



# ANNUAL REPORT 2020

## Aquaculture Research Institute

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# DIRECTOR'S RETROSPECTIVE

Some would describe 2020 as “unprecedented,” “chaotic,” “surreal,” “relentless” or “exhausting.” For me, it was all of these, but it was also a time to reflect and focus. Last March, I was selected to lead the Aquaculture Research Institute as its new Director. No doubt, this is an incredible honor. ARI and its partners are the driving forces behind Idaho aquaculture, which leads the US in salmonid production for human consumption, recreation, and conservation. There is a 32-year legacy of cold-water aquaculture development and fisheries management/conservation research that is unparalleled at any other US institution. I find it exhilarating to build upon that legacy and lead ARI into the future.



Change is never easy, especially with a global pandemic in the background. The retirement of Ron Hardy (prior director) and Gary Fornshell (prior extension educator) have meant adjustments for ARI and its stakeholders. I have been working closely the College of Agriculture and Life Science to fill the extension position and am optimistic to advertise within the year. Even so, we remain down a faculty position and without an associate director for Moscow operations. Due to budgetary constraints, we may not fill these positions soon; however, I am excited to be working with the College of Natural Resources toward the goal of funding an endowed aquaculture position.

Leading ARI during the economic uncertainty of 2020 made me keenly aware of the need to diversify our portfolio. If we plan to be here providing aquaculture and fisheries solutions well into the future, we will need to be innovative and resourceful. For starters, I am seeking to increase our USDA-ARS cooperative agreements, build new federal and state partnerships, and strengthen our industry and tribal partnerships. Thanks to our partners and reputation, we are building some considerable momentum in these areas.

Getting the word out is a big part of my push. Our affiliates are doing great things. ARI affiliate faculty and researchers brought in over \$2.8M in new sponsored projects and published 53 scientific journal articles in 2020. This is on top of numerous virtual outreach activities, teaching, and invited and contributed lectures by our faculty, researchers, students, and staff. I am proud to say ARI remained a stalwart research institute in 2020, with robust industry, agency, and tribal partnerships. I am looking forward to what the future will bring.

A handwritten signature in black ink, appearing to read "Brian C. Small". The signature is stylized and cursive.

Brian C. Small, ARI Director

## ABOUT ARI

Established in 1988, the Aquaculture Research Institute (ARI) is an interdisciplinary entity at the University of Idaho designed to provide a focus for aquaculture and related fisheries research by faculty throughout the University. Aquaculture is a highly diverse activity involving food production, fisheries enhancement, and fisheries stock restoration, and involves application of an array of scientific disciplines, including fish nutrition, genetics, physiology, immunology, and water quality. The Institute leads and facilitates research and education across scientific disciplines involving several Departments and Colleges across the University. ARI works closely with the commercial sector, as well as with federal, state, and tribal agencies, having formal collaborative partnerships with the US Department of Agriculture and the Columbia River Inter-Tribal Fish Commission.

ARI facilitates basic and applied research in aquaculture, focusing on rainbow trout. However, ARI also conducts research with other native and non-native species, such as Atlantic salmon, cutthroat trout, redband trout, sturgeon, burbot, tilapia, catfish, shrimp and freshwater ornamental species, including zebrafish. Research involves fish rearing studies but also basic research into the molecular, cellular, and organismal regulation of phenotypic responses to environment, diet and pathogens. ARI scientists use modern techniques and technology, such as next-gen sequencing, proteomics, metabolomics, and bioinformatics, to address research questions.

*>\$2.8M in newly funded sponsored projects*  
*>\$6.7M in continuing sponsored projects*  
*53 peer-reviewed journal articles*  
*10 technical or trade articles*  
*4 book chapters*  
*>60 invited and contributed presentations*  
*13 Ph.D. students*  
*5 M.S. students*  
*8 Postdoctoral researchers*



Research is primarily conducted at the Hagerman Fish Culture Experiment Station, located in south-central Idaho. However, ARI facilities on the Moscow campus expand research and education opportunities to include marine fish and shrimp for on-campus faculty and students. ARI research is supported by funding from a range of sources, including competitive grants, cooperative agreements, and by contracts with industry. ARI has a strong commitment to assist companies as they develop new aquaculture products, including ingredients and supplements for aquaculture feeds.

Fish nutrition and selective breeding are important aspects of ARI's research programs. Reducing the levels of fishmeal and fish oil in fish feeds is a high priority area. A long-term effort, in collaboration with the USDA, has been made to selectively breed rainbow trout that exhibit high growth performance when fed all plant-protein feeds. Reducing the environmental impacts of fish farming and understanding how the genome and environment drive phenotypic expression are other focuses of ARI research. Overall, ARI is committed to the development of environmentally sustainable aquaculture and fisheries management through advanced research and by training tomorrow's leaders in the aquaculture and fisheries fields.

# 2020 RESEARCH HIGHLIGHTS

## Feeds and Nutrition

- Evaluated numerous feeds, ingredients, and supplements in aquafeeds for rainbow trout, Atlantic salmon, burbot, tilapia, shrimp, channel catfish, largemouth bass, crucian carp, grass carp, yellow perch, and red sea bream.
- Refined feed formulation for dietary fatty acids, leading to the successful use of terrestrial oil blends in maintain fish performance and healthful omega-3 fatty acids in edible fillets.
- First nutritional requirements of cutthroat trout identified.
- First evidence that section for growth leads to increased dietary lysine requirement for optimum protein retention in rainbow trout.
- First comprehensive evaluation of protease supplementation on ingredient digestibility for rainbow trout
- Identified functional supplements for red sea bream feeds.
- Identified potential health benefits of insect meal and oil when fed to rainbow trout.

