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Fish Indicators of Ecosystem Health: Upper Mississippi River System

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Final Report

Upper Mississippi River Restoration Long Term Resource Monitoring Analysis Team

Fish Indicators of Ecosystem Health:

Upper Mississippi River System

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Project Background and Charge of Working Group

The Upper Mississippi River Restoration (UMRR) Program periodically conducts assessments and reports on the status and trends of a variety of environmental resources (e.g., hydrology, vegetation, water quality, fish) in the Upper Mississippi River System (UMRS). The most recent Status and Trends (S & T) report (Johnson and Hagerty 2008) used the data available through the U.S. Army Corps of Engineers' UMRR Long Term Resource Monitoring (UMRR LTRM) element to assess overall ecosystem health for the UMRS. Following the publication of the S & T report (Johnson and Hagerty 2008), the UMRR Analysis Team convened an ad hoc group to evaluate the indicators used and make recommendations for use in future S & T reports. One of the primary charges of this group was to make recommendations for additional indicators to be considered or alterations of indicators to better assess the ecosystem health of the UMRS. These recommendations were endorsed by the Analysis Team and the UMRR Coordinating Committee, technical and policy advisory groups, respectively, to the UMRR Program.

The UMRR LTRM Analysis Team Ad Hoc Indicator Report (LTRM Indicator Report; Hagerty and McCain 2013; Supplemental Material 1) evaluated the indicators used in the 2008 S & T (Johnson and Hagerty 2008). The LTRM Indicator Report outlines which previously used indicators should be eliminated as well as specific recommendations for improving the remaining indicators. For the fishery indicators, a sub-group of regional experts was convened. Their detailed evaluation and recommendations are provided in Appendix C of the LTRM Indicator Report (Hagerty and McCain 2013). The LTRM Indicator Report also recommended additional or alternative multi-species indicators that should be developed, which included: 1) migratory fish indicator and 2) backwater assemblage indicator. The general consensus of UMRR Analysis Team was that these indicators would be used in place of previously used single species indicators and in conjunction with select indicators used in the 2008 S & T (Johnson and Hagerty 2008).

LTRM Indicator Report (Hagerty and McCain 2013) also outlines and discusses what a healthy UMRS fishery is and what essential attributes should be used to assess health. In addition, the LTRM Indicator Report (Hagerty and McCain 2013) describes and recommends alternative reference conditions that should be evaluated in order to appraise ecosystem health status and trends.

Following the UMRR Analysis Team's recommendations, our report describes the development of backwater assemblage and migratory fish indicators and their responses since the beginning of the UMRR LTRM data collection. The data used for these indicators are summarized as pool-wide totals from the UMRR LTRM element. In addition, we also present a practical solution to the problem of determining reference condition in the absence of true reference sites in navigable rivers by using an internal quantitative baseline condition determined by a long-term data trend at the reach-scale. Lastly, we outline our recommendation for the development of indicator that evaluates the young-of-the-year fish assemblage.

Brief Program Background

The Long Term Resource Monitoring (LTRM) element was authorized as part of the U.S. Army Corps of Engineers' Upper Mississippi River Restoration (UMRR) Program in the Water Resources Development Act of 1986 (WRDA 1986; as amended). Since then, the UMRR LTRM has served as an important source of ecological information on the Upper Mississippi River System (UMRS). The primary mission of the UMRR LTRM is to provide resource managers with the information needed to maintain the Upper Mississippi River System as a viable, multi-use ecosystem through standardized monitoring of four key components: 1) water quality; 2) aquatic vegetation; 3) aquatic macroinvertebrates; and 4) fishes (US Army Corps of Engineers, 1997). The primary goal of the UMRR LTRM element is to detect large-scale, systemic trends for the key components, and correlate these trends with environmental variables.

Proposed Indicators of Ecosystem Health

For the UMRR, habitat-based indicators are important because habitat restoration is one of the primary focuses of the UMRR Program. Previously, a single species was selected to represent an entire community because it was either the dominant species or it is highly sensitive to declining habitat quality and quantity. However, these single species indicators may not actually be representative of the entire fish assemblage, not representative of all regions and reaches, or have potential to be influenced by non-habitat factors (e.g., fishing pressure, pollution, disease). In order to combat some of these issues, UMRR LTRM Analysis Team Ad Hoc Indicators Group suggested the use of broader indicator groups in the LTRM Indicator Report (Hagerty and McCain 2013; Supplementary Material 1) including:

1) **Migratory:** Migration is a key functional attribute of UMRS required to maintain diverse and sustainable fish stocks, and migratory species (Table 1) can be impeded by the type of navigational dams present in the UMRS. In addition, this group would also represent additional faunal groups that are health-impaired by restricted fish passage (i.e., freshwater mussels). Indicators using migratory fish will allow the UMRR Program to consider evaluation of ecosystem services or assessment of tradeoff when considering future habitat enhancement projects and management scenarios.

2) **Backwater:** Much of the high species diversity in the UMRS is derived from a hydrological connectivity between the main channel and backwater habitats. Even though portions of the UMRS remain hydrologically connected to these important

backwater habitats, large portions are still restricted by levee systems or are degrading in condition due to anthropogenic impacts (e.g., sedimentation).

Reference Condition for Proposed Indicators

Determining the current status (i.e., health) of the UMRS is not feasible using traditional bioassessment approaches. For example, in a traditional biomonitoring program, annual measures of the health of an ecosystem are compared to a reference condition. For the UMRS, several different definitions of a reference condition were considered including historical, control, desired state, and internal. While the historical reference condition may be the most appropriate for the UMRS, there are still drawbacks, like the need for a period of less-intensive anthropogenic impacts to determine the current ecosystem health and attempts to manage toward. Even in a system where historical data is plentiful, a meaningful quantitative reference may be problematic due to uncertainty of quality and individual biases over time. In addition, the UMRS has a long history of river alteration (e.g., dams, dykes, levees, dredging) and watershed development that extends further back than the UMRR LTRM element itself, so managing toward a not well-defined historical condition may not be realistic. Defining and identifying a comparable control system is one of the more common reference conditions used in bioassessment. Control systems are typically of superior quality or represent a desirable health status. However, no comparable river system exists that could be indexed and used as a reference for the UMRS. Alternatively, an internal reference condition requires the establishment of a baseline condition based on past data collection. Establishing a quantitative baseline condition provides a context for assigning whether or not contemporary conditions are acceptable, in need of improvement, or severely impaired. This method would not only utilize the full breadth of the UMRR LTRM dataset, but would also highlight the importance of long-term monitoring in large river systems in which natural reference conditions are nonexistent. We developed an internal reference condition that is based on a 5-year moving average to determine the health status of each regional trend area (RTA). This method circumvents the problems associated with using a traditional reference approach such as:

1) The internal references (the 6 regional trend areas) are inherently not comparable.
2) No comparable navigable river system exists that could be used as a reference for the UMRS.
3) The study design and the extensive, long-term data collection are unique to the UMRS and should be utilized to the fullest extent.

Methods

Study Area

The Upper Mississippi River System (UMRS), as defined in WRDA 1986, is a large river floodplain system characterized by annual flood pulses that advance and retreat over the floodplain and expands backwater and floodplain lake habitats. The UMRS spans the Upper Mississippi River from Minneapolis, Minnesota to Cairo, Illinois (854 RM); the Illinois Waterway from Chicago to Grafton, Illinois (327 RM); and navigable portions of the Minnesota (15 RM), St. Croix (24 RM), Black (1 RM), and Kaskaskia Rivers (36 RM). The UMRS basin encompasses a total area of approximately 2.6 million acres and includes major portions of five stakeholder states of the UMRR: Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

There are substantial geomorphological changes along the longitude of the river system generating distinct reaches (Koel 2001). There are 4 major reaches defined by general geomorphic and ecological characteristics: 1) Upper Impounded Reach (Pools 1 – 13); 2) Lower Impounded Reach (Pools 14 – 26); 3) Unimpounded Reach (RM 0 – RM 203); and 4) Illinois Waterway (Chicago to Grafton, Illinois). Within each reach, there is at least one regional trend area (RTA) that is monitored as part of the UMRR LTRM element. The RTAs within the Upper Impounded Reach consist of Navigation Pools 4, 8, and 13 and are characterized by abundant backwater habitats, main channel islands, and few levees (Johnson and Hagerty 2008). The Lower Impounded reach RTA (Pool 26) is characterized by fewer backwater habitats with approximately 50% of the floodplain isolated by levee systems (Johnson and Hagerty 2008). The Open River Reach (RM 29 – 80) is located in the Unimpounded Reach and contains no locks and dams, but is characterized by a single main channel constrained by training structures (e.g., wing dikes, chevrons, etc.). Approximately 67% of floodplain of the Open River Reach is isolated by levee systems and a navigational channel is maintained by dredging (Johnson and Hagerty 2008). Finally, the La Grange (RM 80 – 157) RTA is located within the Illinois River Waterway. This reach is characterized by abundant backwater habitats with broad isolated floodplains dominated by agriculture (Johnson and Hagerty 2008).

