02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Delia S Shelton

Gender: ☐ Male ☒ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☒ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☐

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 15-1

NSF 15-501

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NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

DBI - Minority Postdoctoral Research Fellowships

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
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IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

Shelton Delia S

AWARDEE ORGANIZATION CODE (IF KNOWN)

P269966604

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

2712 S Banta Ave.
Bloomington, IN 47403

NAME OF PRIMARY PLACE OF PERF

Indiana University

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE

Indiana University
1001 E. 10th St.
Bloomington ,IN ,474057007 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

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TITLE OF PROPOSED PROJECT **NSF Postdoctoral Fellowship in Biology FY 2016**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **138,000**	**36** months	**09/01/16**	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☒ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date **Planned**
PHS Animal Welfare Assurance Number _____
☒ FUNDING MECHANISM **Fellowship**

☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☒ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
CA GM
☒ COLLABORATIVE STATUS
Not a collaborative proposal

PI/PD DEPARTMENT
Biology

PI/PD FAX NUMBER

PI/PD POSTAL ADDRESS
2712 S Banta Ave.

Bloomington, IN 47403
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Delia S Shelton**	**PhD**	**2016**	**678-431-0516**	**delsshel@indiana.edu**
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

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Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
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(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

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(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research. The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

Application Form

NAME

Shelton	Delia	S.		
Last	First	MI	TITLE	Other Names Used

MAILING ADDRESS for correspondence. It is imperative that you keep NSF informed of a current mailing address.
2712 S Banta Ave.
Bloomington IN 47403

CURRENT ADDRESS (if different from Permanent Mailing Address):

CURRENT E-MAIL ADDRESS: delsshel@indiana.edu

TELEPHONE NUMBERS:
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FAX number:

CURRENT POSITION
Department Biology
Institution Indiana University
Type of Institution PhD granting
Title of Position PhD Candidate
Date this position started 08/24/2010
Source of support Research Assistant

CITIZENSHIP (check one)
✖ US Citizen or National ___ Permanent Resident ___ Foreign National(give country: ___)
If you are a Permanent Resident you must provide your Permanent Resident Registration Number:

HIGHEST DEGREE EARNED: PhD YEAR CONFERRED: 2016

DOCTORAL DEGREE
Department and Institution Biology Indiana University
Date awarded or anticipated date of receipt 05/11/2016

PROPOSED FELLOWSHIP INSTITUTION including department and address
University of Windsor Biological Sciences
401 Sunset Dr.
Windsor, Ontario, Canada

PROPOSED SPONSORING SCIENTIFIC ADVISOR OR MENTOR including title, e-mail address, telephone and FAX numbers:
Higgs Dennis M
Associate Professor dhiggs@uwindsor.ca
(519)253-3000
(Telephone) (FAX)

BRIEF TITLE of your proposed research or field of study:
DEVELOPING GROUPS AND THEIR RESPONSE TO ANTHROPOGENIC CHANGE

Application Form

REFERENCES(do not use your mentor).

	Name	Department	Institution	Phone
1.	Martins Emilia P.	Biology	Indiana University	(812)856-5840
2.	Hurley Laura M.	Biology	Indiana University	(812)856-1991
3.				
4.				

EXPECTED STARTING DATE OF FELLOWSHIP: 09/2016 (Month, year) DURATION OF TENURE: 36 (# of months)

OTHER SUPPORT

Have you applied for any other fellowships or similar appointments for all or part of the tenure herein requested? NO

If so, name of agency or program _____

Have you ever received any NSF postdoctoral fellowship? NO

If yes, when and from what program? _____

Please provide the following information:

OTHER INSTITUTION AND SPONSOR if short-term international experience is proposed

_____

PROJECT SUMMARY

Overview:

Human-induced Rapid Environmental Change (HIREC) is expected to have profound effects on bio-diversity at multiple levels of organization [1]. Like individuals or species, some groups will be able to respond effectively, whereas others will perish in response to anthropogenic change. Identifying successful and susceptible social groups will allow conservationists to detect and then intervene for at-risk social groups, or create more resilient groups. Given that changes in behavior and physiology are intricately linked [2,3], individual variation in physiology is expected to impact individuals that reside in groups, and the group?s response to anthropogenic change [4,5]. This proposal will use a powerful combination of modeling and empirical techniques to understand the social organization of groups, how they develop, and remain resilient against anthropogenic change. This work will be sponsored by Dennis Higgs, University of Windsor, and Jens Krause, Leibniz-Institute.

Intellectual Merit :

By studying how groups develop, we can learn more about successful (e.g. starling flocks) and endangered (e.g. honey bee colonies) group organizations. This information can lead us to predict which groups are resilient (or not) to anthropogenic change. We can then create a system for early detection and design intervention plans to prevent further degradation of at-risk groups. To examine intra-group variation in response to HIREC, the present work will integrate two powerful frameworks (i.e., collective behavior models and personality) used to study animal behavior. The findings from the proposed work can better inform collective behavior models and enhance their predictive value through providing information about parameters important for group organization. The use of high throughput sensory, aggression and dominance assays will provide a more comprehensive understanding of the relationship between traits and particular social roles. The project will establish a link between intra-group variation and group-level complexity, by studying the relationship between individual differences and group social properties. Elucidating the importance of physiological characteristics in organizing the social structure of groups is potentially transformative, because it proposes a novel and, perhaps, a more parsimonious modulator of group dynamics. Products of this research will be of broad interest to a diverse group of scientists, including conservationists, sensory physiologists, and computer scientists.

Broader Impacts :

The applicant is woman of color who is committed to outreach and education and this project presents a unique opportunity to increase individuals from underrepresented groups in STEM through local and global action. Locally, the mentor Higgs and others at the University of Windsor have recently launched a 4Winds STEM Native Outreach group to help recruit first-nation students into STEM fields. Through 4Winds, she will give public talks and organize workshops on agent-based modeling and social network analysis. She will recruit students from underrepresented groups to serve as research assistants. For global efforts, the applicant will also develop a communal mentoring program through the Animal Behavior Society’s (ABS) Charles H. Turner initiative, a program designed to increase representation of undergraduates from underrepresented groups at the meeting. For each student, she will create a personalized mentoring team. She expects this combination of mentors will serve different roles (e.g., recruiter- potential PhD advisor), as the student progresses through the STEM pipeline. The ABS mentoring program has garnered support from the society and was endorsed by the ABS Diversity Committee Chair, Daniel Howard. The products of the project will be added to Dryrad, a digital repository, and EthoSource [6], a guide for sharing and combining animal behavior work; She will publish open-access datasets, add experimental videos, and make available open-source interactive models for predicting group organizations. She will disseminate the results to three main audiences, 1) the scientific community (e.g., publications, datasets), 2) undergraduate students (e.g., mentoring), and 3) the public (i.e., seminars, workshops). She will assess her broader impacts yearly by tracking interactions on her Academia, Researchgate and Figshare accounts, collecting anonymous feedback from guest lectures, following the progress of mentored students and program participants, and quantifying the number of new collaborations and mentorships gained.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

DEVELOPING GROUPS AND THEIR RESPONSE TO ANTHROPOGENIC CHANGE

INTRODUCTION

Anthropogenic change is predicted to have profound effects on biodiversity leading to unprecedented levels of extinction, yet some species are expected to survive and flourish [1]. Although the effects of Human-Induced Rapid Environmental change (HIREC) will permeate all levels of biological organization, most studies have focused on the responses of the extreme levels of organization, such as lower-level organization (e.g., individuals), and higher-level organization (e.g. species). The impact of these non-random effects on mid-level organization (e.g., groups) is expected to be pervasive, as group formations are prevalent amongst almost all animal taxa [7]. For example, approximately 75% of fish species form schools during their development [8], 50% of bird species form feeding flocks [9], and 2% insects species are social constituting 75% of insect biomass [10,11]. However, the response of groups to HIREC has largely been ignored, which represents a bottleneck in our predictive ability, because unique non-additive group-level responses to stressors cannot be simply extrapolated from studying single individuals. This knowledge gap stems, in part, from the perception that groups, which may contain thousands of individuals and tens of thousands of links, are too complex to be easily predictable. However, technological innovation, and integration of modeling and empirical techniques have provided evidence that the structure and dynamics of even very complex groups might be derived from a few relatively simple behavioral rules (e.g., alignment, attraction, avoidance). In addition, some consequences of HIREC may be hidden at lower- and higher-levels of organization [12], but revealed at the group-level, thus group responses may be more sensitive than other levels of organization for detecting consequences of HIREC. The multi-level consequences can be represented with social networks, as it provides a framework for analysis at three main levels: 1) individual, 2) dydadic (pair-wise associations), and the group or population (network). To complement current phenomenological approaches used to predict the impacts of anthropogenic change, **I propose to examine group-level organization, the development of social ties between individuals, and the response of these ties to HIREC by integrating empirical and modeling approaches.**