## Genetics and Genomics

- Developed new and novel genomic tools for Pacific salmonids, lamprey, steelhead trout, white sturgeon, and red band trout to increase our understanding of fish biology and genetics and inform management decisions.
- Using whole genome resequencing, revealed genomic regions associated with thermal adaptation in redband trout.
- Candidate markers validated for adult migration timing and fitness in Chinook Salmon.
- Demonstrated steelhead trout lineages and sexes show variable patterns of association of adult migration-timing and age-at-maturity traits.

## Physiology and Health

- Identified the role of photoperiod on precocious maturation in Chinook salmon.
- Elucidated the impact of chromosomal manipulation (triploidy) on zinc metabolism and oxidative stress in rainbow trout.
- Created the first triploid burbot for aquaculture production in North America.
- Showed negative impacts of environmental cadmium on channel catfish.
- Characterized the gastrointestinal microbiota of rainbow trout, Atlantic salmon, and paddlefish.
- Revealed changes in oral tolerance, microbiota and growth in rainbow trout selected on a plant-based diet.
- Evaluated vaccine efficacy and immune function in rainbow trout and burbot.

# FACILITIES



## Hagerman Fish Culture Experiment Station

The Hagerman Fish Culture Experiment Station is in south-central Idaho approximately 90 miles southeast of Boise, Idaho, the state capital. The University of Idaho leased the facility from the US Fish & Wildlife Service in 1996 and took possession of the 4-acre property in 1998. In 2006, a new 14,000 ft<sup>2</sup> building was dedicated, and included offices, a classroom, and analytical laboratories. A six-bedroom dormitory and additional fish rearing buildings were also constructed, augmenting existing fish rearing facilities and providing housing for trainees and visiting scholars.

Hagerman Station features a 6000 ft<sup>2</sup> wet lab supplied with 2000 gpm, 14.5°C, gravity-fed, first-use spring water. The wet lab contains 142 38-gallon (145-liter) and 42 152-gallon (450-liter) tanks for conducting comprehensive experimental procedures. Egg incubators and hatchery small troughs are used for incubating eggs and start-feeding trout fry. Quarantine facilities with the capacity to heat or chill water and to sterilize the effluent are in a separate, biosecure building. Physiological and behavioral studies can be conducted in a common garden environment consisting of three recirculating aquaculture systems and utilizing state-of-the-art swimming, respirometry, and cardiac output chambers. Thirty covered outdoor tanks utilize second-use water and are suitable for raising groups of fish to maturity. Outdoor, 1/3 scale raceways (8 total) complete the fish rearing facilities. The Hagerman Station also has extensive analytical laboratories used to support research in feeds, molecular biology, population genetics and genomics, including next-gen sequencing.

## Cold Water Laboratory

The 8000 ft<sup>2</sup> Cold Water Laboratory operates on the Moscow campus as a water-limited recirculating facility. There are currently seven independent recirculating systems on backup power that can accommodate a variety of cold-water species, including salmonid species and sturgeon. The facility also



maintains one warmwater system for rearing tilapia. Each system has independent chilling/heating, biofiltration, and UV treatment. The largest system has four four-meter diameter tanks for rearing of large populations or broodstock. The other systems are high-replicate systems, comprised of as many as 66 tanks. The Cold Water Lab has capabilities to incubate eggs in Heath tray incubators and McDonald jars. Fry can also be held in fiberglass troughs and fed with either single pass or recirculating water. Temperatures in the systems can be maintained between 4 °C and 20 °C. The Moscow Cold Water Lab facilities are available to researchers across the University for a nominal fee.

## Aquatic Animal Research Facility



In 2019, the University completed construction of the Aquatic Animal Research Facility (AARF) on the Moscow campus. Adjacent to the Cold Water Laboratory, this two-story facility boasts office and classroom space coupled with a state-of-the-art 4000 ft<sup>2</sup> wet lab. The AARF also operates as a water-limited recirculating facility. There are currently four independent recirculating systems with backup power. Three of these systems were specifically designed to facilitate new species development. A live-feed room to produce artemia and rotifers supports this work. The fourth system is a dedicated, high-replicate marine system suited for shrimp and marine fish research.

## Bozeman Fish Technology Center

Through a cooperative agreement with the USDA/ARS Trout Feeds Program, ARI researchers have access to state-of-the-art diet manufacturing equipment for making fish feeds at the Bozeman Fish Technology Center, Montana. This includes a variety of equipment including a hammer mill, air swept pulverizer, mixers of various sizes and types, pelleting equipment including a Buhler twin screw extruder, feed drier, and a vacuum coater for oil addition.



