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The Physiological Ecology of Seasonal Interactions: How Do Wintering Ground Events Constrain Breeding Success in Neotropical Migrants?

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Final Report for Period: 04/2010 - 03/2011**Submitted on:** 06/02/2011**Principal Investigator:** Holberton, Rebecca L.**Award ID:** 0615701**Organization:** University of Maine**Submitted By:**

Holberton, Rebecca - Principal Investigator

Title:

The Physiological Ecology of Seasonal Interactions: How Do Wintering Ground Events Constrain Breeding Success in Neotropical Migrants?

Project Participants

Senior Personnel

Name: Holberton, Rebecca**Worked for more than 160 Hours:** Yes**Contribution to Project:**

coordinate and oversee field and laboratory studies, in collaboration with P. Marra; collect and analyze data, prepare results for publication, present results at professional meetings and to general public audiences, etc.; mentor post-doctoral research fellow, graduate and undergraduate students in all aspects of research and professional development.

Post-doc

Name: Angelier, Frederic**Worked for more than 160 Hours:** Yes**Contribution to Project:**

In 2009, Dr. Anglier completed his position as a full-time 2-year post-doctoral fellow, working at the Smithsonian MBC/NZ. Dr. Angelier developed several lab and field studies that dovetailed with the work outlined in this proposal. His research expanded the original scope of the project by including his interests in chronic stress, such as immune function, oxidative stress, and aging. During Years 1 and 2, Dr. Angelier completed two field seasons of sample collection in Jamaica and analyzing blood samples. In Year 1, he traveled to Dr. Carol Vleck's lab to learn how to analyze his samples for cellular aspects of oxidative stress. Upon completion of his position on this project, Dr. Angelier took another, similar position with Dr. John Wingfield at UC Davis. To date, Dr. Angelier has given several international symposia presentations and produced several publications on his work with this project. Several more publications are in preparation at this time.

Graduate Student

Name: Tonra, Christopher**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Tonra is in his third year as a full-time doctoral student supported entirely on this project. He has been successful in applying for additional funding from various agencies and organizations to supplement his work. Although his dissertation focuses on the main tenets of this project, Tonra has developed his own set of hypotheses about the role of density-dependence in influencing HPG activity. Further, he has expanded his inquiry into the proximate role that testosterone may play not only in preparation for breeding but also in supporting spring migration. He has tested several hypotheses in laboratory studies and experimental hormone manipulations are planned for free-living redstarts during the departure period in Jamaica in spring 2010. Finally, Tonra has expanded the scope of this work to include other species of Neotropical migrants to look for patterns associated with different life histories within and across species. To augment his samples, he will work on museum specimens (at the Chicago Field Museum) of birds collected during migration to supplement his field work on both the wintering and breeding grounds. He is also learning to do stable isotope analyses at the Smithsonian on tissues collected throughout his work. Finally, Tonra has applied for a pre-doctoral Smithsonian Fellowship and a University of Maine doctoral fellowship to fund his final year as he finishes data collection and analysis. He is expected to defend his dissertation in fall 2011.

Undergraduate Student

Name: Porcelli, Kayla**Worked for more than 160 Hours:** No

Contribution to Project:

Kayla greatly assisted with bird care throughout the captive hormone studies with juncos; assisted with running radioimmunoassays for plasma androgen levels; assisted with developing the modified implant design used in field and lab studies on this project. Kayla was a co-author on a presentation at the 2009 annual meeting of the American Ornithologists' Union about this technique.

Name: Smith, Marie

Worked for more than 160 Hours: No

Contribution to Project:

Marie was funded through a match with federal work merit program; greatly assisted with bird care throughout the captive hormone studies with juncos.

Name: Perez, Doug

Worked for more than 160 Hours: Yes

Contribution to Project:

Doug greatly assisted with bird care throughout the captive hormone studies with juncos. Doug also worked as a summer REU student. His research examined the relationship between arrival dynamics and parental care in American redstarts on the breeding grounds in New Hampshire. The field skills he learned included finding nests, mapping territories, making blood smears, and collecting blood samples.