A key area in complex systems is understanding how living systems become organized. Much has been learned about the organization of living systems by modeling the interactions of identical independent agents using very similar behavioral rules (e.g., attraction, avoidance, alignment). We also know, however, that individuals within social groups are often strikingly different in terms of their behavior, for example, engaging in different social roles within that group (e.g., leaders, followers). Individual phenotypes (e.g. aggression, sensory sensitivity) may serve as the basis for structuring social relationships. Individuals with similar dominance statuses tend to have stronger ties in parrot social networks [13], and individuals with impaired sensory systems tend to be more aggressive [14,15], which may allow them to exert greater influence on the group [16,17]. Experimental ablation of individual traits is the most convincing way to identify individual phenotypes important for structuring social relationships, but this has practical limitations. This challenge can be partly overcome by combining experiments with modeling approaches such as agent-based models (ABMs). While modeling approaches can be highly useful in predicting group outcomes based on different dynamics they are often constrained by a lack of empirical data. Consequently, there is a need to integrate observational data with models and manipulative studies in order to determine the importance of individual characteristics (e.g., sensory sensitivity and dominance) in structuring social relationships.

Environmental perturbations may influence the frequency of the interactions. For example, guppies exposed to turbid conditions form smaller less cohesive shoals and spend more time alone than fish in clear water [18], and birds and frogs in noisy conditions call more to conspecifics. Changes in social dynamics may be mediated by environmental disturbances that affect sensory systems. For example, noisy conditions often mask calls and require that individuals involved in the interaction alter their behavior to enhance communication or risk loss of communication. Examining the response of different network ties to HIREC will allow me to determine whether some social interactions are more resilient to anthropogenic change than others.

Zebrafish are an ideal choice because they are conducive to studying social behavior in the laboratory [19,20], and their sensory systems are well characterized [21–24]. Lateral lines are composed of mechanosensory hair cells that detect vibration and pressure gradients caused by other organisms [25], and its development scales with body size [26]. The lateral line system is important for social interactions, as it is involved in maintaining inter-individual distances [27]. Zebrafish are found in shoals of

2-300 fish [28,29], which requires a small number of individuals to reflect ecologically relevant social groups; therefore, larger sample sizes can be obtained in laboratories, where space is limited. In these small shoals zebrafish maintain short inter-individual distances [30], develop dominance hierarchies, and often chase each other [31]; these behaviors can be used to create undirected and directed social networks. Zebrafish are native to India, Nepal, and Pakistan, regions experiencing rising levels of pollution. For example, there is increased noise pollution from greater activity in waterways, which may impact auditory sensitivity [32,33]. Moreover, zebrafish sensory systems are models for human pathologies (e.g. hearing loss) [34], and used to assay toxic pollutants [35].

RESEARCH PLAN

Research Objectives

The primary objective of this proposal is to investigate group architecture and its response to challenges using computational and empirical approaches. The proposal will address the following questions:

Aim 1- Organizing Principles: Can simple rules of homophily, heterophily, and random assortment predict group organization?
Aim 2- Key Observations: Are phenotypes linked with particular network positions?
Aim 3- Building Successful Groups: Are homophilic ties more resilient to anthropogenic change than heterophilic ties?

Method

I will use a sensory assay, aggression and dominance tests, controlled anthropogenic disturbances, and Agent-Based Models (ABM) with network analysis to address the proposed questions.

Aim 1. Organizing Principles: Can simple rules of homophily, heterophily, or random assortment predict group organization?

The principles that guide group organization may be based on similarities or differences among individuals. Homophily structures network ties according to similarity and suggests that contact between similar individuals occurs at higher rates than among dissimilar individuals [36,37]. For example, many fish prefer to shoal with fish that have similar body size as themselves [38,39]. Similarity, however, in some character traits can lead to avoidance. For example, female animals tend to avoid males with similar Major Histocompatability Complex (MHC), but seek males with different MHC when looking for mates [40–42]. Indeed, another organizing principle is heterophily, or a tendency for opposites to attract and form connections [43]. In some cases, outright individual similarity or differences may not characterize how relationships form and individuals may try to balance between similarity and some dimension of differentiation [44]. Overt characteristics such as body size have been posited as a phenotype for organizing social structure, as this trait can be detected with a number of sensory modalities and scales lawfully with other characteristics such as aggression and dominance [45].

Method: To determine if groups organize by homophily, heterophily, a complicated interaction between the two, or randomly assort I will use a combination of experimental and Netlogo ABM [46] approaches. ABM is necessitated by the practically prohibitive number of permutations of individual differences and similarities that may serve as the scaffold for social relationships.

Agent-based models are ideal because they accommodate sliding scale parameters, which can allow me to simulate different outcomes by changing parameters. In the model, four parameters will be manipulated: 1) group size, 2) variation in individuals with different body sizes 3) attraction to individuals with similar or different characteristics, and 4) sensing of individual phenotypes. For each simulation, the social network structure will be assessed across time and the profiles of agents in different network positions will be characterized (Fig. 1). To test the model's predictions, I will experimentally create groups using parameters from the model that yielded the cleanest predictions. That is, groups will be composed of the size and individual variation that will provide the greatest statistical power for detecting the phenomenon using network metrics. To examine the development of group organization in zebrafish shoals, fish of known body size will be placed together and filmed continuously for 3h, as relatively stable social relationships begin to form within this time period [47,48]. At fixed intervals, connectivity of the

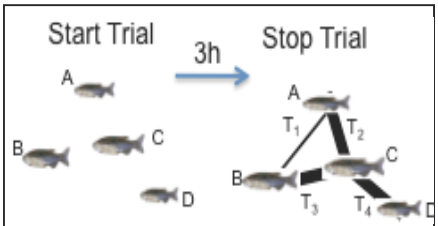

Figure 1.Tie formation (T_1 –T_4) for fish A-D. C is central with high degree and D is on the periphery with low degree. $T_{2\text{-}4}$ are strong and T_1 is weak.

network will be assessed to quantify the degree to which individuals can be considered as part of the same social group over time. I will then use computational methods to compare observed networks against model predictions and null models [49,50]. I will use information theoretic approaches, linear mixed models to determine the relationship between body size and affiliative network metrics [51–54]. To assess dynamic social networks, I will collaborate with Krause and colleagues on developing models and customized code to track multiple interacting zebrafish over time.

Predictions: If fish social organizations are structured by homophily, then I predict that the most similar individuals in the group will be the foci for the organization, and additional ties will radiate out according to degree of similarity. In addition, we expect members closer to the edge of the group's niche will be more dissimilar from the average group phenotype. If heterophily guides social organization, then we expect that the most dissimilar individuals will serve as the foci for the group and additional ties will be initiated according to degree of dissimilarity. Instead, groups could organize by random individual assortment. If some groups randomly assort and others show preferences, then some personalities maybe more conducive to some organizing principles than others (see Aim 2). Deviations from model predictions and significant differences among empirical evaluations will provide clues for important mechanisms.

Aim 2. Key Observations:Are individual phenotypes associated with particular network positions?

A myriad of traits have been linked to individuals with different positions in the network. In some cases, individuals with more central positions in the network are larger, more aggressive, or experienced, whereas in others, central individuals are relatively non-aggressive and physiologically distinct from other members [55,56]. I propose that network positions (e.g., central, peripheral) are driven by suites of correlated traits that are highly dependent on how individuals sense and interact with their social environment. I therefore hypothesize that social roles in zebrafish are largely shaped by sensory abilities and aggression.