# PEOPLE

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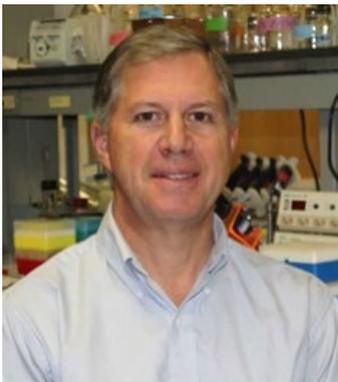


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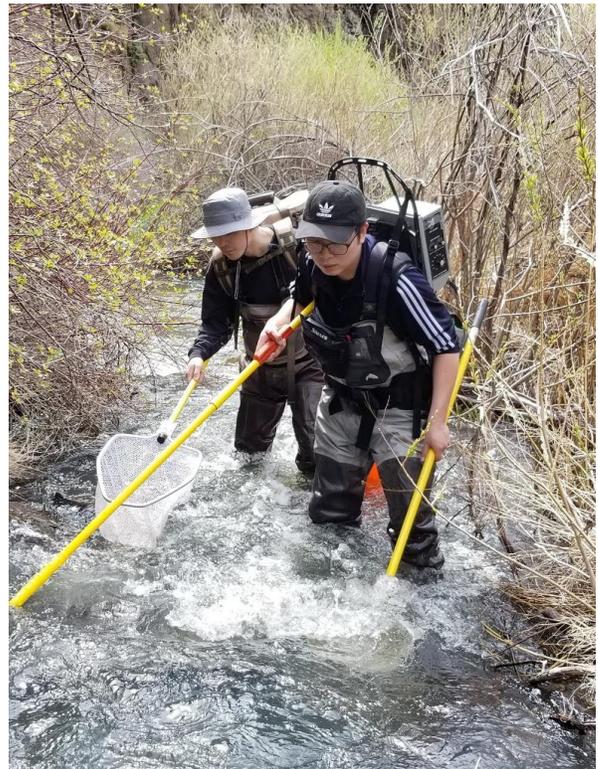
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## MOSCOW AQUATIC ANIMAL RESEARCH FACILITY

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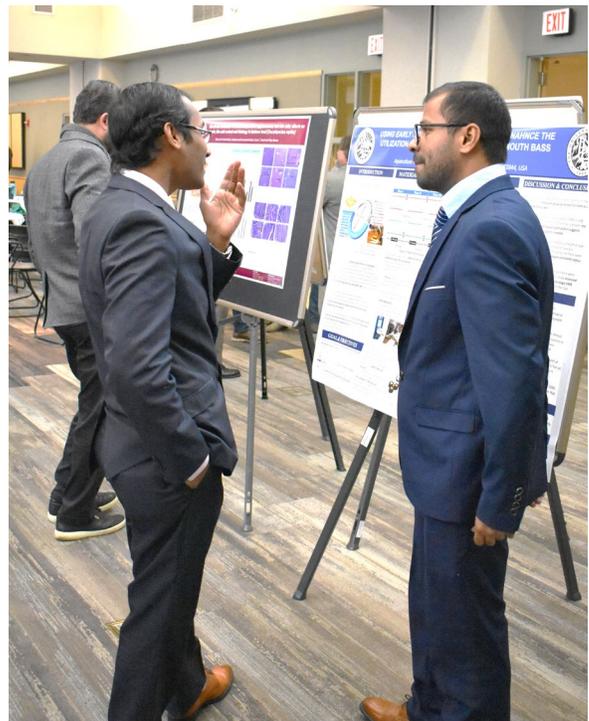
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## BOZEMAN FISH TECHNOLOGY CENTER

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## Trainees

### Visiting Scholars

Dr. Samad Amirkolaei, Sari Agricultural Sciences and Natural Resources University, Iran

Dr. Femi Fawole, University of Ilorin, Nigeria

Dr. Mo Peng, Jiangxi Agricultural University, China

Dr. Shyam Narayan Labh, Tribhuvan University, Nepal

Dr. Gang Yang, Nanchang University, China

Dr. Hector Hernandez, National Autonomous University of Mexico (UNAM), Mexico

Ms. Susana Gomez, Ph.D. student, UNAM, Mexico

## Postdoctoral Researchers

Dr. Tim Bruce  
 Dr. Tim Cavileer  
 Dr. Zhongqi Chen  
 Dr. Jie (Jessie) Ma  
 Dr. Lea Medeiros  
 Dr. Md. Hossain Sakhawat  
 Dr. Travis Seaborn  
 Dr. Hui (“William”) Wang