Data Collection

The spatial coverage of this study incorporated data from all six UMRR LTRM field stations. All six regional trend areas (Navigation Pools 4, 8, 13, 26, Open River Reach, and La Grange) were sampled using standard UMRR LTRM electrofishing methodology (Gutreuter et al. 1995, Ratcliff et al. 2014). Gutreuter et al. (1995) and Ratcliff et al. (2014) outlined the standard UMRR LTRM methodology in detail. Sampling locations were selected using a stratified random design by strata. Electrofishing was conducted using pulsed-DC output with two-ring anodes and the boat hull serving as the cathode. Day-time electrofishing samples were collected from 15 June

1993 to 31 October 2014. A power output of 3000 W was achieved by adjusted the voltage and amperage based on water temperature and conductivity for each sample outing. Electrofishing was conducted along shorelines continuously for 15 minutes at each sample collection site and two field staff collected fish with dip nets. All fish were identified, measured, and enumerated following standard UMRR LTRM protocols (Gutreuter et al. 1995, Ratcliff et al. 2014).

Statistical Analysis

All calculations and analyses were conducted in R version 3.2.1 (R Core Team 2015). See Supplementary Material 2 for complete R scripts and corresponding packages used to calculate indicators and generate graphics.

Indicator Species Analysis

We used Indicator Species Analysis (ISA; Dufrene and Legendre 1997) to test for the affinities of different species to sampling strata across the entire Upper Mississippi River system. Indicator species analysis assigns an indicator value (IndVal) to each taxon. The indicator value is the product of two conditional probabilities, specificity and fidelity. Specificity is the probability that the surveyed site belongs to the target site group (i.e., strata) given that the species has been found. Fidelity is the probability of finding the species in sites belonging to the site group. Random permutations (N=999) of the original data were used to estimate the probability of achieving an indicator value of equal or greater value among groups (p; Dufrene and Legendre 1997). Species with significantly ($p \leq 0.05$) high indicator values for a given group have a high probability of being found in other samples within the same habitat strata. This suggests an affinity by that species for environmental characteristics common to specific strata. Prior to analysis, all non-native species to the UMRS were removed. All gear types across all sampling periods were used in order to generate a backwater assemblage indicator lists that were not bias towards organisms size, life history stage, or movement. Indicator species analysis was performed with the indicspecies package (ver. 1.7.5; De Caceres and Legendre 2009) available for R version 3.2.1 (R Core Team 2015).

Indicator Calculation

A series of fish assemblages were selected using best professional judgment and through discussion with state and federal fisheries experts throughout the UMRR partnership to represent vital attributes of a healthy fish community and aquatic ecosystem (see LTRM Indicators Report; Hagerty and McCain 2013; Supplementary Material 1). The ecological indicators include: migratory species and backwater fish assemblages. Migratory species were based on migration status detailed in the UMRR LTRM Life History Database (O'Hara et al. 2007). The backwater assemblage was defined as the fish species that showed the highest and a significant indicator value for the backwater strata in the Indicator Species Analysis outlined previously. All indicators were calculated based on annual catch-per-unit-effort (CPUE). Migratory and backwater fish assemblage CPUEs are based on the total annual catch for day-time electrofishing. All indicators are based on pool-wide total annual catches. Since the Open River Reach currently has a majority of its backwaters isolated behind levees, no backwater strata are sampled under the UMRR LTRM stratified random sampling design. Only catches of adult fishes were used for both the migratory and backwater fish assemblage indicators. Adult fishes were separated from young-of-year fishes using reported lengths for each species following the methodology of Barko et al. (2004) and Barko et al. (2005) and can be found in Appendix A (Table A 1).

Indicator Internal Reference Condition

In order to quantitatively assess the ecological health status of the UMRS, we adopted an interpretive framework which utilizes the robust long-term dataset generated by the UMRR LTRM element. Instead of using a traditional reference condition approach, we focused on identifying when a meaningful change has occurred within each RTA despite natural variability and background noise. For each indicator metric within each RTA we used a 5-year moving average to set a baseline internal "reference" condition. In addition, we used the moving average ± 1 and 2 standard deviations to serve as concern and target thresholds. We utilized 1 and 2 standard deviations in order to capture 68% and 95% of the observations, respectively. This helps ensure that any samples outside of the 2 standard deviation range constitutes a significant change in the indicator outside of an expected range based on what was observed the previous years. Further management action or additional research may be needed in RTAs in which samples are outside of the expected range in a negative direction for consecutive years. Indicator target values should, at minimum, be within the 1 standard deviation around the 5-year moving average on an annual basis. However, it may be desirable that an indicator exceed 1 standard deviation of the 5-year moving average with significant indicator changes occurring beyond 2 standard deviations. If an indicator 5-year moving average is trending in a negative manner and has exceeded the 2 standard deviations, then management intervention or additional research may be needed to determine causes of decline.

Results

Migratory Indicator

Fish species identified as migratory species (N=34; Table 1) were previously compiled in the UMRR LTRM life history database. The species included in this list varies from extensive long-distance migrants (e.g., American eel) to short-distance migrants that may move between the RTA's or move into adjacent tributaries throughout its lifetime. This larger list was reduced to an exclusive list of UMRS migrants (Table 2), comprised of sturgeon species, American eel, Paddlefish, and Alabama shad. This reduced list of UMRS migrants are thought to be directly impacted by the navigational dams and are being used to compile the migratory indicator. The species that comprise this list are rarely captured in Pools 4, 8, and 13, which results in indicator values near, or at, zero for the majority of UMRR LTRM element history.

Table 1: Common names and corresponding 4-letter fish code for each species identified as a migratory species in the UMRR LTRM Life History database. This list was reduced to a few species which were selected to represent UMRS migrants thought to be impacted by the navigational dams.

Common Name	Fish Code	Common Name	Fish Code
Alabama shad	ALSD	Northern pike	NTPK
American eel	AMEL	Paddlefish	PDFH
Black redhorse	BKRH	Pallid sturgeon	PDSG
Blue catfish	BLCF	Quillback	QLBK
Bigmouth buffalo	BMBF	Sauger	SGER
Blue sucker	BUSK	Shorthead redhorse	SHRH
Channel catfish	CNCF	Skipjack herring	SJHR
Flathead catfish	FHCF	Smallmouth buffalo	SMBF
Freshwater drum	FWDM	Smallmouth bass	SMBS
Goldeye	GDEY	Shovelnose sturgeon	SNSG
Golden redhorse	GDRH	Spotted sucker	SPSK
Highfin carpsucker	HFCS	Silver lamprey	SVLP
Lake sturgeon	LKSG	Silver redhorse	SVRH
Largemouth bass	LMBS	Walleye	WLYE
Longnose gar	LNGR	White bass	WTBS
Mooneye	MNEY	White sucker	WTSK
Northern hog sucker	NHSK	Yellow bass	YWBS

Each RTA exhibits different trends in their migratory catch-per-unit-effort over the course of UMRR LTRM sampling history (Figure 1). The highest CPUE for UMRS migrants occurred in 1998 in the La Grange reach with a total of 3.875/15 min EF run (N=434). No UMRS migrants were captured in Pools 4, 8, and 13 for 8, 10, and 14 years, respectively, out of the 22 year history of the UMRR LTRM element. In the Upper Impounded Reach (Pools 4, 8, 13) all demonstrate highly reduced catches. Open River Reach also exhibits reduced CPUEs (≤ 1 UMRS migrant/15 min EF run) with catches in 1999 and 2006 being >1 UMRS migrant/15 min EF run. The La Grange reach and Pool 26 are the only RTA's that show at least one increase (>3 UMRS migrant/15 min EF run) in UMRS migrant CPUEs, in years 1998 and 2006, respectively.