Method: I will use results from Aim 1 to identify a group size and sample size that is ideal for obtaining detectable variation in network metrics. For each shoal, a focal fish will be selected. Half of the focal fish will be sensory impaired and the others will serve as a control. I will use neomycin an antibiotic that induces hair cell death in the lateral line to impair fish. The effects of this pharmacological technique are reversible, as zebrafish show rapid regeneration of the lateral line system in 24-48h [57]. These focal fish will be returned to the group. The shoals will be recorded for offline network analysis after the fish have been housed together for a day, as zebrafish shoals are relatively stable after this time [48]. I will then phenotype all group members using **high throughput screening assays for sensory sensitivity, aggression, and dominance** developed by Higgs and colleagues at University of Windsor. I will use a fluvial tank to behaviorally assess lateral line function by exposing fish to 5 different flow rates (0 – 12 cm/s) for 120 s and then recording the presence (or absence) of rheotaxis, movement towards the flow. To measure auditory responses I will use the high-throughput auditory-evoked behavior response [58]. I will assess pair-wise interactions (e.g., displacement) for every combination of individuals to construct **dominance hierarchies** for each group, which has been previously validated. A simple way to assess **aggression** is present fish with a mirror, and the reflection of individual fish is sufficient to generate reliable measures of aggression [59]. With guidance from Krause and use of his collaborator's custom built tracking software**,** I will create undirected proximity networks and directed networks based on chases, and use static metrics to identify network structure of the zebrafish shoals. I will then use principal component analysis to identify traits (e.g., dominance rank, aggression, sensory sensitivity) that contribute the most in grouping individuals according to centrality and degree. Finally, I will evaluate model fit to the empirical data using information theoretic approaches [51].

Predictions: Aggression is often used to establish dominance, and hyper-aggressive individuals tend to have a disproportionate effect on the group [16]. I predict these more aggressive individuals will have higher centrality, because they are the primary initiators of interactions. Agonistic interactions involve sensory cues, and levels of aggression during encounters are linked to differential sensory system function [14]. For example, acute impairments in visual function increases aggression [15]. Thus, these hyper-aggressive central individuals may have poorer sensory sensitivity than non-aggressive individuals. In some cases, the relationship between sensory sensitivity and aggression may be complicated by dominance. For example, sensory-impaired dominant crayfish become hyper-aggressive, whereas impaired subordinates do not increase their levels of aggression [14]. In this scenario, I predict dominant and relatively subordinate individuals will have high centrality, as these individuals are the directors and targets of aggression, and, consequently, tied to many other individuals in the group. These dominant and subordinate individuals will vary along an aggression and sensory sensitivity axis. That is, dominant

central individuals will be aggressive and show decreased sensory sensitivity, and subordinate central will be relatively non-aggressive and show high sensory sensitivity.

Aim 3. Building Successful Groups: Are homophilic ties more resilient to anthropogenic change than heterophilic ties?

Human-induced rapid environmental change poses a significant threat to biodiversity by altering ecosystem function and health. Aquatic organisms are expected to experience elevated noise levels [60,61]. Sensory system impairment can have profound effects on social interactions, as they are the gateway for sensation and perception of conspecifics. Not all social relationships are equal, as some are predicted to disintegrate, whereas others are expected to persist in the presence of a disturbance [37,62,63]. Here, I propose to identify social ties that predict a group's ability to cope with HIREC, by examining the response of network ties to sensory-tuned forms of human-induced disturbances.

Method: I will phenotype all individuals using behavioral and sensory assays described in Aim 2. Model predictions and power analyses from Aim 1 will inform the group size, composition, and sample size of tested shoals. I will then assess the network structure of groups classifying ties as homophilic or heterophilic (Fig. 2b). Next, I will expose groups of zebrafish to auditory disturbances, by presenting them with elevated noise levels. Underwater sound stimuli will have the following properties 0.3–4.0 kHz, 142 dB [33]. I will then determine if homophilic ties are maintained longer than heterophilic ties after a disturbance (Fig. 2c). To determine if a tie is lost or maintained, I will assess individual connectivity for the network before and immediately after the disturbance. After exposure to the pollutant, I will compare the average retention of homophilic and heterophilic ties using a Mann-Whitney test, and compare results to model predictions. I will then update Aim 1 model to incorporate a HIREC parameter.

A.

Ties	Sensory	Dominance	Aggression
T_1 (A-B)	hetero	hetero	homo
T_2 (A-C)	homo	homo	hetero
T_3 (B-C)	homo	homo	homo
T_4 (C-D)	hetero	hetero	hetero

B.

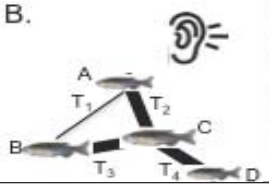

Figure 2. A) Ties (T_1 –T_4) will be classified as hetero- or homophilic according to individual fish (A-D) sensory and behavioral assay results. B) In response to auditory pollution, weak ties (T_1) may break.

Predictions: If homophily helps connections persist during times of crisis or trouble, then homophilic ties will persist longer in the face of the disturbance. That is, connections between fish with similar phenotpyes should remain in the network longer than heterophilic ties in the face of HIREC. Alternatively, heterophilic ties may persist longer as optimal heterophily enhances smooth communication among social networks. If heterophilic ties are more resilient than homophilic ties in a changing environment, then homophilic ties should be less apparent in the network than heterophilic ties after exposure to the disturbance. Homophilic ties that persist may reflect similarity in sensory sensitivity and minimize loss of information during transmission events, whereas heterophilic ties that are resilient may reflect optimally heterophilic ties that enhance transmission of information among diverse members.

JUSTIFICATION OF SPONSORING SCIENTISTS AND HOST INSTITUTIONS

Drs. Dennis Higgs and Jens Krause are ideal co-sponsors because their research interests, skill sets and outreach activities would enhance this project's intellectual development, practical implementation, and broadening participation objectives. Higgs is an associate professor and head of the Dept. of Biology at the University of Windsor. He is known for his work in understanding organization of sensory processing in the brain and across development in aquatic vertebrates (e.g. zebrafish) in a variety of habitats (e.g., polluted, novel) [26,64,65]. Higgs is actively involved in various outreach initiatives at University of Windsor, including 4Winds STEM & Beginning Time Teaching – a collaborative group that encourages Aboriginal/First Nations high school students to consider post secondary education, especially in STEM fields through science camps and workshops. Krause is a Professor and head of Biology and Ecology of fishes at Leibniz-Institute. He is an experimental biologist that integrates modeling and social network approaches to understand mechanisms and functions of group-living in animals [66]. He has made significant contributions to the use of social network analyses to understand group structure and social interactions and their functional consequences [67–69]. His experimental and modeling background will be valuable in navigating the statistical complexities of this project.

I will split time between the University of Windsor where I will conduct all experimental portions (except Aim 1) of the project and Leibniz-Institute where I will conduct all analyses and modeling components (see Time Line). The **University of Windsor is a mecca for sensory ecology research of aquatic**

vertebrates and home to the Great Lakes Institute for Environmental Research (GLIER), which address environmental problems that cross conventional disciplinary boundaries such as the effects of multiple environmental stressors on lakes their watersheds and inhabitants. I will also spend a significant amount of time at **Leibniz-Institute for modeling and social networks mentorship** and collaboration opportunities at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries. My interests fit within the research scope of current grad students and postdocs in Higgs' and Krause's labs, which will provide excellent platforms for mentorship and sharing skills. Both universities have strong collaborative environments that will allow me to learn cutting-edge sensory physiological assays, social network and modeling techniques from faculty across the Biology, Biochemistry, Computer Science and Psychology departments. I will be **continually engaged with both** hosts through Skype when at the other host institution.