## Graduate Students

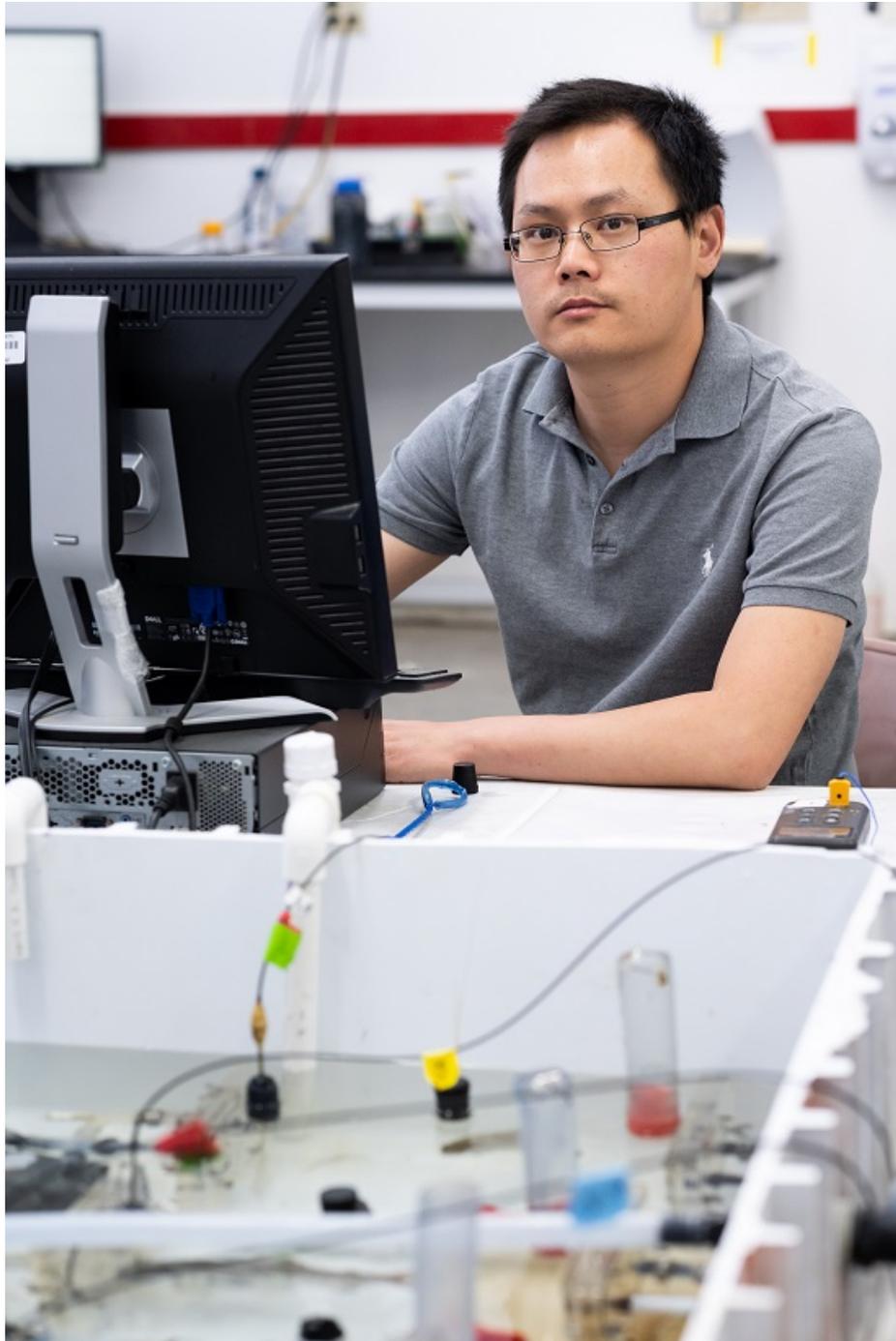
Neil Ashton, Ph.D. in Natural Resources  
 Rance Bare, Ph.D. in Biological Engineering  
 Jacob Bledsoe, Ph.D. in Natural Resources  
 Marina Rubio Benito, Ph.D. in Animal Physiology  
 Nicholas Hoffman, Ph.D. in Biological Sciences  
 Jeongwhui Hong, Ph.D. in Natural Resources  
 Kimia Kajbaf, Ph.D. in Animal Physiology  
 Jonathan Massingale, Ph.D. in Natural Resources  
 Moureen Matuha, Ph.D. in Natural Resources  
 Kristen Meiler, M.S. in Animal Physiology  
 Luke Oliver, Ph.D. in Natural Resources  
 Jose Ortiz, M.S. in Natural Resources  
 Melanie Regan, Ph.D. in Natural Resources  
 Carlie Sharpes, M.S. in Environmental Sciences  
 Ethan Struhs, Ph.D. in Biological Engineering  
 Christine Trahan, M.S. in Natural Resources  
 Amit Yadiv, Ph.D. in Animal Physiology  
 Tsung-Yu (Daniel) Tsai, M.S. in Animal Physiology



## Undergraduate Interns

Malulani Jenkins, College of Natural Resources

Jose Ortiz, College of Natural Resources



# BY THE NUMBERS

## Formal Research Collaboration

1. PI: B.C. Small; Columbia River Inter-Tribal Fish Commission (CRITFC); Est. 2000
2. PI: B.C. Small; USDA Agriculture Research Service, Aberdeen, ID (Cooperative Agreement); Est. 1999
3. PI: B.C. Small; USDA Agricultural Research Service, Franklin, ME (Cooperative Agreement); Est. 2017
4. PI: B.C. Small; USDA Agricultural Research Service, Madison, WI (Cooperative Agreement); Est. 2020

## New Sponsored Projects

1. 2020-2021; PI: B.C. Small; *Private feed company*. Evaluation of ME-PRO digestibility and efficacy as a fish meal replacement in relation to other alternative protein feedstuffs for rainbow trout. (\$55,311).
2. 2020-2021; PI: B.C. Small; *Illinois Corn Marketing Board*, National Corn Ethanol Research Center subaward. Utilization of Corn Ethanol byproduct in Atlantic Salmon feeds. (\$57,174).
3. 2020-2021; PI: B.C. Small; *Private feed company*. Feed benchmarking during grow-out. (\$35,567).
- 2020-2021; PI: B.C. Small; *USDA Agricultural Research Service*. Effect of trout strain on digestibility of alfalfa meal. (\$29,797).
4. 2020-2021; PI: B.C. Small; USDA Agricultural Research Service. Research Towards Precision Salmonid Feeds. (\$18,000).
5. 2020; coPI: M.S. Powell. *PAPIIT (Programa de Apoyo a Proyectos de Investigacion e Innovacion Tecnologica) Mexico*. Estudio sobre el uso de proteinas, lipidos y carbohidratos en la dieta del langostino *Macrobrachium acanthurus*, (\$10,000).
6. 2020-2021; PI: M.S. Powell, coPI: K. Overturf, W. Sealey. *Hatch*. Improving Utilization of Alternate Protein and Oil Sources in Rainbow Trout. (\$2,125).
7. 2020-2024; PI: W.M Sealey, coPI: M.S. Powell. *Western Regional Aquaculture Center*. Mixing up an optimal diet for white sturgeon grow out. (\$423,921).
8. 2020-2021; PI: V. Kumar. *Ohio Soybean council*. Functional feed additive to mitigate the gastrointestinal inflammation in commercial rainbow trout caused by high levels of dietary soybean meal. (\$30,000).

