GCDAMP Knowledge Assessment: Effects of Management Actions

Resource Topic:	Aquatic food base
Preparer(s):	Ted Kennedy, Jeff Muehlbauer, Chris Budwig, Shane Capron, Bill Davis, Craig Ellsworth
Version Date:	3/1/2017

Resource Characteristic	Specific Measure	Management Action	Strength	Direction	Confidence	Rationale: Strength & Direction	Rationale: Confidence	Recommendations
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Macroinvertebrate production flows	Strong	Positive Effect	Low	Kennedy et al. (2016 BioScience) identifies flow regime as limiting food base abundance throughout Glen, Marble, and Grand Canyons. Macroinvertebrate production flows may improve conditions for insects, allowing greater densities of insects and thus increased production of food for fish.	Kennedy et al. (2016 BioScience) provides theory and strong pattern in support of why macroinvertebrate production flows would be beneficial for food base. But such flows have yet be occur. Confidence would increase with monitoring of secondary production (i.e., drift and emergence production) after flow implementation.	Management: 1) Consider 3 consecutive years of these macroinvertebrate production flows to improve food base production. Research: 1)Food base monitoring in concert with a test involving 3 consecutive years of bug flows will greatly advance learning.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Spring HFEs ≤ 45,000 cfs in March or April	Strong	Positive Effect	Low	The 2008 spring HFE had a strong, positive effect on drift concentrations by stimulating production of midges and blackflies densities, and significantly reducing NZMS densities too.	Confidence is low because there is only one well studied spring HFE (2008) to reference. Effects from that HFE were strongly positive for food base production, however.	Management: 1) Consider testing spring HFEs to improve food base secondary production. Research: 1) Opportunities for learning about spring HFEs are limited by the rarity of spring HFEs.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Proactive Spring HFEs ≤ 45,000 cfs in April, May, or June	Strong	Positive Effect	Low	The 2008 spring HFE increased drift by stimulating production of midges and blackflies, and significantly reducing production of inedible NZMS.	Confidence is low because there is only one well studied spring HFE (2008) to reference. Effects from that HFE were strongly positive for food base production, however.	Management: 1) Consider testing spring HFEs to improve food base secondary production. Actual timing (so long as it is in spring) should be less consequential than having a spring HFE, period. Research: 1) Opportunities for learning about spring HFEs are limited by the rarity of spring HFEs.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Fall HFEs ≤ 45,000 cfs in October or November	Moderate	Negative Effect	Low	Drift concentrations and emergence production have steadily declined in Lees Ferry, at the LCR confluence, and throughout Grand Canyon since 2012 when regular testing of fall HFEs began.	Current HFE implementation strategy makes it challenging to draw strong inferences concerning impacts of Fall HFEs. Increasing confidence in impacts of fall HFE (i.e., are these flows NEGATIVE or NEUTRAL with respect to food base?) can only be achieved with a change in HFE implementation strategy.	Management: 1) Fall HFEs, of any sort, are likely to be neutral for the food base at best, and negative at worst. Consider shift to spring HFEs, however, which have potential to increase food base diversity. Research: 1) Complete analysis of long-term drift data. However, any inferences concerning effects of fall HFEs will be necessarily weak owing to poor experimental design (i.e., cessation of HFEs, or change in HFE timing, are required to better understand impacts of fall HFEs specifically).
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Fall HFEs > 96-hr duration	Strong	Negative Effect	Low	Drift concentrations and emergence production have steadily declined in Lees Ferry, at the LCR confluence, and throughout Grand Canyon since 2012 when regular testing of fall HFEs began. Basis for Strong negative impact comes from extending the duration of these fall-timed HFEs.	Current HFE implementation strategy makes it challenging to draw strong inferences concerning impacts of Fall HFEs. Increasing confidence in impacts of fall HFE (i.e., are these flows NEGATIVE or NEUTRAL with respect to food base?) can only be achieved with a change in HFE implementation strategy.	Management: 1) Fall HFEs, of any sort, are likely to be neutral for the food base at best, and negative at worst. Consider shift to spring HFEs, however, which have potential to increase food base diversity. Research: 1) Complete analysis of long-term drift data. However, any inferences concerning effects of fall HFEs will be necessarily weak owing to poor experimental design (i.e., cessation of HFEs, or change in HFE timing, are required to better understand impacts of fall HFEs specifically).

Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Trout management flows	Weak	Negative Effect	Low	Food base production is already fairly low. Testing of TMFs may further reduce production by favoring inedible NZMS, stranding Gammarus, and exacerbating mortality of aquatic insect eggs (see Kennedy et al 2016 BioScience). However, strength of impact is Weak because this would only happen a few times in a year.	Total food base diversity is already fairly low. Simple chain of logic predicts at best neutral to negative effects of TMFs on food base production, but no baseline results exist to improve confidence in assessment.	Management: 1) TMFs are unlikely to be positive for food base. Given that fish in the GCD tailwater are food-limited, do not recommend TMFs as a way to improve food base diversity.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Macroinvertebrate production flows	Moderate	Positive Effect	Low	Kennedy et al. (2016 BioScience) identifies flow regime as limiting food base diversity throughout Glen, Marble, and Grand Canyons. Macroinvertebrate production flows may improve conditions for these insects, allowing tributary taxa to take hold and potentially recolonize mainstem. Relative dominance of big 4 groups expected to shift more toward desirable insect taxa (away from invasive New Zealand mudsnails) due to increased success of egg laying by insects. However, the number of tributaries potentially supplying EPT colonists is low, and tributaries with water temperatures similar to mainstem are even fewer. Thus, response of EPT in Lees Ferry to macroinvertebrate production flows will likely be delayed compared to Grand Canyon.	Kennedy et al. (2016 BioScience) provides theory and strong pattern in support of why macroinvertebrate production flows would be beneficial for food base. Less clear, however, if diversity will increase only due to these flows, or if repatriation of native Colorado River insects might also be required.	Management: 1) Consider testing macroinvertebrate production flows, potentially followed by repatriation of native Colorado River candidate taxa a few years down the line. Research: 1) Continued monitoring of food base will provide baseline data needed to evaluate effectiveness of macroinvertebrate production flows.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Spring HFEs ≤ 45,000 cfs in March or April	Moderate	Positive Effect	Low	Spring HFEs may foster diversity by providing conditions favorable to recolonizing insect species, similar to what was observed in 2008, but this effect is likely to be small relative to EPT taxa. In terms of relative abundance of existing taxa, the 2008 spring HFE was documented by Rosi Marshall et al. (2010) and Cross et al. (2011) as positively impacting insects, and knocking back NZMS for >18 months. Spring HFEs in the March-June timeframe are within the realm of natural flood timing for this river, as evidenced by spring high flow releases being conducted annually on many upper basin dams (e.g., Fontenelle, Flaming Gorge, Navajo). Thus, effects of spring flood disturbances on food base diversity are likely to be more positive than negative.	Total food base diversity is fairly low already. Spring HFEs alone are also unlikely to make total diversity much better on their own. Inferences regarding relative diversity of the big 4 (midges, blackflies, gammarus, and NZMS) are based on only a single spring HFE.	Management: 1) To improve relative diversity of the big 4, consider testing spring HFEs, which may knock back nonnative NZMS and favor insects. Additional spring HFEs, as experiments, would improve confidence in status and trends of results. 2) Consider how timing of spring HFEs might actually be used to mitigate strong trout recruitment response (i.e., would April HFE stimulate food base and not create as many small trout as compared to early March HFE?). Research: 1) Opportunities for learning about spring HFEs are limited until another spring HFE is tested.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Proactive Spring HFEs ≤ 45,000 cfs in April, May, or June	Moderate	Positive Effect	Low	Spring HFEs may foster diversity by providing conditions favorable to recolonizing insect species, similar to what was observed in 2008, but this effect is likely to be small relative to EPT taxa. In terms of relative abundance of existing taxa, the 2008 spring HFE was documented by Rosi Marshall et al. (2010) and Cross et al. (2011) as positively impacting insects, and knocking back NZMS for >18 months. Spring HFEs in the March-June timeframe are within the realm of natural flood timing for this river, as evidenced by spring high flow releases being conducted annually on many upper basin dams (e.g., Fontenelle, Flaming Gorge, Navajo). Thus, effects of spring flood disturbances on food base diversity are likely to be more positive than negative.	Total food base diversity is fairly low already. Spring HFEs alone are also unlikely to make total diversity much better on their own. Inferences regarding relative diversity of the big 4 (midges, blackflies, gammarus, and NZMS) are based on only a single spring HFE.	Management: 1) To improve relative diversity of the big 4, consider testing spring HFEs, which may knock back nonnative NZMS and favor insects. Additional spring HFEs, as experiments, would improve confidence in status and trends of results. 2) Consider how timing of spring HFEs might actually be used to mitigate strong trout recruitment response (i.e., would April HFE stimulate food base and not create as many small trout as compared to early March HFE?). Research: 1) Opportunities for learning about spring HFEs are limited until another spring HFE is tested.

Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Fall HFEs ≤ 45,000 cfs in October or November	Moderate	Negative Effect	Low	Total food base was already fairly low, and fall HFEs may be further reducing diversity. Specifically, recent fall HFEs appear to favor invasive NZ mudsnails and disfavor aquatic insects. However, NZMS were abundant, and insects scarce, prior to the start of fall HFEs in 2012.	Total food base diversity was already low prior to implementation of fall HFEs in 2012, so current HFE implementation strategy makes it challenging to draw strong inferences concerning impacts of Fall HFEs. Increasing confidence in impacts of fall HFE (i.e., are these flows NEGATIVE or NEUTRAL with respect to food base?) can only be achieved with a change in HFE implementation strategy.	Management: 1) Fall HFEs, of any sort, are likely to be neutral for the food base at best, and negative at worst. Consider shift to spring HFEs, however, which have potential to increase food base diversity. Research: 1) Complete analysis of long-term drift data.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Fall HFEs > 96-hr duration	Strong	Negative Effect	Low	Total food base was already fairly low, and fall HFEs appear to be further reducing diversity. Specifically, recent fall HFEs appear to favor invasive NZ mudsnails and disfavor aquatic insects. Basis for Strong negative impact comes from extending the duration of these fall-timed HFEs.	Total food base diversity was already low prior to implementation of fall HFEs in 2012. However, NZMS were abundant, and insects scarce, prior to the start of fall HFEs in 2012. Increasing confidence in fall HFE impacts (i.e., are fall HFEs having a NEGATIVE or NEUTRAL impact on the food base) can only be achieved with a change in HFE implementation strategy.	Management: 1) Fall HFEs, of any sort, are likely to be neutral at best for the food base, and slightly negative at worst. Consider shift to spring HFEs, however, which have potential to be positive. Research: 1) Complete analysis of long-term drift data.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Trout management flows	Weak	Negative Effect	Low	Total food base diversity is already fairly low. Shifts in relative diversity of big 4 groups may be toward undersirable NZMS as a result of TMFs, due to increased egg mortality on insect eggs due to TMFs (see Kennedy et al 2016 BioScience) and potential stranding of Gammarus. However, strength of impact is Weak because this would only happen a few times in a year.	Total food base diversity is already fairly low. Simple chain of logic predicts at best neutral to negative effects of TMFs on relative dominance of big 4 groups, but no baseline results exist to improve confidence in assessment.	Management: 1) TMFs are unlikely to be positive for food base. Given that fish in the GCD tailwater are food-limited, do not recommend TMFs as a way to improve food base diversity.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Humpback chub translocation	Weak	No Effect	High	Moving chub around is unlikely to have any effect on the food base.	Muehlbauer et al. (In prep) found high diversity of invertebrates in the upper LCR with chub translocation, similar to patterns observed in this reach prior to translocation by Robinson et al. (1996 Southwestern Naturalist) and Haden et al. (2002 NAU Report). GCMRC sampling of Shinumo Creek found variable levels of invertebrate diversity in Havasu and Shinumo Creeks during periods of chub translocation, consistent with prior patterns described by Oberlin et al. (1996 Southwestern Naturalist).	Chub translocation should not affect the food base.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Mechanical removal of rainbow trout from LCR reach	Weak	No Effect	High	Trout densities at the LCR confluence are a tiny fraction of those present in Lees Ferry, so removing trout at the LCR is only removing a minor consumer of invertebrates.	Simple chain of logic, combined with numerous stream ecology papers that have only found evidence of fish suppression of the prey base when fish densities are extremely high.	Mechanical removal of trout from the LCR reach should not affect the food base.
Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Larval humpback chub head-start program	Weak	No Effect	High	Moving chub around is unlikely to have any effect on the food base, because chub densities are unlikely to get high enough to actually suppress the prey base.	Muehlbauer et al. (In prep) found high diversity of invertebrates in the upper LCR with chub translocation, similar to patterns observed in this reach prior to translocation by Robinson et al. (1996 Southwestern Naturalist) and Haden et al. (2002 NAU Report). GCMRC sampling of Shinumo Creek found variable levels of invertebrate diversity in Havasu and Shinumo Creeks during periods of chub translocation, consistent with prior patterns described by Oberlin et al. (1996 Southwestern Naturalist).	Chub translocation should not affect the food base.

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Food base diversity	Ephemeroptera-Plecoptera-Trichoptera (EPT) abundance relative to total invertebrate abundance (%), and relative abundance of "big 4" invertebrate groups: Chironomidae, Simuliidae, Gammarus, Potamopyrgus (# or %)	Riparian vegetation restoration	Weak	Positive Effect	High	Large woody debris (log jams and root masses) in river channels is generally good for insect diversity. However, the amount of riparian restoration necessary to have a tangible effect on large woody debris, river wide, is impractical.	A large volume of stream ecology literature documents positive effects of large woody debris on aquatic insect populations, but also underscores that the volume of large woody debris necessary is generally at the river-wide channel clogging scale, which won't happen in Grand Canyon without investment of billions of dollars.	Riparian vegetation restoration cannot hurt the food base, but is not worth pursuing only for the food base.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Humpback chub translocation	Weak	No Effect	High	Moving chub around is unlikely to have any effect on the food base.	Muehlbauer et al. (In prep) found high density of invertebrates in the upper LCR with chub translocation, similar to patterns observed in this reach prior to translocation by Robinson et al. (1996 Southwestern Naturalist) and Haden et al. (2002 NAU Report). GCMRC sampling of Shinumo Creek found variable levels of invertebrate density in Havasu and Shinumo Creeks during periods of chub translocation, consistent with prior patterns described by Oberlin et al. (1996 Southwestern Naturalist).	Chub translocation should not affect the food base.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Mechanical removal of rainbow trout from LCR reach	Weak	No Effect	High	Fish populations are only capable of regulating invertebrate populations when fish densities are very high. Densities of rainbow trout at the LCR confluence are not high enough to reduce invertebrate populations.	Numerous investigators have looked for evidence of top-down control of invertebrate populations by fish. The number of cases where this has been demonstrated are few and far between, and in every case fish populations were large. Rainbow trout populations at the LCR confluence have never been sufficiently large to actually control invertebrate populations.	Mechanical removal of trout from the LCR reach should not affect the food base.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Larval humpback chub head-start program	Weak	No Effect	High	Moving chub around is unlikely to have any effect on the food base.	Muehlbauer et al. (In prep) found high density of invertebrates in the upper LCR with chub translocation, similar to patterns observed in this reach prior to translocation by Robinson et al. (1996 Southwestern Naturalist) and Haden et al. (2002 NAU Report). GCMRC sampling of Shinumo Creek found variable levels of invertebrate density in Havasu and Shinumo Creeks during periods of chub translocation, consistent with prior patterns described by Oberlin et al. (1996 Southwestern Naturalist).	Chub translocation should not affect the food base.
Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Mechanical removal of invasive fish species	Weak	No Effect	High	Mechanical removal of invasive fish species should not affect the food base.	Removal of smallmouth bass or channel catfish is unlikely to even reduce populations of the target fish species (e.g., see for example failure of upper basin efforts to reduce smallmouth bass populations).	Mechanical removal of invasive fish species should not affect the food base.

Secondary production	Invertebrate drift, benthic, and emergence trapping, and fish bioenergetics modeling	Riparian vegetation restoration	Weak	Positive Effect	High	Large woody debris (log jams and root masses) in river channels is generally good for insect diversity. However, the amount of riparian restoration necessary to have a tangible effect on large woody debris, river wide, is impractical.	A large volume of stream ecology literature documents positive effects of large woody debris on aquatic insect populations, but also underscores that the volume of large woody debris necessary is generally at the river-wide channel clogging scale, which could only happen in Grand Canyon with an investment of tens of millions of dollars and would present a navigation hazard to boaters.	Riparian vegetation restoration cannot hurt the food base, but is not worth pursuing only for the food base.