RESEARCH SIGNIFICANCE AND BROADER IMPACTS

The present work will integrate two powerful frameworks used to study animal behavior. The findings from the proposed work can better inform collective behavior models and enhance their predictive value through providing information about parameters important for group behavior. The project will establish a link between intra-group variation and group-level complexity, by studying the relationship between individual differences in sensory physiology, social structure, and the group's response to HIREC. Elucidating the importance of sensory physiology in organizing the social structure of groups is potentially transformative because it **proposes a novel and, perhaps, a more parsimonious modulator of group dynamics**. Further, studying the response of mid-level organizations to anthropogenic stressors fills a knowledge gap between the effects of HIREC on lower- and higher-levels of organization.

All research products will be open-access on websites (i.e., Netlogo, figshare) and publications will be hosted on ResearchGate, when possible. **I practice open science**; my research products, and publications are publicly available, with the goal of broad dissemination and generating reproducible research. Because the study involves zebrafish, a popular model organism, our methods will also be useful for geneticists, developmental biologists, and eco-toxicologists, in the form of assays to phenotype vertebrates, protocols to assess social roles, and information relevant to the effects of contaminants on the behavior and physiology of zebrafish. The results of the study will be disseminated broadly via presentations at local, national, and international conferences, scholarly journals, and public lectures.

I will host a workshop that will give students experience with ABM by allowing them to manipulate and customize publically available Netlogo models [46]. Higgs has previously implemented ABMs in his courses and will provide mentorship. Through games and demonstrations, **I will expose K-12 students and undergraduates to sensory systems and social networks**, which are key topics in my proposed work. For example, cohorts of students will create interaction networks with classmates when they have sensory restrictions (e.g., vision elimination: closed eyes, hearing elimination: ear plugs), and during the process they will experience disturbances (e.g., loud radio, low light) that will mimic the anthropogenic challenges that may impact animal social networks.

BROADENING PARTICIPATION

My previous activities – and proposed programs – highlight my desire to increase diversity and inclusion in the sciences. As a woman of color in STEM, I have benefited greatly from mentoring. I also understand the **transformative power of mentors,** as a former Title 1 high school science teacher and graduate mentor of 18 undergraduates and 4 high school students in full-time summer research programs or multi-week academic year internships. The students were from diverse backgrounds, 15 women, 12 people of color, 2 first generation college students, and 1 veteran. Under my guidance two students co-authored a paper [30], 11 students have presented at local and national conferences, and five students have pursued graduate training. In 2013, my NSF-REU intern and I were featured in a short film about the impact of the NSF Animal Behavior-REU, which has been viewed over 2,393 times (as of 21 Oct. 2015). I can neither attribute my recruitment and retention in STEM nor the success of my mentees to a single individual, as multiple mentors have guided us through the STEM pipeline (i.e., from secondary school, graduate school, and now a postdoc). A program that has been instrumental in retaining my interest in animal behavior is the Animal Behavior Society's (ABS) Charles H. Turner Program, a program designed to increase representation of undergraduates from underrepresented groups at the meeting. As a post-doc, I will join the ABS diversity committee with the goal of implementing a mentoring program. For each Turner scholar, I will create a personalized mentoring team. I expect these combinations of mentors will serve different roles (e.g., recruiter – potential PhD adviser, retention network - senior graduate student, alternative career mentor – an individual with a non-traditional STEM career), as the student scholar

progresses through the STEM pipeline. In years 2-3, I will extend the program to include graduate students and early career scientists and incorporate a networking mixer. The **chair of the ABS Diversity Committee, Daniel Howard, endorsed my ABS mentoring initiative.** Locally, the University of Windsor has recently launched a 4Winds STEM Native Outreach group to help recruit first-nations students into STEM fields. Through 4Winds, I will give public talks and organize workshops on ABM and social network analysis. These technology intensive workshops will serve the dual purpose of **engaging Aboriginal K-12 students in STEM and increasing their computer literacy**, as these groups historically and currently have limited access to technology. I will assess effectiveness of these broadening participation efforts through participant surveys and tracking their milestones.

TRAINING OBJECTIVES AND CAREER DEVELOPMENT

Training in sensory physiology, ABMs and social network techniques will complement my current strengths and areas of expertise. My graduate work focused on how the microenvironment influenced energetics, thermal biology, spacing patterns and group responses in mice and fish, whereas my postdoc integrates empirical and modeling approaches to understand how zebrafish shoals become organized and respond to anthropogenic change. Training in theoretical and experimental approaches will enhance my scientific prowess and allow me to pursue interdisciplinary research in computational modeling and behavioral ecology. I have limited experience using ABMs and network analyses to study and predict how anthropogenic change can influence social relationships within a group. This project would give me strong training in targeted sensory assessment, ABMs, and social network analysis, and build connections across sensory ecology, physiology and conservation biology. I will receive training in sensory physiology from Dennis Higgs and other *Uni. of Windsor* faculty who specialize in different aspects of sensory biology (e.g., audition: Dennis Higgs; olfaction: Barb Zielinski) and eco-toxicology (e.g., Douglas Hafner). I will receive computational training in ABMs and social network analysis using textbooks (e.g., [52,70], and interacting with Jens Krause, professor of fish ecology (*Leibniz-Institute*) and his collaborators (e.g. Max Wolf a computational modeler who specializes in animal personality research). I will mentor at least five undergraduate and graduate students in the Higgs lab. I will guest lecture in Higgs' courses (e.g. Animal Communication, Fish and Fisheries) and receive feedback from the Windsor Peer-to-Peer teaching network to refine my teaching skills. I will participate in K-12 outreach events via 4Winds STEM to gain public communication training.

I am committed to pursuing a career in animal behavior at a university where I can integrate research and education, and increase the representation of underrepresented groups. These training objectives are designed to prepare me to work with students in and out of the classroom, and to conduct cutting-edge interdisciplinary research, while disseminating findings to academic and community groups.

Timeline (*Exp.* – experiment; *Anal.* – Analysis)

	YEAR 1	YEAR 2	YEAR 3
Research Goals	Parameterize ABM, create dynamic networks of different group compositions	Identify phenotypes associated with different network positions	Expose fish to pollutants and access resilience of the networks, update ABM
Broadening Participation Training	**Local:** public talks, provide ABM and social network workshop, recruit undergrad research assist. **Global:** Join ABS Diversity Committee to implement the Mentoring program.	**Local:** participate in 4Winds Native outreach activities. **Global:** Broaden ABS Mentoring Program to include underrepresented early career scientists.	**Local:** public talks, provide ABM and social networks workshop for 4Winds STEM participants. **Global:** host an underrepresented groups networking mixer at ABS.
Dissemination	Present at scientific meetings, and submit 1st manuscript.	Make research products of 1st manuscript publicly accessible (e.g., EthoSource), present at scientific meetings, and submit manuscripts.	Make products of 2nd yr. manuscripts accessible, present at scientific meetings, and submit final manuscripts.
Location	Leibniz Windsor Leibniz	Aim 1 *Model, Exp., Anal* Aim 2 and 3 *Exp.* Aim 2 and 3 *Anal.,* Aim 3 *Mode*l	Sept '16 – June '17 July '17 – May '18 June '18 – May '19

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BIOGRAPHICAL SKETCH – **Delia S. Shelton**

https://sites.google.com/site/sheltondelia/

A. Professional Preparation

Institution	*Major or Area*	*Degree & Year*
Southwestern Univ, TX	Animal Behavior	B.S., 2009
Prairie View A & M, TX	Teacher Certification	Secondary science teacher certification, 2010
Indiana Univ, Bloomington	Double Major: Psychology & Biology; Minor: Cognitive Sci.	PhD. Exp 2016

B. Appointments.

2010-2015	NSF Graduate Research Fellow.
2010-2015	IGERT Fellow. Brain-Body-Environment Systems. Indiana University.
2011	Graduate coordinator and ethics instructor for NSF-REU site program, Indiana University, Bloomington.
2009 - 10	High School science teacher (integrated physics and chemistry). Sam Houston Math Science and Technology Center. Houston Independent School District, TX.
2009	Researcher, University of Ghana (Legon, West Africa). Conducted fish surveys to aid local fishing industry.
2008	Animal caretaker, INBIO Parque (Heredia, Costa Rica). Managed butterfly colony and tended exotic and endangered amphibians.
2007, 2008	United Negro College Fund (UNCF) Merck Fellow Researcher, Merck Research Laboratories (Boston, MA). Developed behavior assays and western blot procedures for studies of early detection of Alzheimer's. Advised by J.-C. Dodart and G. Dillon.
2005-08	Researcher, Aquatic Animal Lab (Southwestern Univ, TX). Studied conditioning in schools of fish (*Fundulus heteroclitus*) using a robotic shark stimulus. Improved husbandry procedures for cuttlefish and other aquatic animals. Advised by J. Purdy.
2005-06	Researcher in NSF-AGEP program (Rice Univ, TX). Developed feeding plan for tigers at the Houston zoo. Advised by L. Meffert.
2004	Researcher in NSF-REU program (Indiana Univ.) Used video playbacks to study audience effect in *Betta* fish. Advised by T. Dzieweczynski and W. Rowland.