Name: Pelletier, Kayla

Worked for more than 160 Hours: No

Contribution to Project:

Kayla greatly assisted with bird care throughout the captive hormone studies with juncos. She also helped analyze a large data set of avian health indicators for another project using statistical skills learned by working on this project.

Name: Marione, Nissa

Worked for more than 160 Hours: No

Contribution to Project:

On 2010, Nissa developed an independent research project that became her Honors thesis - 'The Effects of Coming into Breeding Condition on Feather Quality in Captive Dark-eyed Juncos'. She investigated the additional effects of testosterone levels on feather quality in migratory birds.

Technician, Programmer

Name: Wright, Wesley

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Wright is assigned to Holberton's position in the Maine Agricultural and Forest Experimental Station at UMaine. His position is officially split between Holberton and another faculty member in the department. Wright provides important logistical support such as ordering supplies, managing animal care, overseeing undergraduate workers, etc. and is developing the website for this project.

Name: Thomas, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Mark Thomas is Marra's technician and is based in Washington, DC. Thomas prepares the team for the research in Jamaica and manages much of the research in the field. He is responsible for the collection of all long-term data and for sample storage and data entry.

Name: Reitsma, Robert

Worked for more than 160 Hours: No

Contribution to Project:

Robert Reitsma is Marra's head technician and is based in Washington, DC. Reitsma is responsible for purchasing supplies for all research, for coordinating and obtaining permits, and for the management of all data. Reitsma also helps in collecting field data, but for limited periods of time on the project.

Other Participant

Name: Marra, Peter

Worked for more than 160 Hours: Yes

Contribution to Project:

Marra coordinates and oversees field and laboratory studies, in collaboration with R. Holberton; collects and analyzes data, prepares results for publication, presents results at professional meetings and to general public audiences, etc.; mentors post-doctoral research fellow, graduate and undergraduate students in all aspects of research and professional development.

Research Experience for Undergraduates**Organizational Partners****National Environmental Protection Agency**

The Jamaican National Environmental Protection Agency continues to be actively engaged in the research.

Other Collaborators or Contacts

For Holberton:

Keith Hobson, Environment Canada-Canadian Wildlife Service

Linda Welch, S. Williams: US Fish & Wildlife Service Maine Coastal Islands National Wildlife Refuge

Mark McCollough, US Fish & Wildlife Service

Brad Allen, Tom Hodgman: Maine Inland Fisheries and Wildlife

Bruce Connery: National Park Service

Phil Taylor: Acadia University, Nova Scotia

Antony W. Diamond, University of New Brunswick

Wing Goodale, Biodiversity Research Institute

Activities and Findings**Research and Education Activities:**

Research and Education Activities:

Our overall goals have been to uncover the physiological basis for carry-over effects from the wintering to the breeding period by discovering when birds begin to prepare for breeding, and the degree to which ecological factors on the wintering grounds and during migration influence their level of preparation. Earlier studies have shown that arrival time and/or arrival condition are reliable predictors of breeding success, primarily through the timing of nest initiation. However, studies had not separated the two factors (arrival time and arrival condition) that may, synergistically or independently, influence when individuals can begin breeding. A major goal of our study has been to separate the benefits of arrival time from that of arrival condition, and to link both of these factors to winter habitat occupancy. Specifically, we have been testing hypotheses about when physiological preparation for breeding begins and how it may be modified by environmental factors (e.g. food) on the wintering areas prior to spring departure, during migration, and during the pre-breeding period of arrival on the breeding grounds.

Our focus has been on the American Redstart, a species for which much is known about its wintering and breeding behavior and ecology. The work was divided between 1) wintering ground events in Jamaica, West Indies (across a known habitat suitability gradient and from the mid-winter period of stasis to the period in which birds begin to depart on spring migration), and 2) the breeding grounds during the arrival period and throughout the breeding season at Hubbard Brook (HB) Experimental Forest in New Hampshire where a long-term study on migratory songbirds has been in place for three decades.

In laboratory studies at the University of Maine, we investigated interactions among food availability, energy reserves, and breeding preparation to ask how migrants balance the demands of migration with those of breeding. This activity greatly supported one of our major objectives throughout this project by providing experience in a wide variety of laboratory and field research-related activities for post-doctoral fellows, graduate students, and undergraduate students.