Table 2: Common names and corresponding 4-letter fish code for each species identified as a migratory species in the UMRR LTRM Life History database. This list was reduced to a few species which were selected to represent UMRS migrants thought to be impacted by the navigational dams.

Common Name	Fish Code	Common Name	Fish Code
Alabama shad	ALSD	Paddlefish	PDFH
American eel	AMEL	Pallid sturgeon	PDSG
Blue sucker	BUSK	Skipjack herring	SJHR
Lake sturgeon	LKSG	Shovelnose sturgeon	SNSG

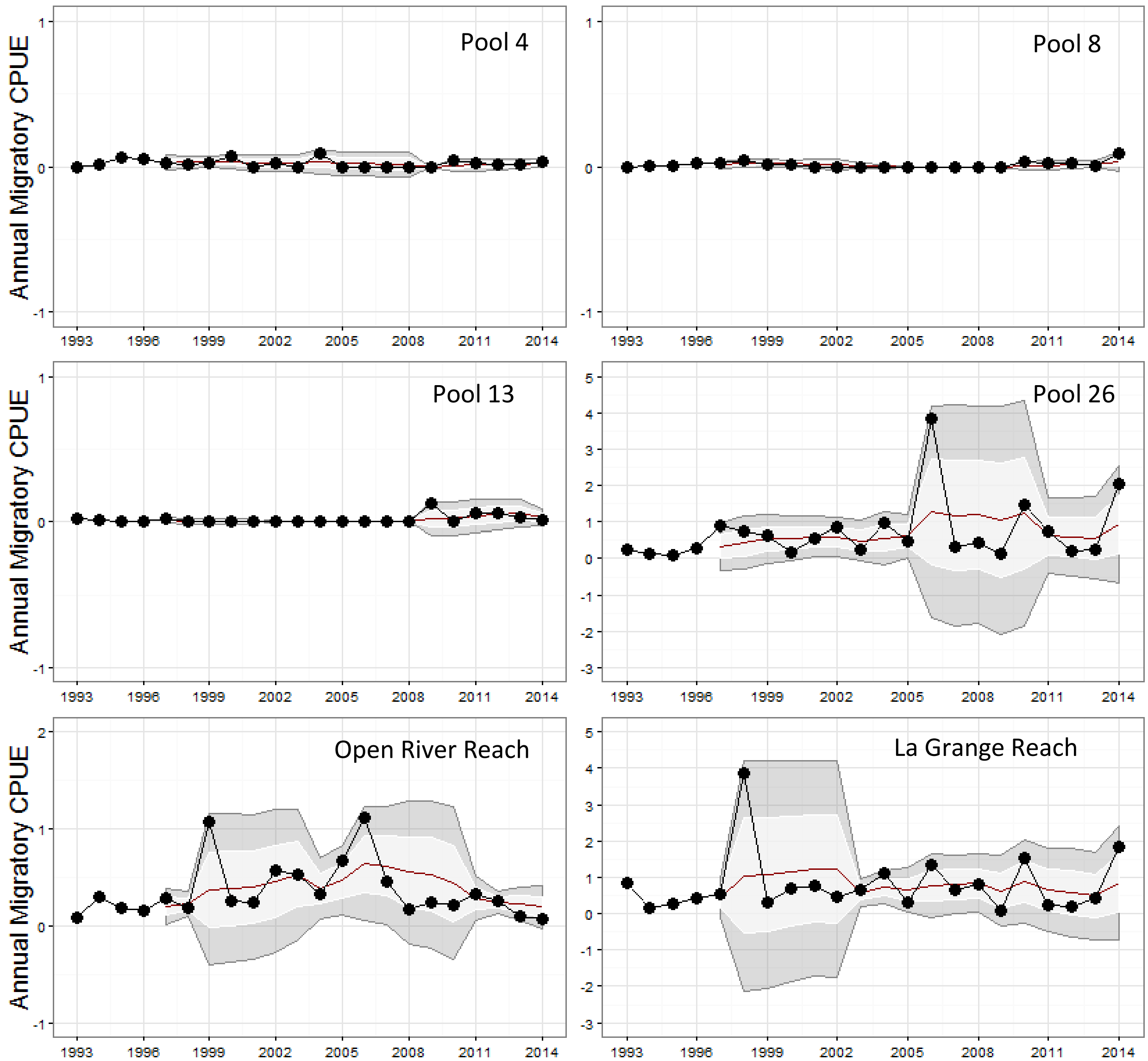

Figure 1: Ecosystem health status of UMRS migrant fish species (Table 2) was evaluated using pool-wide annual catch-per-unit-effort (CPUE; black line) compared to 5-year moving average trends (red line). The shaded areas represent 1- and 2- standard deviations around the 5-year moving average and are used to evaluate the current, and historic, status of migratory species in each pool.

Backwater Assemblage Indicator

Indicator Species Analysis identified 28 species that are indicators of the backwater strata (Table 3). The species with the highest indicator values (IndVal >0.5) are Bluegill, Largemouth bass, and Black crappie. Even though the species representing the backwater strata are also found in other areas, they are most commonly found in the backwater strata throughout the entire UMRS.

Table 3: System-wide backwater fish assemblage indicator species list which was determined by indicator species analysis. Only species with significant (p-value < 0.05) Indicator values (IndVal) are displayed. IndVal's represent the association strength between each species and the backwater habitat strata in which a value of 1 would indicate that a species is only found in one strata.

Common Name	Code	IndVal	p-value
Bluegill	BLGL	0.633	0.001
Largemouth bass	LMBS	0.535	0.001
Black crappie	BKCP	0.521	0.001
Spotted sucker	SPSK	0.443	0.001
Orangespotted sunfish	OSSF	0.44	0.001
Smallmouth buffalo	SMBF	0.428	0.003
White crappie	WTCP	0.418	0.001
Freshwater drum	FWDM	0.415	0.001
Bowfin	BWFN	0.383	0.001
Yellow perch	YWPH	0.356	0.001
Bigmouth buffalo	BMBF	0.336	0.001
Golden shiner	GDSN	0.321	0.001
Northern pike	NTPK	0.279	0.001
Western mosquitofish	MQTF	0.252	0.001
Walleye	WLYE	0.226	0.002
Pugnose minnow	PGMW	0.225	0.001
Warmouth	WRMH	0.209	0.001
Johnny darter	JYDR	0.203	0.002
Yellow bass	YWBS	0.190	0.001
Weed shiner	WDSN	0.187	0.004
Mud darter	MDDR	0.131	0.002
Brown bullhead	BNBH	0.122	0.001
Blackstripe topminnow	BTTM	0.120	0.001
Spotted gar	STGR	0.112	0.001
White sucker	WTSK	0.112	0.001
Pirate perch	PRPH	0.095	0.001
Redear sunfish	RESF	0.075	0.002
Central mudminnow	CMMW	0.062	0.015

The current trends of the backwater assemblage indicator differ among the RTAs (Figure 2). Pools 4 and 8 are the only RTAs in which an increase in the backwater assemblage indicator has been observed. In Pool 4, backwater assemblage CPUE has increased from 12.55 fish/15 min EF run in 1993 to a maximum of 40.44 fish/15 min EF run in 2012. Similar trends were observed in Pool 8 with an increase from 12.2 to 45.33 fish/15 min EF run in 2014 with a maximum CPUE of 167.20 occurring in 2003. Despite yearly fluctuation in catches, Pools 13 and 26 demonstrate steady trends in their backwater fish assemblages. The Open River and La Grange Reaches show declines in CPUE from 6.25 to 3.09 fish/15 min EF run and from 47.58 to 15.45 fish/15 min EF run, respectively. Highly reduced catches in the Open River are due to the lack of available backwater habitats in this RTA. In fact, in this RTA no backwater strata are currently sampled under UMRR LTRM protocols. However, in 1993, a historic flood caused the Miller City/Fayville levee to break (RM 34.2) resulting in the flooding of hundreds of acres of off-channel habitat. UMRR LTRM crews have been sampling a single fixed site, using standardized UMRR LTRM protocols, within this backwater area since 1996. Even though this data was not included in our analysis of the backwater indicator, we recommend that any future restoration efforts aimed to increase backwater habitat be monitored using this indicator and UMRR LTRM protocols to evaluate restoration success.