C. Publications (undergraduate co-authors marked with +)

Five Related Publications

1. Dzieweczynski TL, Bessler AM, **Shelton DS,** Rowland WJ. 2006. Effect of a dummy audience on male–male interactions in Siamese fighting fish, *Betta splendens*. *Ethology* 112: 127-136
2. **Shelton DS**, +Price BC, +Ocasio KM, Martins EP. 2015. Social and physical environment influences shoal cohesion, but not coordination in zebrafish (*Danio rerio*). *Journal of Comparative Psychology, 129*, 72-77.
3. **Shelton DS**, Atagi, E, Keene, JR, and Ross, T. 2015. Netlogo Boomshakalaka model. Indiana University, Bloomington, IN. http://ccl.northwestern.edu/Netlogo/models/community/Boomshakalaka_shelton-atagi-keene-ross
4. Suriyampola, PS, **Shelton DS,** Shukla R, Roy T, Bhat A, Martins EP (Jan., 2016). Zebrafish social behavior in the wild. *Zebrafish* (accepted).

5. **Shelton DS** and Martins, EP. Behavioral variation, adaptation, and evolution (July, 2016). In: Call, J., Burkhardt G, Pepperberg I, Snowdon C, Zentall T. (Eds), APA Handbook of Comparative Psychology. (accepted).

Five Other Significant Publications

1. ^Dillon GM, ^**Shelton DS**, McKinney AP, Caniga M, Marcus JN, Ferguson MT, Kornecook TJ, Dodart JC. 2009. Prefrontal cortex lesions and scopolamine impair attention performance of C57BL/6 mice in a novel 2-choice visual discrimination task. *Behavioral Brain Research* 204: 67-76. ^ authors contributed equally.
2. **Shelton DS**, Alberts JR. 2013. Ontogenesis of group regulatory behavior in mouse litters. Integrative and Comparative Biology 53:E370.
3. +Price BC, **Shelton DS**, Martins EP. 2013. Group-size-dependent cohesion of zebrafish (*Danio rerio*) in the presence of disturbances. Integrative and Comparative Biology 53:E353.
4. **Shelton DS**. 2013. Shared goals. *Bulletin of the Museum of Zoology* 3: 6.
5. **Shelton DS**. 2014. Locating and securing funding. *In*: Smith MJT, Browne MM, Johnson K, Peck W (eds.). GPS for Graduate School: Students Share their Stories. Purdue Univ. Press: Lafayette.

D. Selected Synergistic Activities.

- ***Teaching and Mentoring.*** 2011-present. Mentored 18 undergraduates and 4 high school students in full-time summer research programs or multi-week academic year internships. The students were from diverse backgrounds, 15 women, 12 people of color, 2 first generation college students, and one veteran.
- ***Academic Service*.** 2011-2014. Student member of the IU Center for the Integrative Study of Animal Behavior, with service as Chair and member of the conference planning committee. Graduate student representative to Mechanisms of Behavior group 2011-2013.
- ***EthoSource: a public service guide for sharing and combining behavioral data.*** 2014-present. I presented a talk at on Ethoinformatics at the NSF sponsored EthoSource ontology workshop, a community-wide effort to develop and expand the Animal Behavior Ontology and to link it to other existing ontologies. I am in the process creating wikispot site for EthoSource and populate it with our instructions, video clips, and lists of links for gathering, organizing, storing, and sharing research products.
- ***Outreach and Broadening Participation.*** 2011-Present. Volunteer with Bethel Homework Help, a tutoring service that predominately serves African American youth. I contributed to the efforts that were honored by the 2014 *Be More Engaged Award* from the City of Bloomington Community and Family Resources Department for encouraging literacy.
- **Leadership and Broader Impacts.** 2005-2008 Southwestern University Service including EBONY (Empowering Blacks and Others to Never Yield): Dallas Committee head 2005-2006, Secretary 2006-2007; Multicultural Council 2007-08; Theatre for Social Justice 2006-2008; SHARP (Students Helping Admissions Recruit Prospects) 2005-2008.

E. Collaborators & Other Affiliations (last 48 months)

1.Graduate Advisors

Emília Martins (Ph.D. advisor), Jeffrey Alberts (Ph.D. advisor); Indiana Univ, Bloomington.

2. Other Collaborators

Piyumika Suriyampola, Delawrence Sykes: Indiana University; Rohit Shukla, Tamal Roy, Anuradha Bhat: ISER Kolkata.

3. Research student advisees

Undergraduates: Xenia Davis, Nahrie Kim, Zoe Austin, Anuj Khemka, Karen M. Ocasio, Brittany C. Price, Erik Wegner-Clemens, Devin Jacobs. *High-School*: Hannah Fox-Teague, Roger Morris, Andy Morris.

None Submitted.

Data Management Plan

RESEARCH PRODUCTS

The project will develop four main products: 1) agent-based models using the Netlogo software platform 2) protocols to asses sensory sensitivity in zebrafish 3) several videos of groups of zebrafish interacting in different contexts, 4) multiple social network datasets, which can be used for additional social behavior inquiries and 5) outreach and workshop lesson plans. I plan to organize these data using Dryrad, a digital repository, and EthoSource (Martins, 2004), a formalized guide for sharing and combining animal behavior work. As a result, my data will serve as model for disseminating and storing and sharing integrated empirical and theoretical network data, and associated teaching materials.

DATA TYPE AND STORAGE

Type	Quantity	Format
Behavioral assays: Aggression mirror test, dominance hierarchies, and visual, olfactory and lateral line system assays.	Each fish in the Aims 1-3 will be characterized using the behavioral assays.	AVI files, Excel spreadsheets, tracking files from customized tracking software, protocols for measuring behavior (e.g., ethogram)
Videos of networks: Social interactions of fish will recorded at a single point in time (Aim 1), across time (Aim 2) and in different contexts (Aim 3)	Multiple videos will be generated from the groups used in Aims 1-3.	AVI files, tracking files from customized tracking software, excel sheets for R analysis
Model: Agent-based models used to predict the formation of network ties across time (Aim 1) and their response to anthropogenic change (Aim 3)	Two agent-based models	Netlogo platform code.
Analysis code: R code for data analysis	Multiple	.r script and function code
Lab notebook: Hard copies of behavioral and network data, and protocols.	Multiple	Paper notebook and .pdf images
Outreach: Lesson plan for Agent-based model and Social Network workshops	3 plans: 1 for K-12 students, 1 for undergraduates, and 1 for general public	Word and PDF files, Excel spreadsheets; PDF images; Netlogo platform code

STANDARDS

Data collection and storage will conform to Institutional Care and Use Committee Standards. Behavioral assays will be recorded and the fluvial tank will examined for mechanical integrity by Shelton or Higgs. I will train undergraduate research assistants on behavioral assays and assessed periodically to ensure inter-experimenter reliability during behavioral data collection. In addition, all assistants with maintain laboratory notebooks by entering data and performing crosschecks on a weekly basis. All videos of shoals will be analyzed using a customized automated tracking software, and the tracks will be viewed for accuracy by undergraduate researchers and validated by Shelton or Krause prior to statistical analyses. An Excel file will be compiled for behavioral and social network analyses and kept maintained to ensure responsible research practice.