In winter, our existing study plots in two Jamaican forest habitat types, black mangrove and scrub, span a moisture and habitat quality gradient. We collected stable carbon isotope samples on the wintering grounds to continue to confirm their habitat-dependent signature there. We were able to link winter habitat residency with stable carbon isotope signatures in birds as they arrived at HB to breed. These signatures were ultimately used to link winter habitat occupancy with arrival time, arrival condition (energy reserves and breeding preparation), timing of

breeding onset, and nesting success.

In the field, birds were captured and measured for body size, and recorded as to age, and sex. Birds were fitted with a USGS numbered aluminum leg band and a unique set of plastic color bands for individual identification. Measures of energetic condition included body mass, and fat score. Breeding readiness in males was measured by the degree of hypothalamic-pituitary-gonadal (HPG) axis activity via baseline plasma gonadal steroid (androgen) production, and cloacal protuberance development (males). In a subset of males, HPG axis activity was also measured as a response to a challenge of exogenous GnRH to ascertain whether the pituitary-gonadal component of this axis was responsive to this hypothalamic signal during the wintering period, and, if so, to what degree its activity resulted in changes in plasma androgen levels. The ensuing plasma androgen (testosterone = ?T?) levels in response to GnRH injections were used as a measure of HPG readiness on the wintering as well as on the breeding grounds. Relationships among winter habitat residence (as determined from isotope signature), the stage of breeding preparation (cloacal protuberance development, baseline plasma T and T in response to GnRH), and physiological condition were investigated in birds at both stages of the annual cycle. In the laboratory, food manipulation studies and hormone manipulation studies were used to look at how migrants balance the energetic demands of migration with those of breeding preparation.

Hypotheses, Predictions and Tests

To determine if wintering ground events directly influence when and how well birds begin to prepare for breeding, we 1) first established how much preparation for breeding (measures of breeding readiness) can occur prior to spring departure, 2) determined if the rate of breeding preparation is influenced by food availability and, through it, body condition, and 3) linked variation in breeding readiness with arrival time, energetic condition, and breeding success. We ultimately looked for evidence, via stable carbon-isotope signatures, that this variation can have its origins prior to arrival on the breeding grounds.

Hypothesis I: Preparation for breeding in migratory birds begins on the wintering grounds and is influenced by winter habitat suitability.

Prediction I-1: The onset of breeding in migratory birds begins on the wintering grounds: its timing of onset is earlier and rate of development is greater in birds in better energetic condition; variation in breeding readiness is driven by winter habitat quality.

Test I-1a: (March - April, 2007; Jan. - April, 2008, 2009) Components of breeding readiness and energetic condition were measured in mid and late winter periods in mangrove and scrub habitats in Jamaica. Departure dates were determined for all redstarts by resighting color-banded birds every 3-days across all plots.

Test I-1b: (Jan. - April, 2008, 2009) - Food availability is the primary driver of habitat suitability and food, directly or indirectly through competition, influences both body condition and CORT secretion in wintering redstarts. What we did not know is whether food and habitat suitability influence HPG development. We predicted that HPG activity develops more readily in birds on territories with higher food abundance compared to individuals forced to occupy less suitable habitats. Food was quantified on a territory scale in both seasons on scrub and mangrove plots with sweep netting. Prey were sampled on each territory twice, in early winter and again in late winter. Sweep net contents were placed in a freezer (-10oC) overnight and insects sorted to taxonomic order, preserved in 70 percent ethanol, dried at 50oC for 24 hours, adjusted to reflect redstart diet preference, and weighed (+/- 0.1 mg).

