawdown with dredging	Notes
Fall Chinook salmon	Type III outmigration	20% mortality **reduced** to sublethal effects	With slow drawdown sublethal effects **increased** to 20% mortality	Applies to ~1% of production.
Spring Chinook salmon	Type III outmigration	20% mortality **reduced** to sublethal effects	No difference	<1% of Salmon River production
Coho salmon	Age 1+ winter rearing	No difference	With slow drawdown 20% mortality **reduced** to sublethal effects	Applies to juveniles in mainstem (assume <1% of production).
	Early spring outmigration	20% mortality **reduced** to sublethal effects	No difference	Applies to smolts coming from tributaries in upper mainstem in early spring (~44% of production)
	Late spring outmigration	Degree of stress **reduced**	No difference	Applies to smolts coming from tributaries in the upper mainstem in late spring (~56% of production)
Steelhead	Adult migrants	No difference	With slow drawdown 40% mortality **reduced** to 20% mortality	Applies to adults spawning in mid- and upper-Klamath tributaries (~80% of run). The proportion migrating prior to December 15th (~20%) will not be affected.
	Age 1+ mainstem rearing	60% mortality **reduced** to 20% mortality	No difference	Applies to juveniles in mainstem (~60% of juveniles)
	Age 2+ mainstem rearing	60% mortality **reduced** to 20% mortality	No difference	Applies to juveniles in mainstem (~60% of juveniles)
	Outmigrants	Degree of stress **reduced**	No difference	~47% outmigrate from Trinity River and will have less exposure
Pacific Lamprey	Adult migration	No difference	With slow drawdown 40% mortality **reduced** to 20% mortality	Later-returning adults and those returning to lower tributaries will have less exposure.
	Ammocoete rearing	60% mortality **reduced** to 20% mortality	No difference	Applies to multiple year-classes of ammocoetes in mainstem; majority rear in tributaries and will not suffer mortality
Green sturgeon	Juvenile rearing and outmigration	No difference	With slow drawdown 20% mortality **reduced** to sublethal effects	~30% of juveniles rear in Trinity R. and will be unaffected (based on salmonid literature; effects likely overestimated).

Table 3. Summary of key differences between anticipated impacts of high SCC under Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 ▫ Slow Drawdown with Dredging, for the "worst-case" suspended sediment release scenario (i.e., 10% exceedance probabilities).

Species/Run	Life history stage	Predicted benefit of Scenario 8 drawdown with dredging as compared to Scenario 8 drawdown (Proposed Action)	Predicted differences between Scenario 8 drawdown with dredging and Scenario 8 – slow drawdown with dredging	Notes
Fall Chinook salmon	Type III outmigration	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **reduced** to 40% mortality	Applies to ~1% of production.
Spring Chinook salmon	Type I outmigration	No difference	With slow drawdown Major stress **increased** to reduced growth	Applies to Type I fry from Salmon R. (<1% of Salmon R. production).
	Type III outmigration	No difference	With slow drawdown 20% mortality **increase**d to 40% mortality	
Coho salmon	Age 1+ rearing	No difference	With slow drawdown 60% mortality **reduced** to 40% mortality	Applies to juveniles in mainstem (assume <1% of production).
	Early spring outmigration	60% mortality **reduced** to 20% mortality	With slow drawdown 20% mortality **increased** to 60% mortality	Applies to smolts coming from tributaries in upper mainstem in early spring (~44% of production).
Summer steelhead	Adult migrants	20% mortality **reduced** to sublethal effects	With slow drawdown sublethal effects **increased** to 20% mortality	Applies to fish spawning in mid- and upper-Klamath tributaries (~53% of run).
Winter steelhead	Adult migrants	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **reduced** to 40% mortality	Applies to fish spawning in mid- and upper-Klamath tributaries (~80% of run). The proportion migrating prior to December 15th (~20%) will not be affected.
	Adult runbacks	No difference	With slow drawdown Major stress **increased** to reduced growth	Effects dependent on duration of exposure when in the mainstem.
Summer and winter steelhead	Age 0+ rearing	No difference	With slow drawdown sublethal effects **increased** to 20% mortality	Applies to juveniles in mainstem (~60% of juveniles).
	Age 1+ rearing	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **increased** to 80% mortality	
	Age 2+ rearing	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **increased** to 80% mortality	
Pacific lamprey	Adult migration	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **reduced** to 40% mortality	Later-returning adults and those returning to lower tributaries will have less exposure.
	Ammocoete rearing	100% mortality **reduced** to 60% mortality	With slow drawdown 60% mortality **increased** to 80% mortality	Applies to multiple year classes of ammocoetes in mainstem; majority rear in tributaries and will not suffer mortality.