STORAGE AND DISSEMINATION

All file types can be accessed with commonly media (e.g., Microsoft office, basic media player, adobe reader, R, etc.). Digital notedbooks (Excel) will be updated monthly for analyses. All digitally transcribed will be backed up weekly on external hard drives, and daily via third party cloud storage systems (google drive).

Upon acceptance into a journal, all data will be made freely available for public according to practices established by ecology and evolutionary biology (Whitlock, 2011). I will present all research products on Ethosource and upload manuscript associated media, excel, and other digital files to Dryrad (http://datadryad.org/), an open access repository that provides a permanent and citable doi for all uploaded products. The agent-based model will be housed along with metadata and instructions on the NetLogo website (http://ccl.northwestern.edu/netlogo/) as an open-access tool. Outreach related presentations and lesson plans will be uploaded to figshare (www.figshare.com), an open-access site that provides items with a permanent and citable doi and tracks the use of uploaded materials.

DATA SHARING AND REUSE

To communicate the way data can be reused, all research products will be licensed following the guidelines outlined in the Panton Principles (http://pantonprinciples.org). I will use the Creative Commons Zero (CC0) public domain license for my research products (*i.e.*, code, models, and presentation material). These are liberal licenses that allow software to be accessed and used by others, provided that the author(s) are cited and retain the copyright to the material. Manuscripts will be published in peer-reviewed journals, and later deposited on 'Researchgate' and 'Academia' to increase readership and access.

ROLES AND RESPONSIBILITIES

Shelton will be primarily responsible for data collection, data management, and data dissemination. Higgs at the University of Winsdor will provide guidance for behavioral assay data management, and developing outreach materials and interacting with the public. Krause will provide support for developing, managing and sharing code for the agent-based models and communicating with the Netlogo user community. The data archiving for this project with provide a strong foundation for long-term open-access to data, videos, code, and computational tools.

REFERENCES

Martins, E. P. (2004). EthoSource: Storing, Sharing, and Combining Behavioral Data. *BioScience*, *54*(10), 886. http://doi.org/10.1641/0006-3568(2004)054[0886:ESSACB]2.0.CO;2

Whitlock, M. C. (2011). Data archiving in ecology and evolution: best practices. *Trends in Ecology & Evolution*, *26*(2), 61-65.

SPONSORING SCIENTIST STATEMENT

Drs. Dennis Higgs and Jens Krause enthusiastically support Delia Shelton's post-doctoral fellowship application. The proposed research will provide Delia training in computational modeling, network science, organismal biology, sensory ecology, and education/outreach. Specifically, this proposal merges ideas on anthropogenic change, complexity, development, animal personality, and sensory biology conflict to understand how groups develop and respond to anthropogenic change. A major part of the proposal involves education, outreach and community involvement to target underrepresented groups. Collectively, these opportunities will provide Delia with invaluable skills that will support her professional goals and future independent research career. Below, we explain why the host institutions, University of Windsor and Leibniz-Institute, provide the best environment for Delia's training and proposed research.

CURRENT RESEARCH AND FUNDING

Dr. Higgs is a sensory ecologist with a primary interest in mechanisms of sensory function and how this affects organisms' interactions in both laboratory and natural contexts. His work is currently supported by an NSERC Discovery grant (2015-2020) as PI that focuses on neuroethology of acoustic communication, an NSERC Strategic grant (2013-2015) as co-PI that focuses on growth and development of Chinook salmon for aquaculture, and a new Great Lakes Fisheries Commission Pilot Grant (2015-2016) as co-PI that focuses on using passive acoustics to identify lake trout spawning areas. There is no direct financial overlap with the current and none of the current funding sources provide postdoctoral support.

Dr. Krause is an experimental biologist with a focus on grouping behavior and in particular collective behavior and social networks in fish and humans. He is the head of the Department of Biology and Ecology of Fishes at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries and also holds a position at the Faculty of Life Sciences at the Humboldt University, Berlin. His research is currently supported by an SAW-project grant (2013-2017) as a Co-PI which is focused on the ecological and evolutionary consequences fish behavior types.

COMPLEMENTARY NATURE OF PROPOSED AND ONGOING RESEARCH

Krause' lab is part of the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB) and the Leibniz Association has a general commitment to bridging the gap between basic science and application. In this sense Delia's project would be well placed at the IGB. A further strength is the emphasis on freshwater fish species and existing zebrafish facilities that could be used. The size and composition of groups has been a long-standing focus of research interest in the Krause lab and Delia's research aims would integrate well into the existing activities of the Department of Fish Biology and Ecology.

A major focus of the research in the Higgs lab is how sensory systems influence organismal interactions and how anthropogenic influences can disrupt this interaction. These foci are highly complementary to the current proposed research in that the empirical sensory research in the Higgs lab will directly inform rules inserted into the modeling component and will be used in a predictive sense to model how sensory information processing impacts group dynamics. Higgs has used NetLogo models in undergraduate instruction (4th year Animal Communication course) and thus has an interest in expanding the applicability of these models. In addition, the University of Windsor has a strength in sensory and aquatic biology and Higgs has a strong history of funded collaboration with these groups (sharing funding, publication and students with Drs. Love, Semeniuk, Heath, Pitcher and Zielinski). Thus Delia will be tightly incorporated into a strong group of researchers at Windsor that have direct interest in the types of questions she will be asking and one of the above (Semeniuk) also has an interest and background in agent-based modeling approaches.

DEVELOPMENT OF MENTORING PLAN

Research Planning:

At IGB Delia would join the Department of Fish Biology and Ecology and labs of Jens Krause and Max Wolf. The Krause lab would provide training in all aspects regarding zebrafish behavior, experimental methods, and social network analyses, whereas Wolf's lab would contribute specific modeling expertise. There are a large number of PhD-students and Postdocs currently working on group-living and behavior types in different fish species which would provide many opportunities for Delia to become part of an active community in this research area.

At Windsor Delia will quickly receive training in all aspects of sensory physiology and behaviour from Higgs. Once trained, Delia and Higgs will meet weekly to discuss problems and solutions in initial stages and then weekly as part of Higgs lab meetings. She will also be brought into meetings that regularly happen between Higgs and his collaborators at Windsor and will eventually be given undergraduate and graduate students to mentor, once Delia has made progress on her own work, to help her continue to develop her mentoring skills. Higgs is also an Academic Editor for PLOS One and will use this position to mentor Delia in the manuscript review and editing process.

Teaching and engagement: While the most important aspect of any Postdoctoral Fellowship (PDF) is research productivity, it is also vital that PDFs gain teaching experience to give them valuable training as they launch their independent careers. Higgs was on a teaching fellowship while a PDF at Maryland and found this invaluable as he gained his first University appointment. Delia will be also given this opportunity, first with individual guest lectures and then working into teaching more in-depth modules within a class, while still protecting her research time. Windsor has a peer-to-peer evaluation network where other professors come in to view and give comment on lectures and both Higgs and the peer-to-peer network will observe Delia's teaching and give constructive criticism on her lectures. In this way Delia will gain more experience and be able to adjust her teaching style while still being spending the majority of her time on the research aspects of her proposal.

We will meet with Delia immediately upon her arrival to Leibniz-Institute (Higgs will Skype in) to discuss her professional career goals and her needs for mentoring in research, teaching and career development skills. This initial meeting will be followed by monthly meetings to update our progress on the mentoring goals (in addition to weekly lab meetings and other research-related meetings). Drs. Higgs and Krause will provide direct mentorship when possible, but will also put Delia in contact with other potential faculty mentors, peer mentors, and groups (e.g., postdoctoral scientists in the College of Natural Sciences and professional development workshops on campus), so that she will have a wealth of resources to draw from.

Besides regular Skype meetings, the Higgs and Krause labs will meet in person in years 1 and 2 along with Delia to discuss results and plan future experiments. In year 1, Higgs will travel to Leibniz using his own research funds to discuss sensory experiments and to learn detailed aspects of model requirements. In year 2, Krause will travel to Windsor to discuss model needs and how empirical measurements can be refined to better serve modeling purposes.