9. 2020-2021; PI: V. Kumar. *Private feed company*. Improving the plant ingredients utilization in Nile tilapia via dietary supplementation of xylanase. (\$35,000).
10. 2020-2023; coPI: V. Kumar. *USDA NIFA Foundational Program*. Whole-genome analyses/selection to increase muscle yield and reduce fillet". (\$498,984).
11. 2020-2021; PI: V. Kumar. *Private feed company*. Practical applications of commercial Jefe feed additives (AG175 and AQUANAT *Synergy*) to improve the gut health of rainbow trout. (\$75,614).
12. 2019-2020; PI: V. Kumar. *Private feed company*. Metabolomics investigation of dietary effects on growth performance and survival in white-leg shrimp, *Litopenaeus vannamei*". (\$23,046).
13. 2020-2021; PI: V. Kumar. *Hawaii Feed & Fertilizer LLC. (National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Department of Commerce)*. Assessing the feasibility of a local Hawaiian fishmeal for white-leg shrimp, *Litopenaeus vannamei* diet. (\$56,482).
14. 2020-2021; PI: T. Bruce. *USDA NIFA Educational and Workforce Development (Postdoctoral Fellowship; Project 2018-08177)*. Investigation of gut microbiota, physiological stress response and immune parameters in cultured burbot. (\$159,829)
15. 2020-2023; PI: K.D Cain; *Western Regional Aquaculture Center (WRAC)*. Emerging and re-emerging Flavobacterial pathogens in Aquaculture. (\$326,125)
16. 2020-2021; PI: K.D. Cain; *Private feed company*. Evaluation of survival and immune response to IHNV challenge in juvenile rainbow trout fed commercial health-promoting diets. (\$29,970).
17. 2020-2021; PI: K.D. Cain; *Private animal health company*. Coldwater vaccine optimization for licensing and commercialization. (\$222,250).
18. 2020; PI: K.D. Cain; *Private feed company*. Evaluation of commercial and experimental starter (and grow out) diets for Atlantic Salmon. (\$25,880).
19. 2020-2021; PI: J. Nagler; *Columbia River Inter-Tribal Fish Commission*. The physiology of kelt reconditioning X: developing strategies to increase iteroparity in Snake River steelhead. (\$254,000).
20. 2020-2021; PI: J. Nagler; *Columbia River Inter-Tribal Fish Commission*. Effect of parent age in rate of minijack production among male progeny of spring Chinook IV. (\$218,547).
21. 2019-2022; PI: C.C. Caudill. *USFS, Pacific Northwest Research Station*. Investigating the influence of watershed variability on meta-food web dynamics and salmonid growth in southeast Alaskan streams. (\$262,746).

## Continuing and/or Terminating Sponsored Projects

1. 2019-2024; P.I. B.C. Small; USDA Agricultural Research Service. Improving the Competitiveness of Rainbow Trout Production by the Integrated Development of Improved Feedstuffs, Feeds, and Trout. (\$1,446,600).
2. 2020; PI: B.C. Small; *Columbia River Inter-Tribal Fish Commission*. Hagerman Fish Culture Experiment Station Laboratory Supplies. (\$1,493,901).
3. 2019-2020; P.I. B.C. Small; Private feed company. Evaluation of omega-3-fortified canola oil as a fish oil substitution fed to rainbow trout (*Oncorhynchus mykiss*) over a production cycle. (\$59,999).
4. 2019-2020; P.I. B.C. Small; Private feed company. Blind Study of Trout Feed Formulations. (\$68,852).
5. 2019-2020; P.I. V. Kumar; Ohio Soybean Council. Evaluation of soybean-based diets for commercial scale farming of yellow perch and rainbow trout. (\$69,939).
6. 2019-2020; PI: T. Welker, coPI: M.S Powell, K. Overturf. USDA-ARS Antimicrobial Resistance (AMR) or Alternatives to Antibiotics (ATA) funding opportunity. The use of organic acids and essential oils in rainbow trout and hybrid striped bass feeds to alleviate the use of antibiotics. (\$67,300).
7. 2019-2020; coPI: M. Powell. *Univ. of Idaho FCS Small Grants*. Nutrition education strategies to increase trout consumption in children and families for inflammatory and cognitive benefit. (\$12,000).
8. 2019-2021; PI: T. Welker, coPI: M.S Powell. *USDA-NIFA Aquaculture Program*. Waste Management and Water Quality Improvement on Commercial Trout Farms through Nutritional Strategies. \$183,805 (of \$299,369 total). Oct. 2019-Sep. 2022
9. 2019-2020; PI: V. Kumar. *U.S. Soybean Export Council (USSEC)*. Performance evaluation of tilapia fed soybean meals produced from United States and Brazil origin. (\$50,305).
10. 2019-2020; PI: V. Kumar. *Private feed company*. Insect protein acts as an additive to establish a novel natural gut health in Rainbow trout. (\$25,508).
11. 2019-2020; PI: V. Kumar. *Private feed company*. Evaluation of growth performance, nutrient retention, water quality, metamorphosis, seed quality and survival of *Litopenaeus vannamei* using microencapsulated and enhanced particle diets that are designed to be used in conjunction with live *Artemia* and that are engineered to be environmentally sustainable (\$74,999).