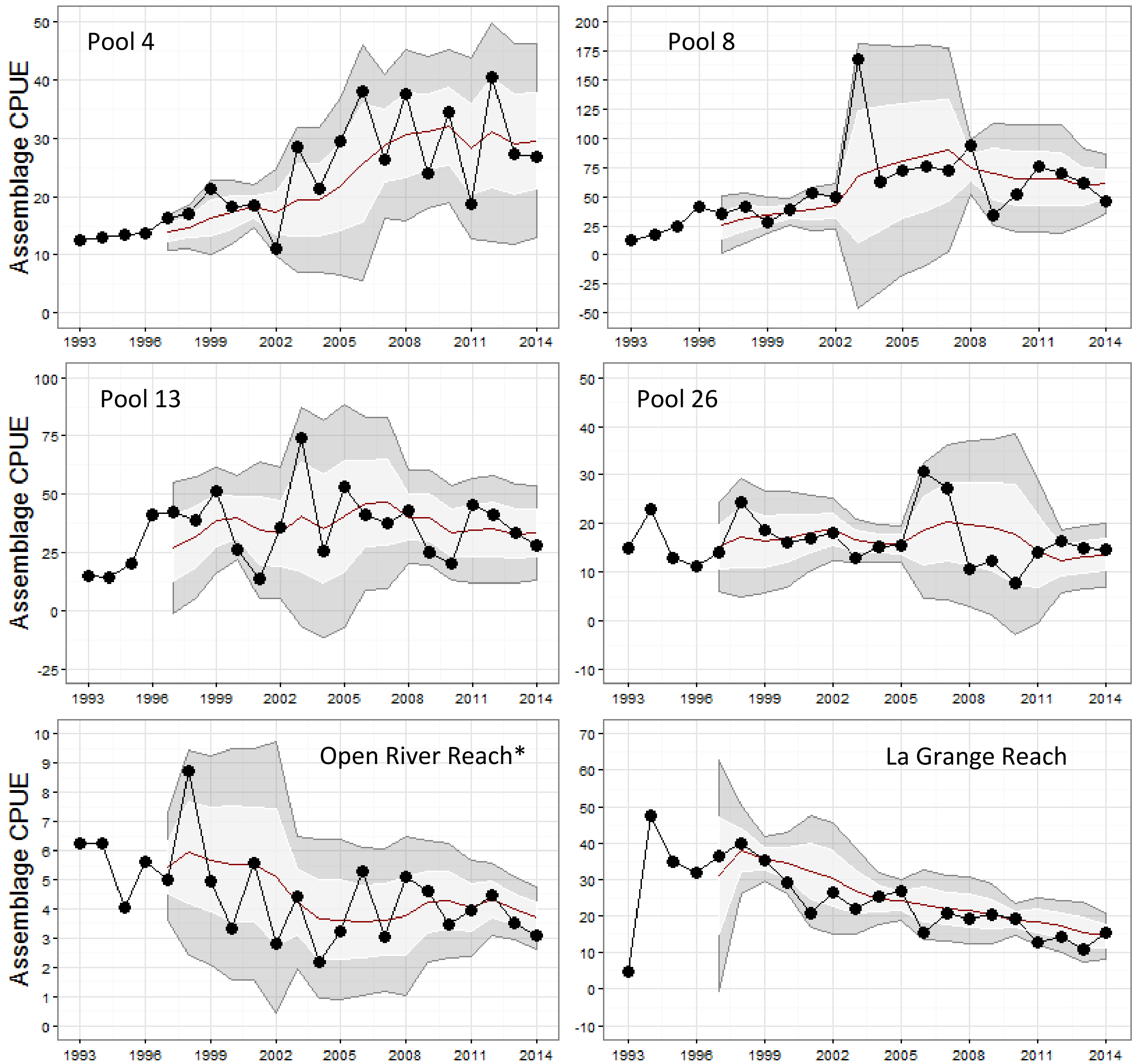

Figure 2: Ecosystem health status of backwater assemblages (Table 2) was evaluated using backwater strata annual catch-per-unit-effort (CPUE; black line) compared to 5-year moving average trends (red line). The shaded areas represent 1- and 2-standard deviations around the 5-year moving average and are used to evaluate the current, and historic, status of backwater assemblages in each pool. * The backwater assemblage indicator for the Open River Reach does not contain data from any backwater strata because of the limited availability of backwater habitats under current UMRR LTRM sampling protocols.

Indicator Recommended for Development

Based on the available data and evaluations of the previously used indicators by the UMRR Analysis Team, this working group recommends the addition of a Young-of- Year (YOY) indicator. Natural fish reproduction is typically a sign of a healthy population because:

1) Reproductive success can be influenced by a wide array of environmental and habitat variables.

2) The overall abundance and condition of juvenile and young-of-year fishes represent reproductive success and recruitment potential, both of which are vital to sustainable and healthy fish populations.
3) Young-of-year fishes make-up a highly susceptible life-history stage that is also influenced by environmental variation, such as floods.
4) Young-of-year generally have very specific habitat needs compared to adults.

We conducted a preliminary analysis of a YOY indicator (Appendix A) using length cut-offs (Appendix A; Table A 1) outlined in Barko et al. (2004) and Barko et al. (2005). After review of the preliminary analysis, it was determined that additional research is needed to determine system dependent YOY cut-off lengths for all fishes encountered in the UMRR LTRM database.

Summary

Following the recommendations of the LTRM Indicator Report (Hagerty and McCain 2013; Supplementary Material 1), we have evaluated the use of two fish community health indicators: migratory species and backwater assemblages. Membership into the migratory species indicator was determined by information compiled by UMRR LTRM personnel in the UMRR LTRM Life History database. Membership into the backwater assemblage indicator was determined using statistical analysis (i.e., Indicator Species Analysis) which objectively classified species into each stratum across the UMRR. During further discussions within the working group, an additional indicator was added: Young-of-year. The addition of this indicator attempts to fill a missing element (i.e., fish recruitment) in the current indicator list that is important to ecosystem health. This report also outlines a reference approach that not only utilizes UMRR LTRM data to its fullest extent, but also provides a practical method to evaluate the current status of the indicators. In addition, the use of the 5-year moving average provides a method to evaluate the direction of the current trend of each indicator by lessening the stochastic variation inherent in aquatic ecosystems.

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Appendix A: Young-of-Year Indicator Development

Young-of-year fishes were separated from adult fishes using reported lengths for each species following the methodology of Barko et al. (2004) and Barko et al. (2005) and can be found in Table A 1.

Young-of-Year Life Stage Results

The catch-per-unit-effort of the native young-of- year individuals is an indicator suggested to aid in assessing ecosystem health (Figure A 1). All of the indicators used in the Status and Trends (2008), and evaluated in this report, exclude young-of- year individuals. Developing an indicator that solely focuses on this vulnerable life stage may help determine problems with fish communities before they are reflected in the adult populations. The highest observed YOY CPUE occurred in the La Grange Reach in 1997 with 845.49 fish/net-night. The lowest observed YOY CPUE occurred in Pool 8 in 2009 with 2.77 fish/net-night. A slight increase in YOY CPUE is evident in Pool 4 from 27.3 fish/net-night in 2009 to 115.6 fish/net-night in 2014. Slight decreases in YOY CPUE are observed in Pool 8 and the Open River Reach. However, several recent sampling events in both RTA's have exceeded the 5-year MA indicating an increasing trend should be expected. A steady trend in native YOY CPUE is observed in Pools 13 and 26, with more recent samples collecting approximately 100 fish/net-night. The La Grange reach also has a steady decreasing trend in native YOY CPUE despite cyclical increases and decreases since approximately 2000.

Figure A 1: Ecosystem health status of young-of-the-year life stage was evaluated using pool-wide annual catch-per-unit-effort (CPUE; black line) compared to 5-year moving average trends (red line). The shaded areas represent 1- and 2- standard deviations around the 5-year moving average and are used to evaluate the current, and historic, status of the young-of-the-year life stage in each pool.

Table A 1: Common names and corresponding 4-letter fish code for each species in the Upper Mississippi River Restoration Long-term Resource Monitoring Life History database are listed below. The lengths listed for each species are described Barko et al. (2004) and Barko et al. (2005) and were used to distinguish young-of-year (YOY) individuals for indicator calculation.