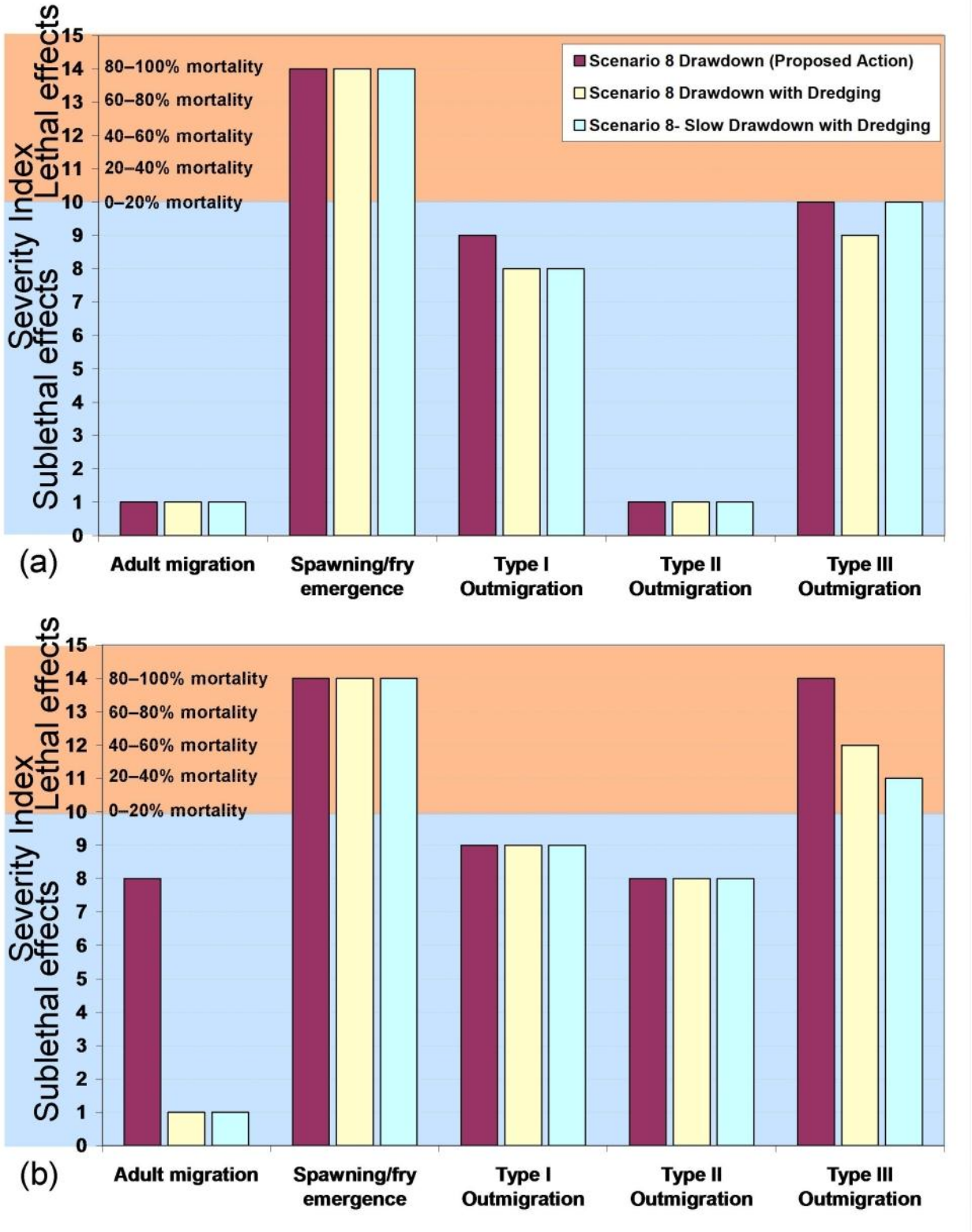

Figure 5. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for fall-run Chinook salmon; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

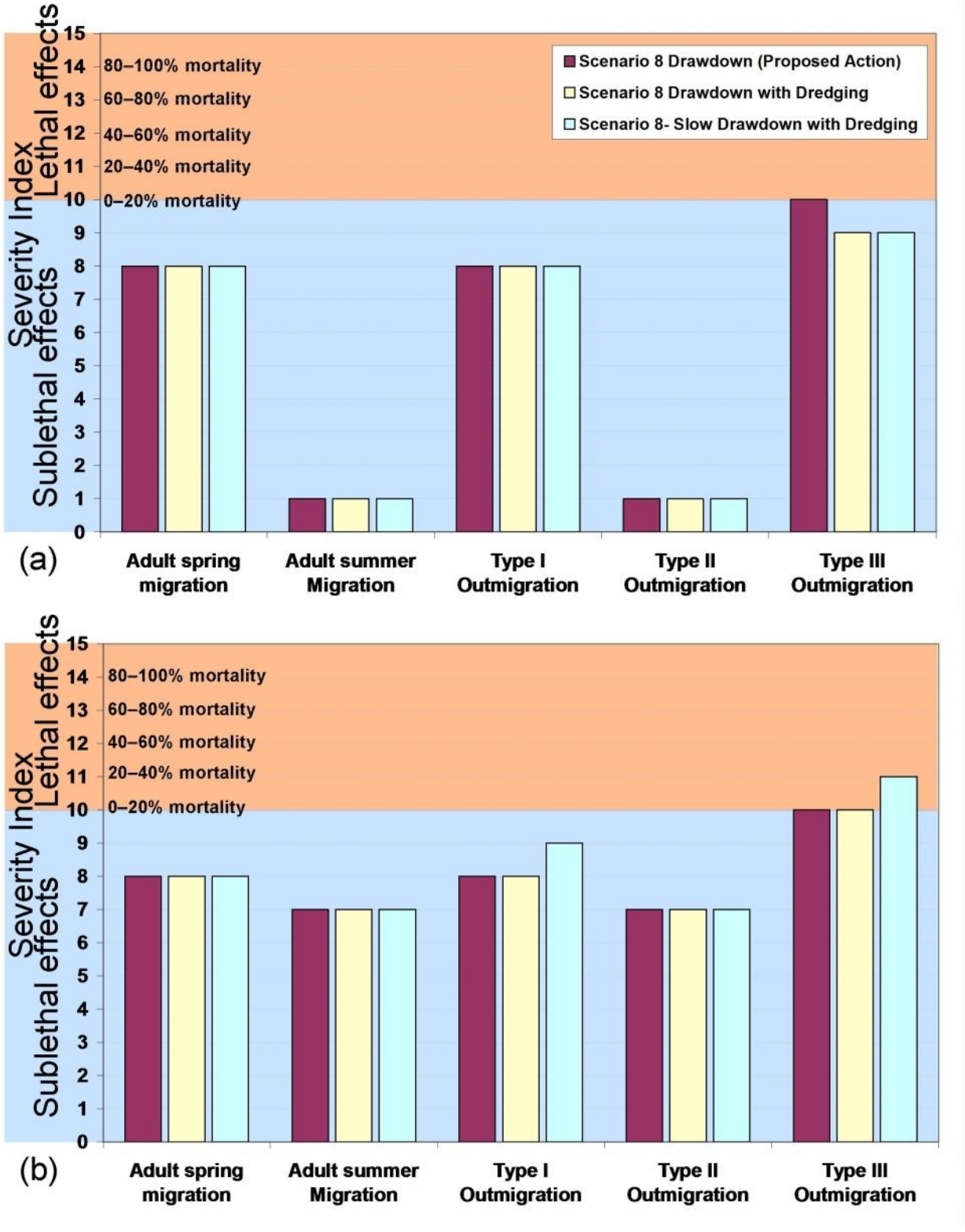

Figure 6. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for spring-run Chinook salmon; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