12. 2018-2021; PI: V. Kumar. *Soy Aquaculture Alliance*. Indirect criteria to select the farmed fish lines to enhance the efficiency of soybean meal utilization in their diet. (\$169,159).
13. 2018-2023; coPI: Chris Caudill, coLead: B.C. Small; NSF-EPSCoR. RII Track-1: Linking Genome to Phenome to Predict Adaptive Responses of Organisms to Changing Landscapes. (\$24,000,000 total; >\$1M to Caudill and Small).
14. 2018-2021; P.I. V. Kumar; Private feed company. Dietary requirements and metabolic roles of organic and inorganic mineral (Zinc) in a commercial strain of RBT and effects on fillet quality. (299,790); P.I. V. Kumar, co-PI's R. Hardy, B. Small
15. 2018-2020; P.I. V. Kumar; Soy Aquaculture Alliance. Alternative approach to select the farmed fish strains to enhance the efficiency of soybean meal utilization in their diet. (\$124,159).
16. 2019-2023; PI: K.D. Cain; Cain, coPI: T. Bruce, J. Ma. Western Regional Aquaculture Center. Development of oral vaccine delivery methods for prevention of disease in finfish culture, (\$479,000).
17. 2017-2021; coPI: K.D. Cain. *USDA-NIFA*. Understanding the duration and mechanisms of long-lasting protection of nasal vaccines in rainbow trout. (\$500,000).
18. 2017-2021; PI: K. Cain, coPI: G. Fornshell. *Western Regional Aquaculture Center*. Developing "freshwater cod" or burbot (*Lota lota*) into a viable commercial aquaculture species in the United States. (\$444,783).
19. 2019-2020; PI: C.C. Caudill. *USACE Portland District-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation*. Evaluation of interim management strategies for adult Chinook salmon and winter steelhead at Big Cliff and Detroit Dams: above- versus below-dam adult outplanting, (\$68,500).
20. 2019-2020; PI: C.C. Caudill. *USACE Portland District-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation*. Evaluation of alternative outplant methods in relation to temperature and spawning success of natural-origin adult Chinook salmon collected at the Foster Adult Fish Facility. (\$61,550).

## Peer-Reviewed Papers Published

1. Abdel-Gawad, F., Kumar, V. et al. 2020. The Duckweed, *Lemna minor* Modulates Heavy Metal-Induced Oxidative Stress in the Nile Tilapia, *Oreochromis niloticus*. *Water* 12(11). DOI: 10.3390/w12112983
2. Blaufuss, P., Bledsoe, J., Gaylord, G., Sealey, W., Overturf, K., and Powell, M. 2020. Selection on a plant-based diet reveals changes in oral tolerance, microbiota and growth in rainbow trout (*Oncorhynchus mykiss*) when fed a high soy diet. *Aquaculture*. doi.org/10.1016/j.aquaculture.2020.735287.
3. Brezas, A. & Hardy, R.W. 2020. Improved performance of a rainbow trout selected strain is associated with protein digestion rates and synchronization of amino acid absorption. *Scientific Reports*. <https://doi.org/10.1038/s41598-020-61360-0>
4. Bruce, T.J., J. Ma, J., C. Knupp, T.P. Loch, M. Faisal, and K.D. Cain. 2020. Cross-protection of a live- attenuated *Flavobacterium psychrophilum* immersion vaccine against novel *Flavobacterium* spp. and *Chryseobacterium* spp. strains. *Journal of Fish Diseases* 43(8):915-928.
5. Bruce, T.J., J. Ma, L. P. Oliver, B.R. Lafrentz, and K.D. Cain. 2020. Isolation and experimental challenge of cultured burbot (*Lota lota maculosa*) with *Flavobacterium columnare* and *Aeromonas* sp. isolates. *Journal of Fish Diseases* 43(8):839-851.
6. Bruce, T.J., S. Gulen, L.P. Oliver, J. Ma, and K.D. Cain. 2020. Evaluation of commercial and experimental grower diets for use in intensive burbot (*Lota lota maculosa*) culture. *Aquaculture* 528:735490.
7. Chen, Z, Narum, SR. 2020. Whole genome resequencing reveals genomic regions associated with thermal adaptation in redband trout. *Molecular Ecology* 30: 162-174. <https://doi.org/10.1111/mec.15717>
8. Collins, EE, Hargrove, JS, Delomas, TA, and SR Narum. 2020. Distribution of genetic variation underlying adult migration timing in steelhead of the Columbia River basin. *Ecology and Evolution*; 10: 9486- 9502. <https://doi.org/10.1002/ece3.6641>
9. Medeiros LR, Nagler JJ, Pierce AL. 2020. Establishment of Time-Resolved Fluoroimmunoassays for Detection of Growth Hormone and Insulin-like Growth Factor I in Rainbow Trout Plasma. *Comp. Biochem. Physiol. Part A* 110751.
10. Dunkle, M.R., R.T. Lampman, A.D. Jackson, and C.C. Caudill. 2020. Factors affecting fate of Pacific lamprey carcasses and resource transport to riparian and stream macrohabitats. *Freshwater Biology*. <https://doi.org/10.1111/fwb.13510>.