Fishcode	Common Name	Length (mm)	Fishcode	Common Name	Length (mm)
AMEL	American eel	58	FHMW	Fathead minnow	23
BDDR	Banded darter	36	FKMT	Freckled madtom	49
BDSN	Bleeding shiner	33	FLER	Flier	59
BESN	Bigeye shiner	33	FWDM	Freshwater drum	112
BHCP	Bighead carp	125	GDEY	Goldeye	200
BHMW	Bullhead minnow	30	GDFH	Goldfish	152
BKBF	Black buffalo	140	GDRH	Golden redhorse	97
BKBH	Black bullhead	8	GDSN	Golden shiner	85
BKCP	Black crappie	48	GNSF	Green sunfish	25
BKSB	Brook stickleback	35	GSCP	Grass carp	200
BKSS	Brook silverside	60	GSDR	Greenside darter	64
BLCF	Blue catfish	145	GSPK	Grass pickerel	198
BLGL	Bluegill	13	GTSN	Ghost shiner	38
BMBF	Bigmouth buffalo	193	GZSD	Gizzard shad	99
BNBH	Brown bullhead	152	HFCS	Highfin carpsucker	72
BNDC	Blacknose dace	45	IDSS	Inland silverside	25
BNDR	Bluntnose darter	31	IODR	Iowa darter	34
BNMW	Bluntnose minnow	41	JYDR	Johnny darter	32
BNTT	Brown trout	193	LESF	Longear sunfish	71
BPTM	Blackspotted topminnow	28	LGPH	Logperch	74
BRBT	Burbot	145	LMBS	Largemouth bass	28
BSDR	Blackside darter	50	LNGR	Longnose gar	475
BSMW	Brassy minnow	58	MDDR	Mud darter	40
BTSN	Blacktail shiner	23	MMSN	Mimic shiner	43
BTTM	Blackstripe topminnow	28	MNEY	Mooneye	112
BUSK	Blue sucker	51	MQTF	Western mosquitofish	22
BWFN	Bowfin	177	NHSK	Northern hog sucker	38
CARP	Common carp	165	NTPK	Northern pike	190
CKCB	Creek chub	51	OSSF	Orangespotted sunfish	25
CLSR	Central stoneroller	33	PDFH	Paddlefish	102
CMMW	Central mudminnow	51	PDSN	Pallid shiner	38
CNCF	Channel catfish	53	PGMW	Pugnose minnow	36
CNLP	Chestnut lamprey	186	PNMW	Plains minnow	33
CNSN	Channel shiner	43	PNSD	Pumpkinseed	43
DYDR	Dusky darter	51	PRPH	Pirate perch	66
ERSN	Emerald shiner	33	QLBK	Quillback	241

Fishcode	Common Name	Length (mm)	Fishcode	Common Name	Length (mm)
FHCF	Flathead catfish	84	RBST	Rainbow smelt	75
RKBS	Rock bass	27	STBS	Spotted bass	53
RRDR	River darter	48	STCT	Stonecat	79
RVCS	River carpsucker	81	STGR	Spotted gar	250
RVSN	River shiner	38	STSN	Spottail shiner	38
SBSN	Silverband shiner	33	SVCB	Silver chub	52
SDBS	Striped bass	198	SVCP	Silver carp	125
SFCB	Sicklefin chub	25	SVLP	Silver lamprey	89
SFSN	Spotfin shiner	41	SVMW	Mississippi silvery minnow	50
SGER	Sauger	145	SVRH	Silver redhorse	89
SHDR	Slenderhead darter	51	TFSD	Threadfin shad	61
SHRH	Shorthead redhorse	107	TPMT	Tadpole madtom	35
SHTM	Starhead topminnow	46	TTPH	Trout perch	51
SJHR	Skipjack herring	76	WDSN	Weed shiner	29
SKCB	Speckled chub	25	WLYE	Walleye	203
SMBF	Smallmouth buffalo	61	WRMH	Warmouth	51
SMBS	Smallmouth bass	36	WSDR	Western sand darter	41
SMMW	Suckermouth minnow	56	WTBS	White bass	185
SNGR	Shortnose gar	178	WTCP	White crappie	58
SNSG	Shovelnose sturgeon	213	WTPH	White perch	90
SNSN	Sand shiner	43	WTSK	White sucker	71
SPSK	Spotted sucker	61	YLBH	Yellow bullhead	30
SPSN	Striped shiner	36	YWBS	Yellow bass	196
SRBD	Southern redbelly dace	41	YWPH	Yellow perch	66

Supplemental Material: Fish Indicators R Code

##Data Set-up##

#Packages needed:

```
library("vegan", lib.loc="~/R/win-library/3.2")
library("plyr", lib.loc="~/R/win-library/3.2")
library("reshape2", lib.loc="~/R/win-library/3.2")
library(stringr)
```

#working directory for LTRM_FISH_DATA_ENTIRE.txt

```
setwd("C:/Users/Alison Anderson/Desktop/LTRM Project Background/LTRM Data/Indicator Base Files")
```

#UMRS Site/Fish dataset

```
umrs<-read.table("LTRM_FISH_DATA_ENTIRE.txt", header=TRUE, sep=",",
col.names=c("site","barcode","fstation","sitetype","stratum","sdate","stime","fdate","ftime","pool","lco
de","gear","period","rep","summary","project","effdist","effhr","effmin","pwrgoal","pwrused","volts","
v_qf","amps","a_qf","pulses","p_qf","dutycyc","dc_qf","utmzone","utm_e","utm_n","gisgrid","zone15e
","zone15n","gpsmeth","gpsacc","secchi","s_qf","temp","t_qf","depth","d_qf","cond","c_qf","current","
cv_qf","do","do_qf","stageht","sh_qf","sveg92","vegd","eveg92","esveg92","substrt","snag","wingdyke"
,"trib","riprap","inout","closing","flooded","othrstrc","labind","contanrs","shtcnt","totfishc","leader","p
ageno","rec_site","rownum","fishcode","length","tfs","grp_wdth","catch","weight","pathcode","subproj
","userdef","recorder","nfsh_cnt","orphflag","batchno"), fill=TRUE, na.strings="NA",
nrows=1322000,quote = "")
```

#Removes "" around the values in the umrs data set

```
del <- colwise(function(x) str_replace_all(x, '\"', ""))#replaces matching values str_replace_all(x, pattern,
replacement)
umrs <- del(umrs)
umrs$catch<-as.numeric(umrs$catch)
umrs$totfishc<-as.numeric(umrs$totfishc)
```

#Pulls out the year sampled from start date and creates a new column

```
umrs$sdate<-as.Date(umrs$sdate, format="%m/%d/%Y")
umrs<-mutate(umrs, Year=format(sdate, "%Y"))
```

#Augmenting and data subsets

#removes sites unsampleable

```
umrs_subset<-subset(umrs, summary!=1&summary!=2)
```

```
#removes entries prior to 1993
umrs_subset2.1<-subset(umrs_subset,Year>1992)
#removes species with 0 catch recorded
umrs_subset2.2<-subset(umrs_subset2.1,catch>0)
#replace pool 04 with pool 4
umrs_subset3 <- mutate(umrs_subset2.2,pool=ifelse(pool=="04","4",pool))
#replace pool 08 with pool 8
umrs_subset3 <- mutate(umrs_subset3,pool=ifelse(pool=="08","8",pool))
#writes new text file.
write.table(umrs_subset3, "LTRM_FISH_DATA_SUBSET_Nov2016.txt", sep="/t")


#Attributing traits to fish caught & removing hybrids/unknown species

#bring in LTRM fish life history information
traits<-read.csv("LTRMP_LifeHistory.csv", header=T, sep=",")
#Joins life history data and LTRM base file together by fishcode
umrs_traits<-merge(umrs_subset3, traits, by.x="fishcode", by.y="Fishcode", all.x=TRUE)
#removes any blank fishcodes, there are none
umrs_completed<-umrs_traits[!(umrs_traits$fishcode==""), ]
#removes any hybrids or unknown species
umrs_completed2<-subset(umrs_completed, ID.status=="Species")
write.table(umrs_completed2, "LTRM_FISH_DATA_TRAITS_Nov2016.txt", sep="\t")

#Removing Tailwater and Tributary sites (fixed sites)

umrs_completed2<-read.table("LTRM_FISH_DATA_TRAITS_Nov2016.txt", header=TRUE, sep="\t")

umrs_srs<-subset(umrs_completed2,
stratum!="TWZ"&stratum!="TRI"&stratum!="UXO"&stratum!="CTR")

#Combining strata types

umrs_srs<-mutate(umrs_srs, stratum2=ifelse(stratum=="BWC-O"|stratum=="BWC-S", "BWC",
ifelse(stratum=="IMP-O"|stratum=="IMP-S", "IMP",

                                                   ifelse(stratum=="MCB-U"|stratum=="MCB-W",
"MCB",

                                                       ifelse(stratum=="SCB"|stratum=="SCB-
C"|stratum=="SCB-O"|stratum=="SCB-S","SCB",NA)))))

write.table(umrs_srs, "LTRM_SRS_DATA_Nov2016.txt", sep="\t")
```