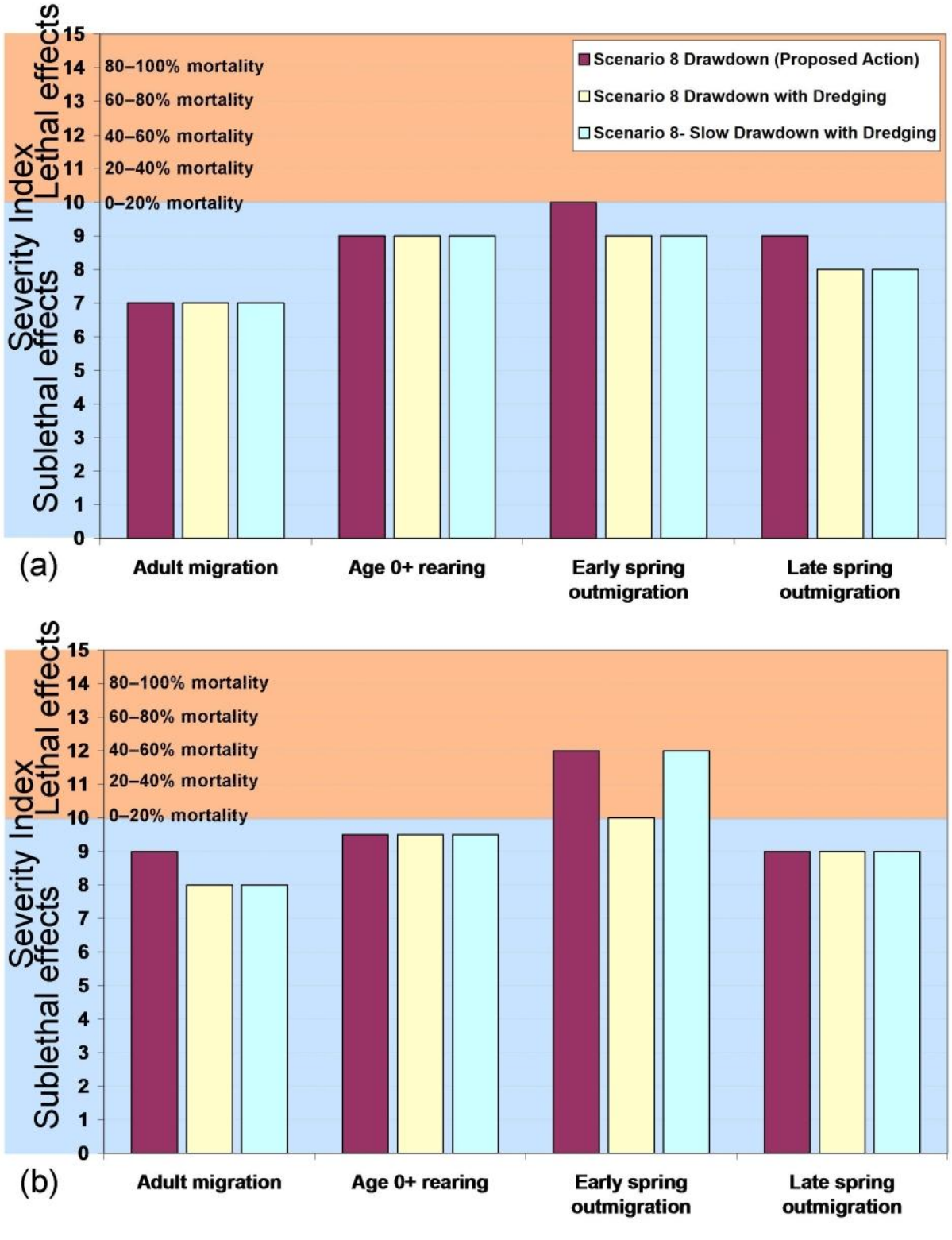

Figure 7. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for coho salmon; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