ROLE OF SPONSORS AND OTHER RESOURCES

The proposed research will require Delia to learn new computational and laboratory skills, and will require an integrative perspective on animal behavior by incorporating sensory, behavioral, social network, modeling, and ecological tools. She has established a team of researchers to help her in this endeavor with her sponsors, as well as Dr. Max Wolf and Dr Christina Semeniuk

(experts in computational modeling of animal groups) and Dr. Tim Landgraf (an expert at developing tracking software for fish). We will work closely with Delia throughout all phases of the proposed research, from developing the methodology to collecting and analyzing data and writing manuscripts for publication. Delia will receive further training and guidance from her collaborators throughout the project. She will also gain educational experience by leading her proposed outreach program, by guest lecturing in two of Dr. Higgs' undergraduate courses (*Biology of Fishes* and *Animal Communication*), by attending teaching seminars and workshops, and through interactions with faculty and graduate students in the School of Education and Aboriginal Education Centre. Delia will receive guidance on her outreach plan from her sponsors, Animal Behavior Society Diversity Committee Chairperson, Dr. Daniel Howard, as well as the resources of the Windsor Aboriginal Education Centre and colleagues in the School of Education. Consultation with colleagues on the Animal Behavior Society Diversity Committee and Aboriginal Education Council (e.g., Shirley Miller, an expert in educational program assessment) will ensure that an appropriate assessment plan is in place to gauge the success of the outreach program.

We will meet regularly with Delia to discuss research and education progress, exchange ideas, and provide general mentoring (e.g. writing manuscripts, development of presentations, time management, and teaching). Other activities will include co-reviewing manuscripts to enhance peer-review skills, working on a competitive job application (CV, teaching and research statement, seminar, interviewing strategies), and writing grant proposals. Delia will be expected to attend seminars in the Departments of Biology (University of Windsor) and Fish Biology and Ecology (Leibniz-Institute), as well as relevant seminars in Great Lakes Institute for Environmental Research that will enhance her research and education. We will promote Delia's scientific research and will foster collaborations by introducing her to colleagues at universities and conferences.

Drs. Higgs and Krause will connect Delia with diversity offices and initiatives on campus to ensure that she is well poised to make significant contributions toward broadening the participation of underrepresented groups in biology.

LIMITATIONS

Upon completion of the postdoctoral fellowship, the collected data will be freely available to Delia, and he will be able to utilize them without any limitations. She will also be free to pursue research in this area or other related fields without any restrictions placed on she by her sponsors.

Dennis M. Higgs
Department of Biological Sciences
University of Windsor
http://www.uwindsor.ca/higgslab

Professional Preparation

Michigan State University Zoology BSc., 1987
Northern Illinois University Biological Sciences MSc. 1990
University of Texas at Austin Marine Science PhD. 1996
University of Arizona NIH Postdoctoral Fellow Cellular and Molecular Biology 1996-1998
University of Maryland NIH Postdoctoral Fellow Neuroscience 1998-2001

Appointments

Since 2013 Head, Department of Biological Sciences University of Windsor
Since 2007 Associate Professor Department of Biological Sciences University of Windsor
2003-2007 Assistant Professor Department of Biological Sciences University of Windsor
2001-2003 Research Scientist Department of Biological Sciences University of Maryland

Products

Five Related Publications

Low J. & **Higgs D.M.** 2014. Sublethal effects of cadmium on auditory structure and function in fathead minnows (*Pimephales promelas*). Fish Physiology and Biochemistry 2014:1-13.

Radford C.A., Montgomery J.C., Caiger P., Johnston P., Lu J. & **Higgs D.M.** (2013). A novel hearing specialization in the New Zealand bigeye, *Pempheris adspersa*. Biology Letters 9**,** 21020163.

Niemiller M.L., **Higgs D.M.** & Soares D. (2013). Evidence for hearing loss in amblyopsid cavefishes. Biology Letters 9:*9*(3), 20130104.

Cott P.A., Johnston T.A. Gunn J.M. & **Higgs D.M.**(2013). Hearing sensitivity of the burbot. *Transactions of the American Fisheries Society* 142:1699-1704.

Higgs D.M. & C.A. Radford (2013). The contribution of the lateral line to “hearing” in fish. *Journal of Experimental Biology* 216:1484-1490.

Five Other Significant Publications

Poling K.R., Smit J. & **Higgs D.M.** 2013. In-class use of laptop computers to enhance engagement within an undergraduate biology curriculum: findings and lessons learned*. Bioscience Education* 21:29-41.

Zeyl J.N., Love O.P. & **Higgs D.M.** (2013). Condition-dependent auditory processing in the round goby (*Neogobius melanostomus*): links to sex, reproductive condition, and female estrogen levels. *Journal of Experimental Biology* 216:1075-1084.

Falica, B. & **D.M. Higgs** (2013) Paternal genetic effects on offspring swimming performance vary with age of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). *Evolutionary Biology* 40:355-365.

Radford C.A., Montgomery J.C., Caiger P. & **Higgs, D.M.** (2012) Pressure and particle motion detection thresholds in fish: a re-examination of salient auditory cues in teleosts. *Journal of Experimental Biology* 215:3429-3435

Kasurak A.K., B.S. Zielinski, & **D.M. Higgs.** (2012). Reproductive status influences multisensory integration responses in female round gobies, *Neogobius melanostomus*. *Animal Behaviour* 83:1179-1185.

Synergistic Activities

- *Teaching and Mentoring*: I am committed to improving pedagogical development and previously secured $85,000 with two co-PIs from Hewlett-Packard to bring computers into the classroom, resulting in a publication (Poling et al., above) and numerous presentations on the effectiveness of technology engagement for undergraduates. I have won 4 teaching awards at the department level, 1 at the Faculty of Science level, and one at the University level for excellence in undergraduate education and the enhanced delivery of Science education is very important to me. I also have a strong record of mentoring in the lab environment, averaging 3-4 graduate students, 4 4th-year thesis students, and 6-8 undergraduate research volunteers in my lab each year.
- *Instructional Infrastructure*: Apart from my own success in securing pedagogical funding I have also had success securing funds to enhance the experience in other Biological Sciences courses. I recently secured $50,000 from the University to complete revamp the neuroscience laboratories for undergraduate and graduate courses, bringing in brand-new neurophysiology rigs for experiential learning, secured funding from the American Society of Microbiology for an undergraduate resource room, and also completely renovating our first-year lab spaces.
- *Broadening Participation*: Since becoming Department Head I have been intimately involved in our 4Winds Stem Initiative in partnership with the University Aboriginal Affairs Group and the Department of Chemistry. Each summer we bring students from the local area, including a large tribal community on Walpole Island, to the University for a series of hands-on workshops on STEM topics. In addition, the University of Windsor has a high proportion of first-generation Canadians of a range of ethnicities so a priority has been bringing these students into our Biology programs.

Former Advisors: Arthur Popper (PDF mentor, University of Maryland), Gail Burd (PDF mentor, University of Arizona), Lee Fuiman (PhD mentor, University of Texas), Carl von Ende (MSc mentor, Northern Illinois University).

Collaborators (last 48 months): Craig Radford (U Auckland), Keith Tierney (U Alberta), Peter Cott (U Alberta), Daphne Soares (New Jersey Institute Technology), Matthew Niemiller (U Kentucky), Nicholas Johnson (USGS).

Students mentored: 17 graduate students, 15 of whom were women, and 34 senior thesis students.

Jens Krause
Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Department of Biology and Ecology of Fishes, Müggelseedamm 310, 12587 Berlin, Germany
Humboldt University of Berlin, Faculty of Life Sciences, Invalidenstraße 42, 10115 Berlin, Germany
http://www.igb-berlin.de/staff-igb/show/311.html

Professional Preparation

Free University Berlin, Germany; Biology, Diploma 1985
Cambridge University, Queens College, UK; Applied Biology, M. Phil. 1989
Cambridge University, St John's College, UK; Zoology, Ph.D. 1993

Appointments

Assistant Professor (1996-1998, Leeds University, UK)
Associate Professor (1998-2004, Leeds University, UK)
Full Professor (2004-2009, Leeds University, UK)
Full Professor, Head of Department (2009-now, IGB and Humboldt University, Germany)

Products

Five related publications

Wilson A.D.M., Krause S., James R., Borner K., Clement R., Ramnarine I.W. & **Krause J.** 2014. Dynamic social networks in guppies (*Poecilia reticulata*). *Behavioral Ecology and Sociobiology* 68: 915-925.