#Calculating Length-based Categories

#Both Young of year (YOY) and Forge fish categories are based on length measurements and need to be calculated prior to any additional database manipulation

```
umrs_srs<-read.table("LTRM_SRS_DATA_Nov2016.txt", header=TRUE, sep="\t")#same as umrs_completed2 from previous section
umrs_yoy<-read.table("LTRM_YOY.csv", header=TRUE, sep=",")#List was compiled by B. Ickes
umrs_completed<-merge(umrs_srs, umrs_yoy, by="fishcode", all=FALSE)# 3 species were listed in the LTRM dataset that did not have a published YOY cutoff
```

#removes fish with no length recorded

```
umrs_na.rm<-umrs_completed[complete.cases(umrs_completed$length),]
```

#adds new binary column (YOY) to umrs_completed

```
umrs_na.rm<-mutate(umrs_na.rm, YOY=ifelse(length<CutoffLength,1,0))
```

#Compiles counts based on binary column (1=meets YOY criteria) and catch (# fish caught in the length range)

```
umrs_na.rm <- mutate(umrs_na.rm,YOY_Counts=YOY*catch)
```

#adds new binary column (FORGE) to umrs_completed

```
umrs_na.rm <-
mutate(umrs_na.rm,FORGE=ifelse(fishcode=="ERSN"|fishcode=="GZSD"|length<80&Native=="Native",1,0))
```

#Compiles counts based on binary column (1=meets FORGE criteria) and catch (# fish caught in the length range)

```
umrs_na.rm <- mutate(umrs_na.rm,FORGE_Counts=FORGE*catch)
```

#Adult Fish Only

#adds new binary column (ADULT) to umrs_completed

```
umrs_na.rm<-mutate(umrs_na.rm, ADULT=ifelse(length>=CutoffLength,1,0))
```

#Compiles counts based on binary column (1=meets adult criteria) and catch (# fish caught in the length range)

```
umrs_na.rm <- mutate(umrs_na.rm,ADULT_Counts=ADULT*catch)
write.table(umrs_na.rm, "LTRM_FISH_DATA_Nov2016.txt", sep="\t")
```

#Day-Time Electrofishing Only

```
umrs_na.rm<-read.table("LTRM_FISH_DATA_JUNE2016.txt", header=TRUE, sep="\t")
umrs_dayelectro<-subset(umrs_na.rm, gear=="D")
write.table(umrs_dayelectro, "LTRM_FISH_DAYELECTRO_Nov2016.txt", sep="\t")
```

#Sums Species by Pool & Strata & YEAR

```
umrs_dayelectro<-read.table("LTRM_FISH_DAYELECTRO_Nov2016.txt", header=TRUE, sep="\t")
```

```
umrs_summary<-ddply(umrs_dayelectro,
c("pool","stratum2","Year","fishcode"),summarise,Counts=sum(catch),
Forge_Abundance=sum(FORGE_Counts), YOY_Abundance=sum(YOY_Counts),
ADULT_Abundance=sum(ADULT_Counts))
umrs_pooltraits<-merge(umrs_summary,traits,by.x="fishcode", by.y="Fishcode", all.x=TRUE)
```

#FILE USED TO CALCULATE INDICATORS

```
write.csv(umrs_pooltraits, "PoolStrata_Annual_Species_Counts_Nov2016.csv")
```

 # Calculating Electrofishing Effort

```
umrs_dayelectro<-read.table("LTRM_FISH_DAYELECTRO_JUNE2016.txt", header=TRUE, sep="\t")
umrs_dayeffort<-ddply(umrs_dayelectro,
c("barcode","pool","Year","stratum2"),summarise,EFFORT=unique(effmin))
umrs_dayeffort<-mutate(umrs_dayeffort, EF_Run_Effort=EFFORT/15)
umrs_stratumeffort<-ddply(umrs_dayeffort,
c("pool","Year","stratum2"),summarise,Stratum_Effort=sum(EF_Run_Effort))
write.csv(umrs_stratumeffort, "UMRS_StrataEffortNov2016.csv")
write.csv(umrs_dayeffort, "UMRS_EFRunEffortNov2016.csv")
```

 # Mini-Fykes (YOY Indicator ONLY)

```
umrs_na.rm<-read.table("LTRM_FISH_DATA_Nov2016.txt", header=TRUE, sep="\t")
umrs_mini<-subset(umrs_na.rm, gear=="M")
write.table(umrs_mini, "LTRM_FISH_MINIFYKE_Nov2016.txt", sep="\t")
```

#Sums Species by Pool & Strata & YEAR (Mini-Fykes)

```
umrs_mini<-read.table("LTRM_FISH_MINIFYKE_Nov2016.txt", header=TRUE, sep="\t")
umrs_summary<-ddply(umrs_mini,
c("pool","stratum2","Year","fishcode"),summarise,Counts=sum(catch),
YOY_Abundance=sum(YOY_Counts), ADULT_Abundance=sum(ADULT_Counts))
umrs_pooltraits<-merge(umrs_summary,traits,by.x="fishcode", by.y="Fishcode", all.x=TRUE)
```

#FILE USED TO CALCULATE YOY INDICATOR

```
write.csv(umrs_pooltraits, "PoolStrata_Annual_Species_Counts_MiniNov2016.csv")
```

 # Calculating Mini-Fyke Effort

```
umrs_minifyke<-read.table("LTRM_FISH_MINIFYKE_Nov2016.txt", header=TRUE, sep="\t")
```

```
umrs_minieffort<-mutate(umrs_minifyke, EFFORT_Mins=effmin+(effhr*60),
EFFORT_Days=EFFORT_Mins/1440)
umrs_minieffort2<-ddply(umrs_minieffort,
c("pool","Year","stratum2","barcode"),summarise,EFFORT=unique(EFFORT_Days))
umrs_ministratumeffort<-ddply(umrs_minieffort2,
c("pool","Year","stratum2"),summarise,STRAT_EFFORT=sum(EFFORT))
umrs_minipooleffort<-ddply(umrs_ministratumeffort,
c("pool","Year"),summarise,POOL_EFFORT=sum(STRAT_EFFORT))
write.csv(umrs_minipooleffort, "UMRS_TotalPoolEffortMFNov2016.csv")
```

CALCULATING INDICATORS AND GENERATING GRAPHICS

#Packages needed:

```
library("vegan")
library("plyr")
library("reshape2")
library(stringr)
library("ggplot2")
library("TTR")
library("dplyr")
library("zoo")
library(gridExtra)
library(indicspecies)

setwd("C:/Users/Alison Anderson/Desktop/LTRM Project Background/LTRM Data/Indicator Base Files")
umrs_annual<-read.csv("PoolStrata_Annual_Species_Counts_Nov2016.csv", header=T, sep=",")
umrs_native<-subset(umrs_annual, Native=="Native")

umrs_effort<-read.csv("UMRS_StrataEffortNov2016.csv", header=T, sep=",")
umrs.pooleffort <- ddply(umrs_effort,c('pool','Year'),summarise,TOT_EFFORT=sum(Stratum_Effort,
na.rm=TRUE))

umrs.pool <- ddply(umrs_native,c('pool','Year'),mutate,TOTLPIND=sum(Counts, na.rm=TRUE),
TOT_FORGE=sum(Forge_Abundance, na.rm=TRUE), TOT_YOY=sum(YOY_Abundance, na.rm=TRUE),
TOT_ADULT=sum(ADULT_Abundance, na.rm=TRUE))
```