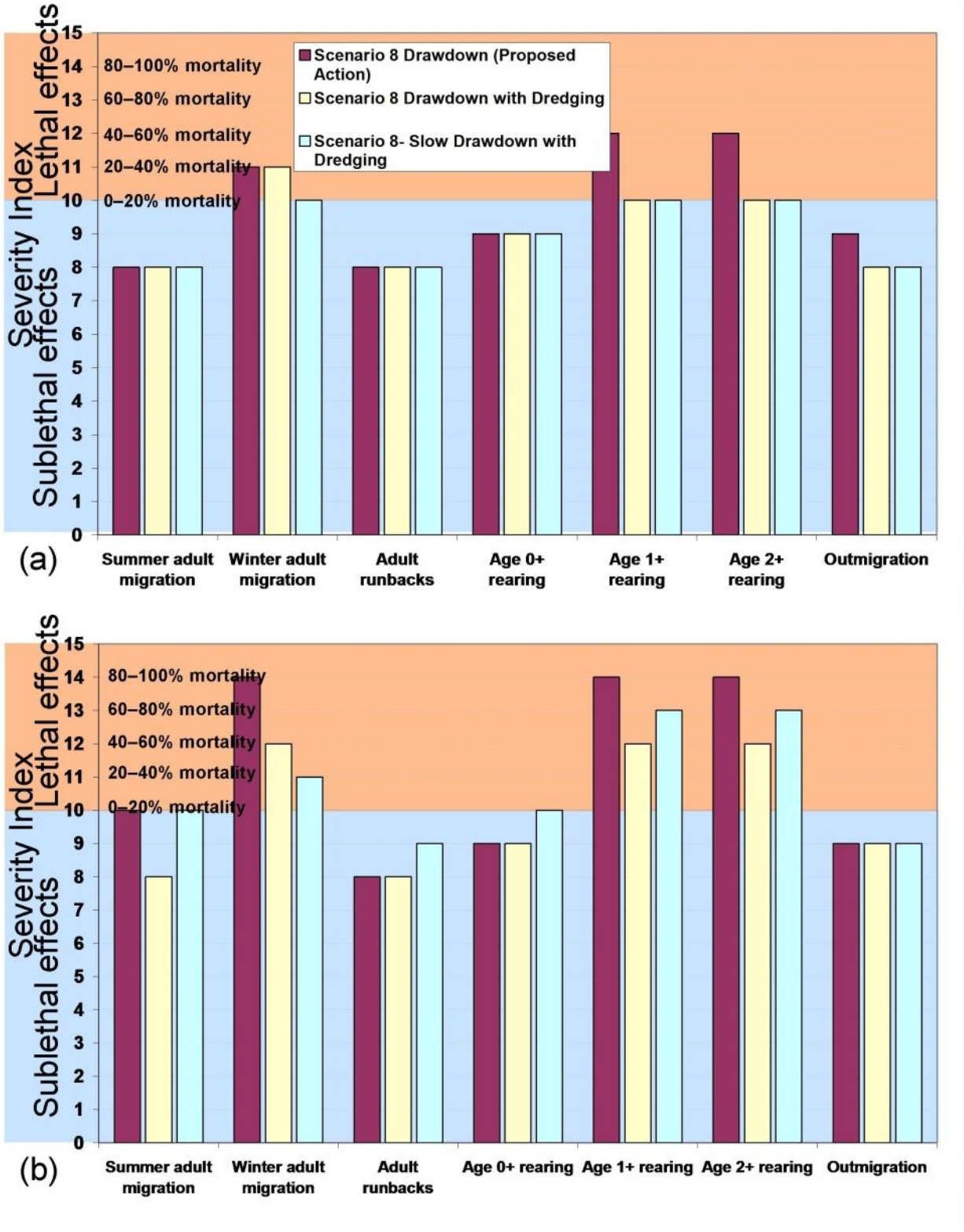

Figure 8. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for summer and winter steelhead; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