11. Habte-Tsion, H-M., Kolimadu, G., Waldemar Rossi W., Kumar, V. 2020. Effects of Schizochytrium and micro-minerals on the immune, antioxidant, inflammatory, and lipid metabolism status of Largemouth bass (*Micropterus salmoides*) fed high and low fishmeal diets". *Scientific Reports*. (Nature Publisher). *Scientific Reports* 10(1):7457. DOI: 10.1038/s41598-020-64286-9.
12. Happel, A., W.M. Sealey, C.A. Myrick and M.S. Powell. 2020. Effects of varying dietary levels of digestible protein and digestible energy on growth performance in juvenile cutthroat trout (*Oncorhynchus clarkii*) *Aquaculture Reports* 17:100336
13. Hargrove, J., C.A. Camacho, W.C. Schrader, J.H. Powell, T.A. Delomas, J.E. Hess, S.R. Narum, M.R. Campbell. 2020. Parentage-based tagging improves escapement estimates for ESA-listed adult Chinook Salmon and Steelhead in the Snake River basin. *Canadian Journal of Fisheries and Aquatic Sciences*, DOI: 10.1139/cjfas-2020-0152.
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15. Hess, J. S. Jeremiah, N. Timoshevskaya, C. Baker, C.C. Caudill, D. Graves, M.L. Keefer, M. Moser, L. Porter, G. Silver, S. Whitlock, and S. Narum. 2020. Genomic islands of divergence infer a phenotypic landscape in Pacific lamprey. *Molecular Ecology*. 29 (20), 3841-3856. <https://doi.org/10.1111/mec.15605>
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18. Hossain, M.S., Sony, N.M., Koshio, S., Kumar, V. 2020. Comparative assessment of purine nucleotides adenosine, guanosine and inosine monophosphates as functional supplements on growth and health performances of red sea bream, *Pagrus major* juvenile. *Aquaculture Nutrition*. DOI: 10.1111/anu.13177
19. Hossain, M.S., Sony, N.M., Koshio, S., Kumar, V. 2020. Long term feeding effects of functional supplement 'cytidine monophosphate' on red sea bream, *Pagrus major* performances. *Aquaculture*. DOI: 10.1016/j.aquaculture.2020.736150
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25. Kumar, V., Fawole, N. Romano, M.S. Hossain, S. Labh, K. Overturf, B. Small. 2020. Insect (black soldier fly, *Hermetia illucens*) meal supplementation prevents the soybean meal-induced intestinal enteritis in rainbow trout and health benefits of using insect oil. Fish and Shellfish Immunology, 109:116-124.
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31. Lee, S., M.K. Chowdhury, R.W. Hardy, and B.C. Small. 2020. Apparent digestibility of protein, amino acids and gross energy in rainbow trout fed various feed ingredients with or without protease. *Aquaculture*, p.735270. DOI: 10.1016/j.aquaculture.2020.735270
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35. Meiler, K., Kumar, V. 2020. Organic and Inorganic Zinc in the Diet of a Commercial Strain of Diploid and Triploid Rainbow Trout (*Oncorhynchus mykiss*): Effects on Performance and Mineral retention. *British Journal of Nutrition*. (Submitted)
36. Narum, S.R., J. Kelley, and B. Sibbett. 2020. Editorial. *Molecular Ecology Resources* 20:1-13.
37. Oliver, L.P., J. Ma, T.J. Bruce, J.T. Evavold, D.B. Korb, and K.D. Cain. 2020. Triploid induction in cultured burbot (*Lota lota*) using thermal and hydrostatic shock. *Aquaculture* 515:734582.
38. Paul, J. and B.C. Small. 2020. Chronic exposure to environmental cadmium affects growth and survival, cellular stress, and glucose metabolism in juvenile channel catfish (*Ictalurus punctatus*). *Aquatic Toxicology*, 230:105705. DOI: 10.1016/j.aquatox.2020.105705.
39. Ragaza, A.R., Hossain, S.M., Meiler, K., Kumar, V. 2020. A review on Spirulina: alternative media for cultivation and nutritive value as an aquafeed. *Reviews in Aquaculture*. DOI: 10.1111/raq.12439
40. Romano, N., Kumar, V., Yang, G., Kajbaf, K., Rubio, M., Overturf, K., Brezas, A., and Hardy, R. 2020. Bile acid metabolism in fish: disturbances caused by fishmeal

- alternatives and some mitigating effects from dietary bile inclusions. *Reviews in Aquaculture*. doi: 10.1111/raq.12410.
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46. Yadav, A.K., Waldemar Rossi W., Habte-Tsion, H-M., Kumar, V. 2020. Impacts of dietary eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) level and ratio on the growth, fatty acids composition and hepatic-antioxidant status of largemouth bass (*Micropterus salmoides*). *Aquaculture*. DOI: 10.1016/j.aquaculture.2020.735683
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DOI: 10.1111/are.14411
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## Peer Reviewed Papers Submitted

1. Amirkolaie, A.K., Small, B.C., and Kumar, V. In Review. Bile acid supplementation in alternative lipid (soybean oil and fat powder) based diets: Effects on growth, histology (liver and intestine) and digestibility in Rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*.
2. Bruce, T.J., J. Ma, and K.D. Cain. In Press. Quantification and comparison of iron regulation and metabolism in a virulent and attenuated strain of *Flavobacterium psychrophilum*. *Journal of Fish Diseases*.
3. Bruce, T.J., Ma, J., Jones, E.M., Vuglar, B.M., Oliver, L.P. and Cain, K.D. In Press. Assessment of *Flavobacterium psychrophilum* strain virulence in Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*). *Journal of fish Diseases*.
4. Fawole, J.F., Hossain, M.S., Overturf, K., Small, B.C. Hardy, R., Kumar, V. In Review. Insect oil as a potential substitute for fish/soy oil in the fish meal-based diet of Rainbow trout (*Oncorhynchus mykiss*). *Animal Nutrition*.