Migratory Indicator ADULT ONLY: Restrictive Migratory List- System Migrants###

```
umrs.migratory <-
ddply(umrs.pool,c('pool','Year','UMRS_MIGRANT'),summarise,Num_IND=sum(ADULT_Abundance))
umrs.migratory.long <-
melt(umrs.migratory,id.vars=c('pool','Year','UMRS_MIGRANT'),measure.vars=c('Num_IND'))
```

```
umrs.migratory.long <-
mutate(umrs.migratory.long,metname=paste(UMRS_MIGRANT,variable,sep='_'))
umrs.migratory.wide <- dcast(umrs.migratory.long,pool+Year~metname,value.var='value')
umrs.migratory.wide[is.na(umrs.migratory.wide)] <- 0
umrs.adult.mig.cpue<-merge(umrs.migratory.wide, umrs.pooleffort, by=c("pool", "Year"))
umrs.adult.mig.cpue<-mutate(umrs.adult.mig.cpue, MIG_CPUE=(Migrant_Num_IND/TOT_EFFORT),
TOT_CPUE=((Migrant_Num_IND+Other_Num_IND)/TOT_EFFORT))
write.csv(umrs.adult.mig.cpue,"UMRS_ADULTMigratoryAnnualNov2016.csv")
```

#Calculating 5 year moving average and SD: Full Migratory List: Adults Only #

```
pool04<-subset(umrs.adult.mig.cpue, pool=="04"|pool=="4")
pool04<-mutate(pool04,SMA_5_BWC=rollapply(pool04$MIG_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool04<-mutate(pool04,SMA_5sd_BWC=rollapply(pool04$MIG_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool08<-subset(umrs.adult.mig.cpue, pool=="08"|pool=="8")
pool08<-mutate(pool08,SMA_5_BWC=rollapply(pool08$MIG_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool08<-mutate(pool08,SMA_5sd_BWC=rollapply(pool08$MIG_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool13<-subset(umrs.adult.mig.cpue, pool=="13")
pool13<-mutate(pool13,SMA_5_BWC=rollapply(pool13$MIG_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool13<-mutate(pool13,SMA_5sd_BWC=rollapply(pool13$MIG_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool26<-subset(umrs.adult.mig.cpue, pool=="26")
pool26<-mutate(pool26,SMA_5_BWC=rollapply(pool26$MIG_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool26<-mutate(pool26,SMA_5sd_BWC=rollapply(pool26$MIG_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

poolLG<-subset(umrs.adult.mig.cpue, pool=="LG")
poolLG<-mutate(poolLG,SMA_5_BWC=rollapply(poolLG$MIG_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
poolLG<-mutate(poolLG,SMA_5sd_BWC=rollapply(poolLG$MIG_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

poolOR<-subset(umrs.adult.mig.cpue, pool=="OR")
```

```
poolOR<-mutate(poolOR,SMA_5_BWC=rollapply(poolOR$MIG_CPUE, width=5,FUN=mean, fill=NA, 
align="right"))#moving avg using previous 10 years of data
poolOR<-mutate(poolOR,SMA_5sd_BWC=rollapply(poolOR$MIG_CPUE, width=5,FUN=sd, fill=NA, 
align="right"))
```

#GRAPHICS: Full Migratory List: Adults Only #

```
P4<-ggplot(pool04, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18), 
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0), 
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-1,1),breaks=seq(-1, 1, 1))+scale_x_continuous(breaks=seq(1993, 2014, 
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)), 
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC), 
fill="white", color="white", alpha=0.7)+
  annotate("line",x=pool04$Year, y=pool04$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")


P8<-ggplot(pool08, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(), 
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0), 
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-1,1),breaks=seq(-1,1, 1))+scale_x_continuous(breaks=seq(1993, 2014, 
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)), 
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC), 
fill="white", color="white", alpha=0.7)+
  annotate("line",x=pool08$Year, y=pool08$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P13<-ggplot(pool13, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
```

```
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-1,1),breaks=seq(-1,1, 1))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=pool13$Year, y=pool13$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P26<-ggplot(pool26, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-3,5),breaks=seq(-3, 5, 1))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=pool26$Year, y=pool26$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

PLG<-ggplot(poolLG, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-3,5),breaks=seq(-3, 5, 1))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=poolLG$Year, y=poolLG$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")
```

```
POR<-ggplot(poolOR, aes(x=Year, y=MIG_CPUE))+
  theme_bw()+ylab("Annual Migratory CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-1,2),breaks=seq(-1, 2, 1))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=poolOR$Year, y=poolOR$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

grid.arrange(P4, P8, P13, P26, POR,PLG,ncol=2)
```

BACKWATER ASSEMBLAGE INDICATOR: Adults only & Pool-wide data

```
habitat.ind<-read.csv("UMRS_IndList.csv", header=T, sep=",")
umrs.ind<-merge(umrs_annual, habitat.ind, by="fishcode", all=TRUE)
umrs_native.ind<-subset(umrs.ind, Native=="Native")
umrs.hab <- ddply(umrs_native.ind,c('pool','Year'),mutate,TOTLPIND=sum(Counts))
umrs.habitat <-
ddply(umrs.hab,c('pool','HABITATIND','Year'),summarise,Num_IND=sum(ADULT_Abundance))
umrs.habitat.long <-
melt(umrs.habitat,id.vars=c('pool','HABITATIND','Year'),measure.vars=c('Num_IND'))
umrs.habitat.long <- mutate(umrs.habitat.long,metname=paste(HABITATIND,variable,sep='_'))
umrs.habitat.wide <- dcast(umrs.habitat.long,pool+Year~metname,value.var='value')
umrs.habitat.wide[is.na(umrs.habitat.wide)] <- 0
umrs.cpue<-merge(umrs.habitat.wide, umrs.pooleffort, by=c("pool","Year"))
umrs.cpue<-mutate(umrs.cpue, BWC_CPUE=(BWC_Num_IND/TOT_EFFORT))
write.csv(umrs.cpue,"UMRS_AnnualBWCADULTCPUENov2016.csv")
```

CALCULATING 5 year moving average: BW Adult indicator

```
Pool04_BWC_UMRS<-subset(umrs.cpue, pool=="4")
Pool04_BWC_UMRS<-
mutate(Pool04_BWC_UMRS,SMA_5_BWC=rollapply(Pool04_BWC_UMRS$BWC_CPUE,
width=5,FUN=mean, fill=NA, align="right"))#moving avg using previous 10 years of data
```

```
Pool04_BWC_UMRS<-
mutate(Pool04_BWC_UMRS,SMA_5sd_BWC=rollapply(Pool04_BWC_UMRS$BWC_CPUE,
width=5,FUN=sd, fill=NA, align="right"))

Pool08_BWC_UMRS<-subset(umrs.cpue, pool=="8")
Pool08_BWC_UMRS<-
mutate(Pool08_BWC_UMRS,SMA_5_BWC=rollapply(Pool08_BWC_UMRS$BWC_CPUE,
width=5,FUN=mean, fill=NA, align="right"))#moving avg using previous 10 years of data
Pool08_BWC_UMRS<-
mutate(Pool08_BWC_UMRS,SMA_5sd_BWC=rollapply(Pool08_BWC_UMRS$BWC_CPUE,
width=5,FUN=sd, fill=NA, align="right"))

Pool13_BWC_UMRS<-subset(umrs.cpue, pool=="13")
Pool13_BWC_UMRS<-
mutate(Pool13_BWC_UMRS,SMA_5_BWC=rollapply(Pool13_BWC_UMRS$BWC_CPUE,
width=5,FUN=mean, fill=NA, align="right"))#moving avg using previous 10 years of data
Pool13_BWC_UMRS<-
mutate(Pool13_BWC_UMRS,SMA_5sd_BWC=rollapply(Pool13_BWC_UMRS$BWC_CPUE,
width=5,FUN=sd, fill=NA, align="right"))

Pool26_BWC_UMRS<-subset(umrs.cpue, pool=="26")
Pool26_BWC_UMRS<-
mutate(Pool26_BWC_UMRS,SMA_5_BWC=rollapply(Pool26_BWC_UMRS$BWC_CPUE,
width=5,FUN=mean, fill=NA, align="right"))#moving avg using previous 10 years of data
Pool26_BWC_UMRS<-
mutate(Pool26_BWC_UMRS,SMA_5sd_BWC=rollapply(Pool26_BWC_UMRS$BWC_CPUE,
width=5,FUN=sd, fill=NA, align="right"))

ORR_BWC<-subset(umrs.cpue, pool=="OR")
ORR_BWC<-mutate(ORR_BWC,SMA_5_BWC=rollapply(ORR_BWC$BWC_CPUE, width=5,FUN=mean,
fill=NA, align="right"))#moving avg using previous 10 years of data
ORR_BWC<-mutate(ORR_BWC,SMA_5sd_BWC=rollapply(ORR_BWC$BWC_CPUE, width=5,FUN=sd,
fill=NA, align="right"))

LG_BWC_UMRS<-subset(umrs.cpue, pool=="LG")
LG_BWC_UMRS<-mutate(LG_BWC_UMRS,SMA_5_BWC=rollapply(LG_BWC_UMRS$BWC_CPUE,
width=5,FUN=mean, fill=NA, align="right"))#moving avg using previous 10 years of data
LG_BWC_UMRS<-mutate(LG_BWC_UMRS,SMA_5sd_BWC=rollapply(LG_BWC_UMRS$BWC_CPUE,
width=5,FUN=sd, fill=NA, align="right"))
```