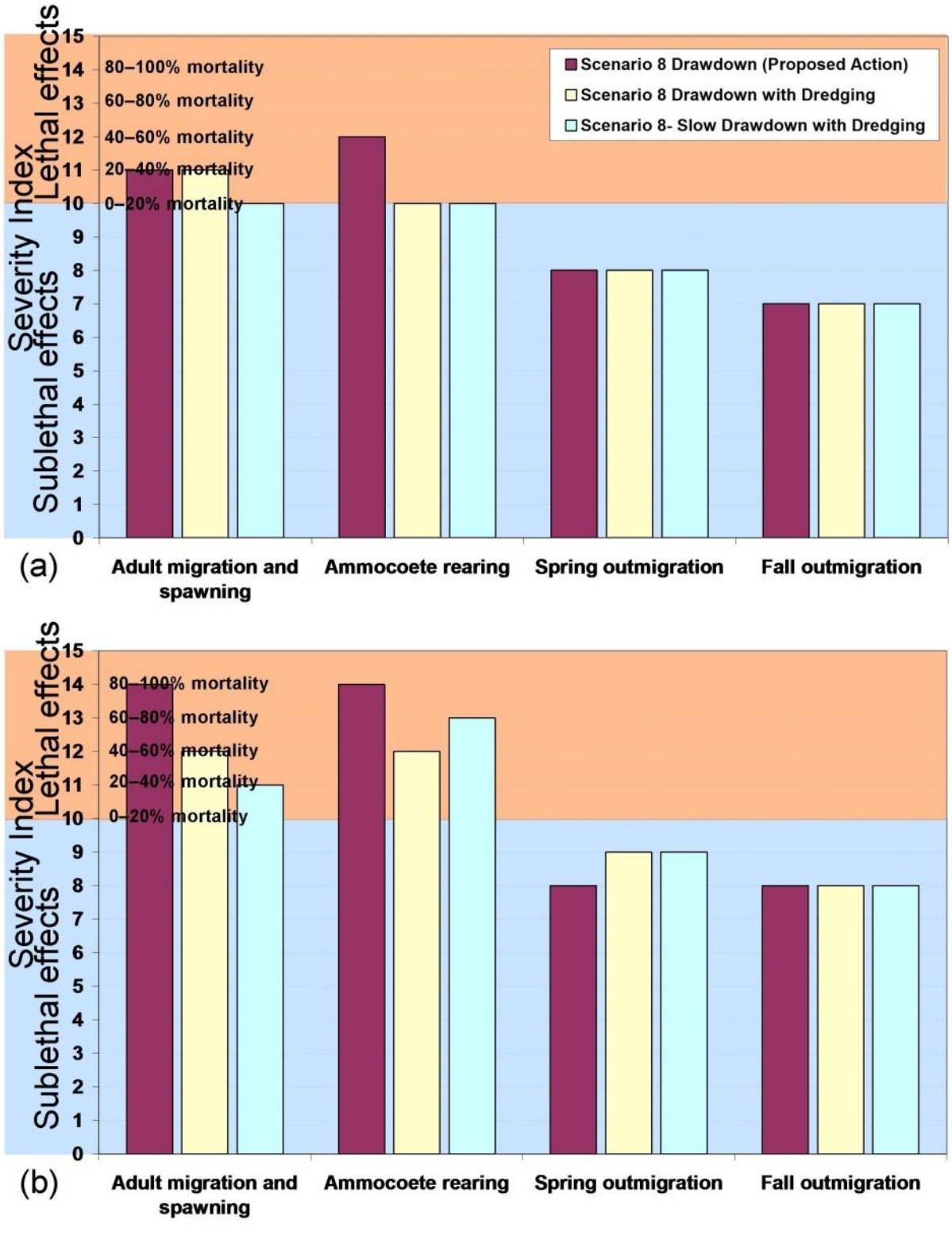

Figure 9. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for Pacific lamprey; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

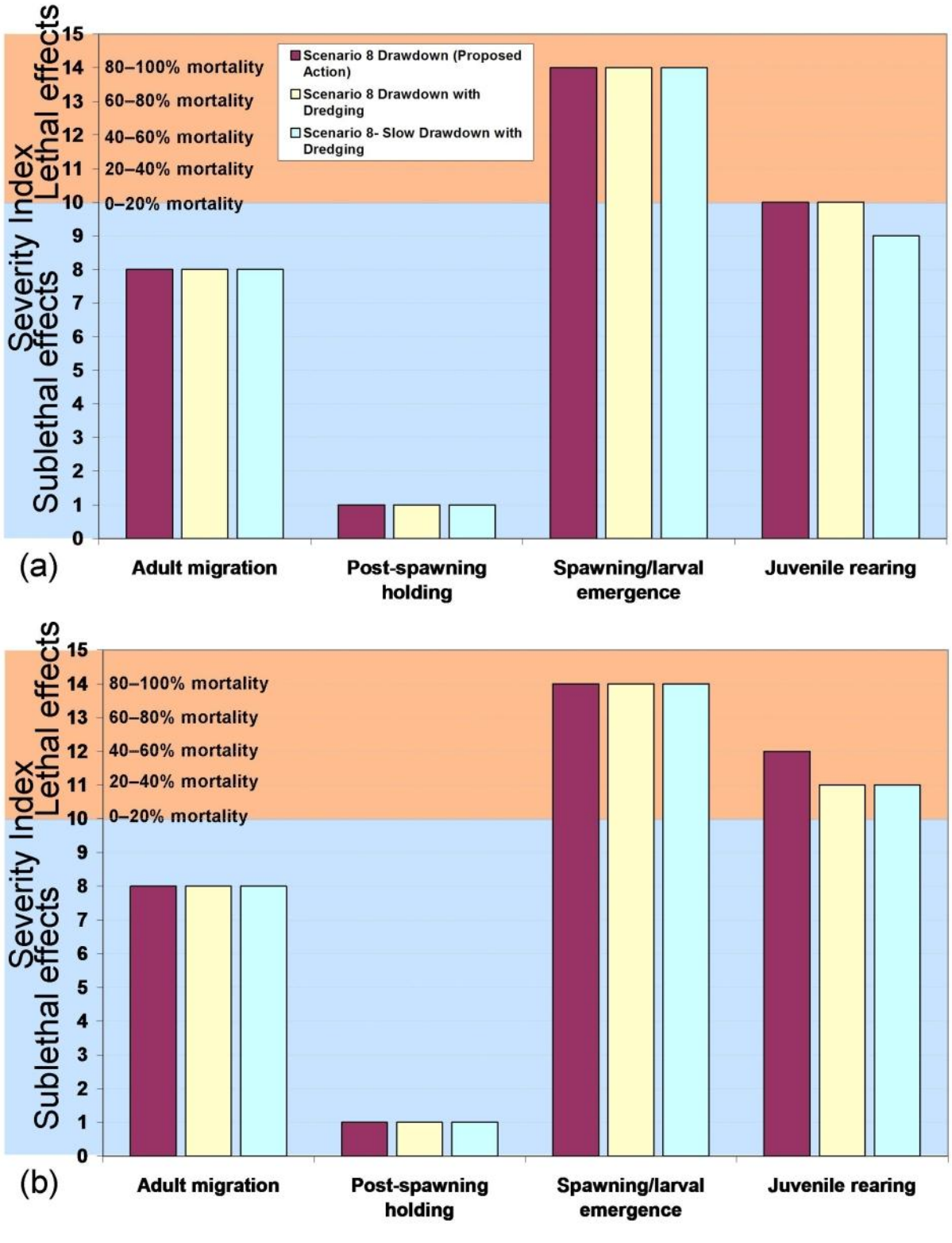

Figure 10. Scenario 8 Drawdown (Proposed Action) compared with Scenario 8 Drawdown with Dredging, and with Scenario 8 with slow Drawdown with Dredging for green sturgeon; (a) most-likely to occur suspended sediment release scenario, and (b) worst-case suspended sediment release scenario. Severity Index based on Newcombe and Jensen (1996).

Acknowledgement: Special thanks to Blair Greimann (USBR) for his help in modeling sediment transport using the SRH-1D model.

6 REFERENCES

Greimann, B. P., D. Varyu, J. Godaire, K. Russell, and Y. G. Lai. 2010. Hydrology, hydraulics and sediment transport studies for the Secretary's determination on Klamath River dam removal and basin restoration, Klamath River, Oregon and California. Draft Technical Report SRH-2010-XX. Bureau of Reclamation, Mid-Pacific Region.

Huang, J. V., B. Greimann, and Y. Lai. 2010. User's manual for SRH-1D 2.6, Sedimentation and River Hydraulics – One Dimension, Version 2.6. Technical Report SRH-2010-25. U. S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, Technical Service Center, Denver, Colorado.

Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693–727.

Stillwater Sciences. 2008. Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical Report. Prepared for California Coastal Conservancy, Oakland, California.

Appendix A

Summary of Anticipated Impacts to Focal Fish Species for the Proposed Action Scenario 8 Drawdown with and without Mechanical Sediment Removal

Table A-1. Anticipated impacts to fish species for the "most-likely" suspended sediment release scenario (i.e., 50% exceedance probabilities) under Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging.

Species/Run	Life History Stage				
	Adult migration	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Fall Chinook salmon	**Scenario 8 Drawdown (Proposed Action)**				
	No effects	Up to 100% mortality of the progeny of mainstem spawners (~8% of escapement)	Juvenile rearing is assumed to take place primarily in tributaries; no effects predicted	N/A	**Type I:** Major stress and reduced growth for Type I fry (~60% of production)
					Type II: No effects
					Type III: Major stress, reduced growth, and up to 20% mortality for Type III outmigrants (<1% of production)
	Scenario 8 Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	N/A	**Type I:** Major stress
					Type II: Same as Proposed Action
					Type III: Major stress, reduced growth; ***no mortality***
	Scenario 8 - Slow Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	N/A	**Type I:** Same as Scenario 8 drawdown rates
					Type II: Same as Proposed Action
					Type III: Same as Proposed Action
Spring Chinook salmon	**Scenario 8 Drawdown (Proposed Action)**				
	Spring Migration: Major stress, impaired homing for adults returning to Salmon R. (~5% of run) **Summer Migration:** No effects	Most spawning takes place in tributaries; no effects predicted	Juveniles primarily rear in tributaries; no effects predicted	Juveniles primarily rear in tributaries; no effects predicted	**Type I:** Major stress for Type I fry from Salmon R. (~80% of Salmon R. production)
					Type II: No effects (~20% of Salmon R. production)
					Type III: Major stress, reduced growth, and up to 20% mortality for Type III juveniles from Salmon R. (<1% of Salmon R. production)
	Scenario 8 Drawdown with Dredging				
	Spring Migration: Same as Proposed Action **Summer Migration:** Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Type I:** Same as Proposed Action
					Type II: Same as Proposed Action
					Type III: Major stress and reduced growth; ***no mortality***
	Scenario 8 - Slow Drawdown with Dredging				
	Spring Migration: Same as Proposed Action **Summer Migration:** Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Type I:** Same as Proposed Action
					Type II: Same as Proposed Action
					Type III: Same as Scenario 8 drawdown rates

Species/Run	Life History Stage				
	Adult migration	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Coho salmon	**Scenario 8 Drawdown (Proposed Action)**				
	Major stress and impaired homing	Up to 100% mortality of progeny of mainstem spawners (typically <1% of run)	**Age 0+ summer:** Reduced growth for age 0+ from 2020 cohort in upper mainstem (<50% of fry)	**Age 1+ winter:** Major stress, reduced growth, and up to 20% mortality for age 1+ juveniles from 2019 cohort in mainstem (assume <1% of juveniles)	**Early spring outmigration:** Major stress, reduced growth, and up to 20% mortality for smolts coming from tributaries in upper mainstem in early spring (~44% of production)
					Late spring outmigration: Major stress and reduced growth for smolts coming from tributaries in the upper mainstem in late spring (~56% of production)
	Scenario 8 Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	**Age 0+ summer:** Same as Proposed Action	**Age 1+ winter:** Same as Proposed Action	**Early spring outmigration:** Major stress and reduced growth; ***no mortality***
					Late spring outmigration: Major stress
	Scenario 8 -□ Slow Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	**Age 0+ summer:** Same as Proposed Action	**Age 1+ winter:** Major stress, reduced growth, ***No mortality***	**Early spring outmigration:** Same as Scenario 8 drawdown rates
					Late spring outmigration: Same as Scenario 8 drawdown rates

Table A-1 (continued). Anticipated impacts to fish species for the "most-likely" suspended sediment release scenario (i.e., 50% exceedance probabilities) under Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 □ Slow Drawdown with Dredging.

Species/Run	Life history stage					
	Adult migration	**Runbacks/Half-pounder residency**	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Summer and winter steelhead	**Scenario 8 Drawdown (Proposed Action)**					
	Summer run: Major stress and impaired homing for fish spawning in mid- and upper-Klamath tributaries (~53% of escapement) **Winter run:** Major stress, impaired homing, and up to 40% mortality for fish spawning in mid- and upper-Klamath tributaries (~80% of escapement)	**Adult runbacks:** Major stress; depending on time spent in mainstem **Half-pounder residency:** Most assumed to remain in tributaries; major stress for any remaining in mainstem	Most spawning takes place in tributaries; no effects predicted	Major stress resulting in reduced growth for age 0+ juveniles in mainstem (~60% of juveniles)	**Age 1+ rearing:** Major stress, reduced growth, and up to 60% mortality for juveniles in mainstem (~60% of juveniles) **Age 2+ rearing:** Reduced growth and up to 60% mortality for juveniles in mainstem (~60% of juveniles)	Major stress and reduced growth; ~47% outmigrate from Trinity R. and will have less exposure
	Scenario 8 Drawdown with Dredging					
	Summer run: Same as Proposed Action **Winter run:** Same as Proposed Action	**Adult runbacks:** Same as Proposed Action **Half-pounder residency:** Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Age 1+ rearing:** Major stress, reduced growth, and up to 20% mortality; ***lower mortality*** **Age 2+ rearing:** Reduced growth and up to 20% mortality; ***lower mortality***	Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging					
	Summer run: Same as Proposed Action **Winter run:** Major stress, impaired homing, and up to 20% mortality ***lower mortality***	**Adult runbacks:** Same as Proposed Action **Half-pounder residency:** Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Age 1+ rearing:** Same as Scenario 8 drawdown rates **Age 2+ rearing:** Same as Scenario 8 drawdown rates	Same as Proposed Action