5. Fuchs, N.T., C.C. Caudill, A.R. Murdoch, and B.L. Truscott. In Press. Overwintering distribution and post-spawn survival of Steelhead in the upper Columbia River Basin. In final revision, North American Journal of Fisheries Management.
6. Granados, Y.V., S.A.F. Gómez, L.H.H. Hernández, M.S. Powell and F. Vega-Villasante. In Press. Effects of mannooligosaccharides and fructooligosaccharides on the growth and non-specific immune responses of juvenile freshwater prawn *Macrobrachium acanthurus*. Latin American Journal of Aquatic Science.
7. Hossain, M.S., F. Fawole, S. Labh, K. Overturf, B.C. Small, V. Kumar. In Press. Insect meal inclusion as a novel feed ingredient in soya-based diets improves performances of rainbow trout (*Oncorhynchus mykiss*). Aquaculture.
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12. Seaborn, T., D. Griffith, A. Kliskey, and C.C. Caudill. In press. Building a Bridge Between Definitions and Concepts of Adaptive Capacity and Adaptive Potential. Global Change Biology.
13. Syms, J.C., M.A. Kirk, C.C. Caudill, and D. Tonina. In Press. A biologically based measure of turbulence intensity for predicting Pacific lamprey passage behaviors. Journal of Ecohydraulics.
14. Wang, H., T. Seaborn, Z. Wang, C.C. Caudill, and T.E. Link. In Review. Modeling tree canopy height using machine learning over mixed vegetation landscapes. Journal of Applied Earth Observations and Geoinformation.

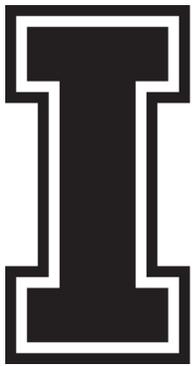
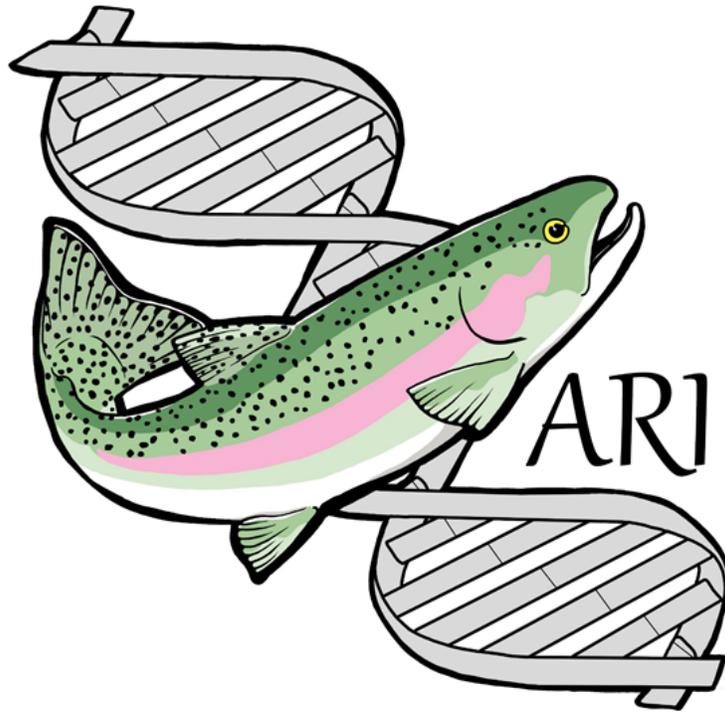
## Trade Articles and Technical Bulletins

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8. The freshwater cod with a Lota potential for farming. The Fish Site. 2020.  
<https://thefishsite.com/articles/the-freshwater-cod-with-a-lota-potential-for-farming>
9. Hardy, R. and C.C. Caudill. 2020. Investigating the Nature vs. Nurture Question. The Researcher-Idaho NSF EPSCoR Spring Newsletter pg. 5-6.
10. Seaborn, T., and C.C. Caudill. 2020. Simulating Trout Distribution to Understand Environmental Change. The Researcher-Idaho NSF EPSCoR Fall Newsletter pg. 5-6.

## Book Chapters

1. Bledsoe J.W. and B.C. Small. In press. Current status and impacts of direct fed microbials in aquaculture” In: Callaway, T.R. and S.C. Ricke, (Eds.), Direct Fed Microbials/Prebiotics for Animals: Science and Mechanisms of Action: 2nd Edition, Springer: Verlag, New York.
2. Kumar, V., Hossain, S.M., Benito M.R., Ragaza, J.A. 2020. The Potential Impacts of Soy Protein on Fish Gut Health in the book “Soybean for Human Consumption and Animal Feed”. Editor: Aleksandra Sudarić. Publisher: IntechOpen. ISBN: 978-1-83881-019-1. Print ISBN: 978-1-83881-018-4. eBook (PDF) ISBN: 978-1-83881-020-7.
3. Ragaza, A.R., Hossain, M.S., Kumar, V. 2020. The potential of invasive alien fish species as novel aquafeed ingredients in the book “Sustainable Aquafeeds: Technological Innovation and Novel Ingredients”. Editors: Jesús Simal (University of Vigo, Spain) and Jose M. Lorenzo (Centro Tecnológico de la Carne, Spain). Publisher: CRC Press, Taylor & Francis Group, LLC.
4. Small, B.C. In press. Nutritional Physiology, In: Hardy, R.H., (Ed), Fish Nutrition, 4th Edition. Academic Press, Amsterdam.





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