Dyer J.R.G., Croft D.P., Morrell L.J. & **Krause J.** 2009. Shoal composition determines foraging success in the guppy. *Behavioral Ecology* 20: 165-171.

Wilson A.D.M., Krause S., Dingemanse N. & **Krause J.** 2013. Network Position: A key component in the characterization of social personality types. *Behavioral Ecology and Sociobiology* 67: 163-173.

Ward A.J.W., Herbert-Read J.E., Sumpter D.J.T. & **Krause J.** 2011. Fast and accurate decisions through collective vigilance. *Proceedings of the National Academy of Sciences of the United States of America* 108: 2312-2315.

Ward A.J.W., Sumpter D.J.T., Couzin I.D., Hart P.J.B. & **Krause J.** 2008. Quorum decision-making facilitates information transfer in fish shoals. *Proceedings of the National Academy of Sciences of the United States of America* 105: 6948-6953.

Five other significant publications

Krause J., James R., Franks D.W. & Croft D.P. (eds) 2014. Animal Social Networks. Oxford University Press, Oxford.

Wolf M., Kurvers R.H.J.M., Ward A.J.W., Krause S. & **Krause J.** 2013. Accurate decisions in an uncertain world: collective cognition increases true positives while decreasing false positives. *Proceedings of the Royal Society London B* 280 (1756): 20122777.

Brown C., Laland K.N. & **Krause J.** (eds; 2nd edition with additional chapters) 2011. Fish Cognition and Behavior. Wiley-Blackwell Publishing, Oxford.

Faria J.J., Dyer J.R.G., Clement R.O., Couzin I.D., Holt N., Ward A.J.W., Waters D. & **Krause J.** 2010. A novel method for investigating the collective behaviour of fish: introducing “Robofish”. *Behavioral Ecology and Sociobiology* 64: 1211-1218.

Krause J. & Ruxton G.D. 2002 (reprinted 2005). Living in Groups. Oxford University Press, Oxford.

Synergistic Activities

- *Teaching and Mentoring:* I am committed to mentoring scientists at the postdoctoral, graduate, and undergraduate levels. I have supervised 11 postdoctoral researcher, 16 graduate students. Almost all of my former postdocs and almost half of my former PhD-students have tenured positions in academic institutions now.
- *Outreach:* As a member of the Berlin-Brandenburg-Academy of Science I regularly give lectures on collective behaviour and collective intelligence at high-schools in the region. I also take elected high-school-students every year on research trip to Trinidad where they participate in our work.
- *Biomimetics:* We study information processing in biological systems – in particular how groups of organisms solve problem using collective behaviour and collective intelligence. We model the mechanisms of selected components of these biological solutions and apply them to problems in the human domain. An example of this is a recent application of how fish deal with true and false positives in their environment and how this can be used for cancer diagnosis in the medical domain.
- *Science meets parliament:* I work regularly as an adviser to members of parliament partly through the Leibniz program “Science meets parliament” and partly on request when my expertise on collective intelligence is needed.

Former Advisors: Bryan Shorrocks (PDF), Dan Rubenstein (PDF), Jean-Guy Godin (PDF), Nick Davies (Ph.D.), Sarah Corbert (M.Phil.), Dietmar Todt (Diploma).

Collaborators (last 48 months): Paolo Domenici (IAMC-CNR, Oristano, Italy), Jens Steffensen (Copenhagen University, Denmark), Andy Bogart (Knight Cancer Institute, Oregon, USA), Dirk Helbing (ETH Zürich, Switzerland), Lenin Arias-Rodriguez (University of Tabasco, Mexico), Indar Ramnarine (University of the West Indies, Trinidad and Tobago), Steve Roberts (Oxford University, UK), David Sumpter (Uppsala University, Sweden), Giuseppe Argenziano Second (University of Naples, Italy), Iris Zalaudek Medical University of Graz, Switzerland).

Students mentored: 11 postdoctoral researchers, and 16 graduate students.

DISSERTATION TITLE: **A tale of scales and tails: simple environmental mechanisms shape complex behavior in two model systems, mice (*Mus musculus*) and zebrafish (*Danio rerio*).**

My graduate work has focused on simple environmental mechanisms that shape complex behaviors in small animal groups, mouse huddles and zebrafish shoals. In mice, I studied how nest structure influences the development of behavioral regulation. My work suggests that huddle structure is important for altering the expression of regulatory behavior and has thermal and energetic consequences. In zebrafish, I examined how the physical environment influences shoal cohesion and group responses. I found that density was important in shaping shoal cohesion, but not coordination, and environmental pollutants can have profound indirect effects on group behavior. My dissertation work has four aims:

AIM 1: DEVELOPMENT OF REGULATORY BEHAVIOR IN HOUSE MICE

Huddling is a strategy adopted by many animals to combat cold challenges. A huddle's structure is context specific and it is expected the thermal consequences are functionally linked to specific huddle formations. In the microenvironment of the natal nest, litters of mouse pups behave adaptively as a group. I tested the effects of environmental variables on the group behavioral regulation in mice at during their first week of life. I found that group that the manifestation of behavioral regulation was influenced by temperature and was age and nest structure dependent. These findings provide insight into how physical and behavioral parameters of a nest environment shape individual behaviors from which adaptive group behavior emerges.

AIM 2: PHYSIOLOGICAL CONSEQUENCES OF 2-D AND 3-D HUDDLES IN INFANT MICE

The formations made by gregarious animals can range from planar shapes (e.g., penguin huddles) to complex polyhedra (e.g., bee swarms). In large groups of adults, the functional consequences are dependent on the group geometry and consequently the contact patterns. Here we test whether mouse pups in three-dimensional (3-D) contact are warmer, consume less oxygen, and show enhanced regulation of exposed huddle area in comparison to infants in two-dimensional (2-D) contact. We exposed huddles to a cool challenge in either a flat or concave nest. We found that 3-D huddles were warmer than 2-D huddles, while showing a 40% reduction in metabolic activity when in 3-D contact. We found that nest structure that enhances contact among members, leads to greater thermal benefits, and is accompanied by greater thermogenic efficiency.

AIM 3: DENSITY AND GROUP SIZE INFLUENCE SHOAL COHESION, BUT NOT COORDINATION IN ZEBRAFISH (*DANIO RERIO*)

The formations made by gregarious animals can range from loose aggregates to highly synchronized and ordered structures. For very large, coordinated groups, both physical and social environments are important for determining the physical arrangement of individuals in the group. Here, we tested whether physical and social factors are also important in determining the structure of small, loosely coordinated groups of zebrafish. We found that even though our fish were not crowded and did not use most of the available space, the distance between individual fish was explained primarily by the amount of available space (i.e., density). Zebrafish in a larger space spread out more and the total dimensions of the shoal were an additive function also of group size. We, however, did not find any impact of social or physical environment on the orientation of individual fish or shoal. Thus, both physical and social factors were important for shoal spatial arrangements, but not individual orientation and shoal alignment. The manuscript resulting from the following study is published in the *Journal or Comparative Psychology*.

Aim 4: HIDDEN IN PAIRS REVEALED IN GROUPS: AN ENVIRONMENTAL POLLUTANT HAS INDIRECT EFFECTS ON ZEBRAFISH SHOALS

Profound differences can exist between the behaviors exhibited by dyads and larger groups. Trace metals are known to interfere with behaviors involved in social interactions. Zebrafish are highly social, found in small animal groups, and native to an area experiencing a rise in levels of cadmium. Here, we test the effects of sublethal levels of cadmium on the exploratory behavior of zebrafish in pairs and larger groups. I found a difference in the response of pairs and group response, which suggests that pollutants can have profound and indirect effects on group behavior.