Species/Run	Life history stage					
	Adult migration	**Runbacks/Half-pounder residency**	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Pacific lamprey	**Scenario 8 Drawdown (Proposed Action)**					
	Major stress, reduced growth, and up to 40% mortality; later-returning adults and those returning to lower tributaries will have less exposure	N/A	See adult migration	**Ammocoete rearing*:*** Major stress, reduced growth, and up to 60% mortality for multiple year classes of ammocoetes in mainstem; majority rear in tributaries and will not suffer mortality		**Spring outmigration*:*** Major stress **Fall and winter outmigration*:*** Moderate stress
	Scenario 8 Drawdown with Dredging					
	Same as Proposed Action	N/A	See adult migration	**Ammocoete rearing*:*** Major stress, reduced growth, and up to 20% mortality; ***lower mortality***		**Spring outmigration*:*** Same as Proposed Action **Fall and winter outmigration*:*** Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging					
	Major stress, reduced growth, and up to 20% mortality ***lower mortality***	N/A	See adult migration	**Ammocoete rearing*:*** Same as Scenario 8 drawdown rates		**Spring outmigration*:*** Same as Proposed Action **Fall and winter outmigration*:*** Same as Proposed Action

Table A-1 (continued). Anticipated impacts to fish species for the "most-likely" suspended sediment release scenario (i.e., 50% exceedance probabilities) under the Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging.

Species/Run	Life history stage			
	Adult migration	**Adult post-spawning holding**	**Spawning through larvae**	**Juvenile rearing (year-round) and outmigration**
Green sturgeon	**Scenario 8 Drawdown (Proposed Action)**			
	Major stress; 75% of adults not expected to migrate in 2020	No effects	100% mortality for all mainstem production; ~30% that spawn in Trinity R. will be unaffected (based on salmonid literature; effects likely overestimated)	Reduced growth and up to 20% mortality; ~30% of juveniles rear in Trinity R. and will be unaffected (based on salmonid literature; effects likely overestimated)
	Scenario 8 Drawdown with Dredging			
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging			
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Major stress and reduced growth; ***no mortality***

Table A-2. Anticipated impacts to fish species for the "worst-case" suspended sediment release scenario (i.e., 10% exceedance probabilities) under the Proposed Action, Scenario 8 Drawdown with Dredging, and Scenario 8 □ Slow Drawdown with Dredging.

Species/Run	Life history stage				
	Adult migration	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Fall Chinook salmon	**Scenario 8 Drawdown (Proposed Action)**				
	No effect	Up to 100% mortality of the progeny of mainstem spawners (~8% of escapement)	Juvenile rearing is assumed to take place primarily in tributaries; no effects predicted	N/A	**Type I:** Major stress and reduced growth for the ~60% of fry entering mainstem in April/May
					Type II: Moderate to major stress for the ~40% of Type II juveniles entering mainstem in Sept/Nov
					Type III: Major stress, reduced growth, and up to 100% mortality for <1% juveniles entering mainstem in Feb-April
	Scenario 8 Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	N/A	**Type I:** Same as Proposed Action
					Type II: Same as Proposed Action
					Type III: Major stress, reduced growth, and up to 60% mortality; ***lower mortality***
	Scenario 8 -□ Slow Drawdown with Dredging				
	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	N/A	**Type I:** Same as Proposed Action
					Type II: Same as Proposed Action
					Type III: Major stress, reduced growth, and up to 40% mortality; ***lower mortality***
Spring Chinook salmon	**Scenario 8 Drawdown (Proposed Action)**				
	Spring Migration: Major stress and impaired homing **Summer Migration:** Impaired homing	Most spawning takes place in tributaries; no effects predicted	Juveniles primarily rear in tributaries; no effects predicted	Juveniles primarily rear in tributaries; no effects predicted	**Type I:** Major stress for Type I fry from Salmon R. (~80% of Salmon R. production)
					Type II: Moderate stress for Type II juveniles from Salmon R. (~20% of Salmon R. production)
					Type III: Major stress, reduced or no growth, and up to 20% mortality for Type III juveniles from Salmon R. (<1% of Salmon R. production)
	Scenario 8 Drawdown with Dredging				
	Spring Migration: Same as Proposed Action **Summer Migration:** Impaired homing	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Type I:** Same as Proposed Action
					Type II: Same as Proposed Action
					Type III: Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging				
	Spring Migration: Same as Proposed Actionrates **Summer Migration:** Same as Scenario 8 drawdown rates	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Type I:** Major stress ***and reduced growth***
					Type II: Same as Proposed Action
					Type III: Major stress, reduced or no growth, and up to 40% mortality; ***higher mortality***

Table A-2 (continued). Anticipated impacts to fish species for the "worst-case" suspended sediment release scenario (i.e., 10% exceedance probabilities) under Scenario 8 Drawdown (Proposed Action), Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging.