#GRAPHICS: BW Indicator Adults only

```
P4_BWC_UMRS<-ggplot(Pool04_BWC_UMRS, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(0,50),breaks=seq(0, 50, 10))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=Pool04_BWC_UMRS$Year, y=Pool04_BWC_UMRS$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P8_BWC_UMRS<-ggplot(Pool08_BWC_UMRS, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-50,200),breaks=seq(-50,200, 25))+scale_x_continuous(breaks=seq(1993,
2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=Pool08_BWC_UMRS$Year, y=Pool08_BWC_UMRS$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P13_BWC_UMRS<-ggplot(Pool13_BWC_UMRS, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-25,100),breaks=seq(-25,100, 25))+scale_x_continuous(breaks=seq(1993,
2014, 3))+
```

```
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=Pool13_BWC_UMRS$Year, y=Pool13_BWC_UMRS$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P26_BWC_UMRS<-ggplot(Pool26_BWC_UMRS, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-10,50),breaks=seq(-10,50, 10))+scale_x_continuous(breaks=seq(1993,
2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=Pool26_BWC_UMRS$Year, y=Pool26_BWC_UMRS$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

OR_BWC<-ggplot(ORR_BWC, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(0,10),breaks=seq(0, 10, 1))+scale_x_continuous(breaks=seq(1993, 2014,
3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=ORR_BWC$Year, y=ORR_BWC$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

PLG_BWC_UMRS<-ggplot(LG_BWC_UMRS, aes(x=Year, y=BWC_CPUE))+
  theme_bw()+
```

```
  ylab("Assemblage CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(limits=c(-10,70),breaks=seq(-10,70, 10))+scale_x_continuous(breaks=seq(1993,
2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_BWC-(2*SMA_5sd_BWC), ymax=SMA_5_BWC+(2*SMA_5sd_BWC)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_BWC-SMA_5sd_BWC, ymax=SMA_5_BWC+SMA_5sd_BWC),
fill="white", color="white", alpha=0.7)+
  annotate("line",x=LG_BWC_UMRS$Year, y=LG_BWC_UMRS$SMA_5_BWC, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

grid.arrange(P4_BWC_UMRS, P8_BWC_UMRS, P13_BWC_UMRS, P26_BWC_UMRS,
OR_BWC,PLG_BWC_UMRS,ncol=2)
```

YOUNG OF THE YEAR INDICATOR (Native)

```
umrs_minifyke<-read.table("PoolStrata_Annual_Species_Counts_MiniNov2016.csv", header=TRUE,
sep=",")
umrs_mfeffort<-read.table("UMRS_TotalPoolEffortMFNov2016.csv", header=TRUE, sep=",")

umrs.pool <- ddply(umrs_minifyke,c('pool','Year'),mutate,TOTYOY=sum(YOY_Abundance, na.rm=TRUE))

umrs.invasive <-
ddply(umrs_minifyke,c('pool','Year','Native'),summarise,Num_YOY=sum(YOY_Abundance))
umrs.invasive.long <- melt(umrs.invasive,id.vars=c('pool','Year','Native'),measure.vars=c('Num_YOY'))
umrs.invasive.long <- mutate(umrs.invasive.long,metname=paste(Native,variable,sep='_'))
umrs.invasive.wide <- dcast(umrs.invasive.long,pool+Year~metname,value.var='value')
umrs.invasive.wide[is.na(umrs.invasive.wide)] <- 0
```

#Calculating CPUE

```
umrs.cpue<-merge(umrs.invasive.wide, umrs_mfeffort, by=c("pool","Year"))
umrs.cpue<-mutate(umrs.cpue, YOYNN_CPUE=(Nonnative_Num_YOY/POOL_EFFORT),
YOYN_CPUE=(Native_Num_YOY/POOL_EFFORT), TOTYOY=(Nonnative_Num_YOY+Native_Num_YOY),
TOTYOY_CPUE=(TOTYOY/POOL_EFFORT))

write.csv(umrs.cpue,"UMRS_YOYNativeNonNativeAnnual.csv")
```

#Calculating 5 year moving average

```
pool04<-subset(umrs.cpue, pool=="04"|pool=="4")
```

```
pool04<-mutate(pool04,SMA_5_YOY=rollapply(pool04$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool04<-mutate(pool04,SMA_5sd_YOY=rollapply(pool04$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool08<-subset(umrs.cpue, pool=="08"|pool=="8")
pool08<-mutate(pool08,SMA_5_YOY=rollapply(pool08$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool08<-mutate(pool08,SMA_5sd_YOY=rollapply(pool08$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool13<-subset(umrs.cpue, pool=="13")
pool13<-mutate(pool13,SMA_5_YOY=rollapply(pool13$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool13<-mutate(pool13,SMA_5sd_YOY=rollapply(pool13$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

pool26<-subset(umrs.cpue, pool=="26")
pool26<-mutate(pool26,SMA_5_YOY=rollapply(pool26$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
pool26<-mutate(pool26,SMA_5sd_YOY=rollapply(pool26$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

poolLG<-subset(umrs.cpue, pool=="LG")
poolLG<-mutate(poolLG,SMA_5_YOY=rollapply(poolLG$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
poolLG<-mutate(poolLG,SMA_5sd_YOY=rollapply(poolLG$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))

poolOR<-subset(umrs.cpue, pool=="OR")
poolOR<-mutate(poolOR,SMA_5_YOY=rollapply(poolOR$YOYN_CPUE, width=5,FUN=mean, fill=NA,
align="right"))#moving avg using previous 10 years of data
poolOR<-mutate(poolOR,SMA_5sd_YOY=rollapply(poolOR$YOYN_CPUE, width=5,FUN=sd, fill=NA,
align="right"))
```

#Graphics: Native YOY indicator

```
P4<-ggplot(pool04, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(0, 300, 50))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
```

```
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=pool04$Year, y=pool04$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P8<-ggplot(pool08, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(-50, 150, 50))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=pool08$Year, y=pool08$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P13<-ggplot(pool13, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(-300, 800, 100))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=pool13$Year, y=pool13$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

P26<-ggplot(pool26, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(-100, 400, 50))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
```

```
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=pool26$Year, y=pool26$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

POR<-ggplot(poolOR, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_text(size=18),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(-50, 200, 50))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=poolOR$Year, y=poolOR$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

PLG<-ggplot(poolLG, aes(x=Year, y=YOYN_CPUE))+
  theme_bw()+ylab("Annual YOY CPUE")+
  theme(plot.title=element_blank(),axis.title.y=element_blank(),
axis.title.x=element_blank(),axis.text.x=element_text(size=10, angle=0),
axis.text.y=element_text(size=10))+
  scale_y_continuous(breaks=seq(-300, 1000, 100))+scale_x_continuous(breaks=seq(1993, 2014, 3))+
  geom_ribbon(aes(ymin=SMA_5_YOY-(2*SMA_5sd_YOY), ymax=SMA_5_YOY+(2*SMA_5sd_YOY)),
fill="grey53", color="grey53", alpha=0.3)+
  geom_ribbon(aes(ymin=SMA_5_YOY-SMA_5sd_YOY, ymax=SMA_5_YOY+SMA_5sd_YOY), fill="white",
color="white", alpha=0.7)+
  annotate("line",x=poolLG$Year, y=poolLG$SMA_5_YOY, colour="darkred")+
  geom_line(colour="black")+
  geom_point(size=4,colour="black")

grid.arrange(P4, P8, P13, P26, POR, PLG, ncol=2)
```