Species/Run	Life history stage					
	Adult migration	**Runbacks/Half-pounder residency**	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Coho salmon	**Scenario 8 Drawdown (Proposed Action)**					
	Major stress and impaired homing	N/A	Up to 100% mortality of progeny of mainstem spawners (typically <1% of run)	**Age 0+ summer:** No growth for 2020 cohort rearing in upper mainstem (< 50% of fry)	**Age 1+ winter:** Major stress, reduced growth and up to 60% mortality for 2018 age-1+ cohort in mainstem (assume <1% of juveniles)	**Early spring outmigration:** Major stress, reduced growth, and up to 60% mortality for smolts coming from tributaries in upper mainstem in early spring (~44% of production) **Late spring outmigration:** Major stress and reduced growth for smolts coming from tributaries in the upper mainstem in late spring (~56% of production)
	Scenario 8 Drawdown with Dredging					
	Same as Proposed Action	N/A	Same as Proposed Action	**Age 0+ summer:** Same as Proposed Action)	**Age 1+ winter:** Same as Proposed Action	**Early spring outmigration:** Major stress, reduced growth, and up to 20% mortality; ***lower mortality*** **Late spring outmigration:** Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging					
	Same as Proposed Action	N/A	Same as Proposed Action	**Age 0+ summer:** Same as Proposed Action	**Age 1+ winter:** Major stress, reduced growth and up to 40% mortality; ***lower mortality***	**Early spring outmigration:** Same as Proposed Action **Late spring outmigration:** Same as Proposed Action

Species/Run	Life history stage					
	Adult migration	**Runbacks/Half-pounder residency**	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Summer and winter steelhead	**Scenario 8 Drawdown (Proposed Action)**					
	Summer run: Major stress, impaired homing, and up to 20% mortality for fish spawning in mid- and upper-Klamath tributaries (~53% of run) **Winter run:** Major stress, impaired homing, and up to 100% mortality for fish spawning in mid- and upper-Klamath tributaries (~80% of run). The proportion migrating prior to January will not be affected.	**Adult runbacks:** Major stress; exposure dependant on time it takes runbacks to return to sea **Half-pounder residency:** Major stress and reduced growth for any in mainstem; Most assumed to remain in tributaries;	Most spawning takes place in tributaries; no effects predicted	Major stress and reduced growth for age 0+ juveniles in mainstem (~ 60% of juveniles)	**Age 1+ rearing:** Stress, reduced growth, and up to 100% mortality for juveniles in mainstem (~ 60% of juveniles) **Age 2+ rearing:** Stress, reduced growth and up to 100% mortality for juveniles in mainstem (~ 60% of juveniles)	Major stress and reduced growth
	Scenario 8 Drawdown with Dredging					
	Summer run: Major stress, impaired homing; ***no mortality*** **Winter run:** Major stress, impaired homing, and up to 60% mortality; ***lower mortality***	**Adult runbacks:** Same as Proposed Action **Half-pounder residency:** Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	**Age 1+ rearing:** Stress, reduced growth, and up to 60% mortality; ***lower mortality*** **Age 2+ rearing:** Stress, reduced growth and up to 60% mortality; ***lower mortality***	Same as Proposed Action
	Scenario 8 -□ Slow Drawdown with Dredging					
	Summer run: Same as Proposed Action **Winter run:** Major stress, impaired homing, and up to 40% mortality; ***lower mortality***	**Adult runbacks:** Major stress and reduced growth; ***includes reduced growth*** **Half-pounder residency:** Same as Proposed Action	Same as Proposed Action	Major stress, impaired homing, and up to 20% mortality; ***higher mortality***	**Age 1+ rearing:** Stress, reduced growth, and up to 80% mortality; ***lower mortality*** **Age 2+ rearing:** Stress, reduced growth, and up to 80% mortality; ***lower mortality***	Same as Proposed Action

Table A-2 (continued). Anticipated impacts to fish species for the "worst-case" suspended sediment release scenario (i.e., 10% exceedance probabilities) under the Proposed Action, Scenario 8 Drawdown with Dredging, and Scenario 8 – Slow Drawdown with Dredging.

Species/Run	Life history stage				
	Adult migration	**Spawning through fry emergence**	**Age 0+ rearing**	**Age 1+ rearing**	**Outmigration**
Pacific lamprey	**Scenario 8 Drawdown (Proposed Action)**				
	Major stress, reduced growth, and up to 100% mortality; later-returning adults and those returning to lower tributaries will have less exposure	N/A	See adult migration	**Ammocoete rearing:** Major stress, reduced growth, and up to 100% mortality for multiple year classes of ammocoetes in mainstem; majority rear in tributaries and will not suffer mortality	**Spring outmigration:** Moderate to major stress and reduced growth **Fall and winter outmigration:** Major stress
	Scenario 8 Drawdown with Dredging				
	Major stress, reduced growth, and up to 60% mortality; ***lower mortality***	N/A	See adult migration	**Ammocoete rearing:** Major stress, reduced growth, and up to 60% mortality; ***lower mortality***	**Spring outmigration:** Same as Proposed Action **Fall and winter outmigration:** Same as Proposed Action
	Scenario 8 - Slow Drawdown with Dredging				
	Major stress, reduced growth, and up to 40% mortality; ***lower mortality***	N/A	See adult migration	**Ammocoete rearing:** Major stress, reduced growth, and up to 80% mortality; ***lower mortality***	**Spring outmigration:** Same as Proposed Action **Fall and winter outmigration:** Same as Proposed Action
Green sturgeon	**Scenario 8 Drawdown (Proposed Action)**				
	Major stress; ~25% of adults expected to be exposed in 2020	**Adult Post-spawning Holding:** Short period (<1 wk) of relatively low SSC, not expected to result in adverse effects; ~75% of adults hold in mainstem after spawning; remainder return to ocean	100% mortality for all mainstem production; ~30% that spawn in Trinity R. will be unaffected (based on salmonid literature; effects likely overestimated)	**Juvenile Rearing (year-round) and Outmigration:** Reduced growth and up to 40% mortality; ~30% of juveniles rear in Trinity R. and will be unaffected	N/A
	Scenario 8 Drawdown with Dredging				
	Same as Proposed Action	**Adult Post-spawning Holding:** Same as Proposed Action	Same as Proposed Action	**Juvenile Rearing (year-round) and Outmigration:** Same as Proposed Action	N/A
	Scenario 8 - Slow Drawdown with Dredging				
	Same as Proposed Action	**Adult Post-spawning Holding:** Same as Proposed Action	Same as Proposed Action	**Juvenile Rearing (year-round) and Outmigration:** Same as Proposed Action	N/A