Test I-2: (Oct., 2008 - March, 2009) To reduce possible confounding effects of social interactions, etc., in Year 2, we measured breeding readiness and energetic condition in birds brought into reproductive and migratory condition in captivity with either free access to food (controls) or periods of different levels of food limitation during the migration period. Because redstarts do not adjust well to captivity, we initially planned to use the Yellow-rumped warbler (*Dendroica coronata*), a species that does extremely well in captive studies. However, a severe national shortage of commercially produced mealworms and waxworms needed to support insectivorous birds in captivity had a major impact on researchers, zoos, and the pet trade across the continent in 2008. Several major producers with which we had long-standing business told us that they could not assure us that they would be able to supply the food needed once they were brought in to captivity. Should supplies have failed during the winter months in Maine, the warblers would have been destroyed as they could not be released to the wild at that time of year. However, we were able to successfully test this hypothesis with a seed-eating comparable migrant, the Dark-eyed junco (*Junco hyemalis*).

Prediction I-2: In order to depart on spring migration, birds must be in optimal energetic condition on the wintering grounds.

Test I-2: Throughout the April 15-May 15-departure period (2008, 2009) redstarts were captured and assessed for breeding readiness and energetic condition, and these data were linked with the individuals' departure schedules.

Hypothesis II: Winter habitat impacts breeding success through its influence on preparation for breeding and spring migration schedules.

In field studies, we looked for physiological carry-over effects from winter to summer mediated by winter habitat. We continued to capitalize on our ability to use stable isotopes as tracers of winter habitat to examine how winter events are related to several physiological variables,

measured on arrival at breeding areas, associated with individual breeding performance (arrival time, condition on arrival, and number of young fledged).

Prediction II-1: Breeding readiness and energetic condition at arrival on the breeding grounds, acting together, influence breeding success and are linked with winter habitat suitability.

Test II-1: On the HB breeding grounds during the arrival period in May through July (2008, 2009) redstarts were measured for indicators of breeding readiness and energetic condition. Relationships among arrival time, energetic condition, and breeding readiness upon arrival, as well as stable-carbon isotope signatures of winter habitat occupancy were investigated and ultimately linked with nesting success (onset of clutch initiation, # young fledged).

Timeline: The project's activities were initially proposed for a full three years but the timing of the award (April 1, 2007) resulted in a shortened initial field season. However, we received a no-cost extension because we remained committed to three years of fieldwork, laboratory analyses of field samples, and statistical analyses. Field demography data were collected on the wintering grounds and breeding grounds in all three years, and preliminary analyses began in Year 2. The 2008-2009 isotope and hormone samples from the wintering grounds have been collected and lab work is completed. All data collection, lab work, and data analysis from the breeding grounds are complete and results from this portion were accepted for publication in *Journal of Avian Biology* in April, 2011. The data collected from the field measurements of food availability are still being analyzed. The captive study on food limitation is completed and the resulting manuscript is in preparation. Tonra's captive study testing trade-offs between migration and early breeding preparation was completed during the winter 2008-09. The data from that study were presented at several national and international meetings, and a manuscript is currently in review with *Journal of Experimental Biology*. Field measures of energetic condition and breeding readiness continued in 2010, and all hormone samples have been analyzed. The study has been written up as a manuscript that has also been accepted upon revision. A final experimental field study in which circulating plasma levels of androgens were manipulated in male redstarts on the wintering grounds during the late winter-spring period leading to departure was conducted April, 2011. This study was designed to test the effects of enhanced androgen levels on measures of the development of migratory condition. The study was completed in late April and the results are being analyzed and prepared for an additional manuscript for publication.

Findings:

Findings to date:

Once notification of funding was received, applicants for the doctoral student and post-doctoral fellow were reviewed. The first year of funding began April 1, 2007, which precluded doing all of the proposed fieldwork on the wintering grounds in Jamaica for 2007. However, we used other funding sources to send the doctoral student, Christopher Tonra, to Jamaica in February, 2007 so as to familiarize him with the study area and begin collecting samples from redstarts. As of March, 2011, the project has encompassed the first partial winter field season (2007), three additional full wintering ground seasons (~ Jan. - Mar., 2008, 2009, 2010) and the final late winter study (2011). Four seasons on the breeding grounds at HB were also accomplished (2007, 2008, 2009, 2010). Although the project's official end date was March 31, 2010, we received a one-year no-cost extension for this project so that Tonra's research assistantship would continue to cover his work on this project through spring 2011, which has been supplemented with the Smithsonian Pre-doctoral fellowship and an NSF DDIG to fund him through his final year of study.

Hypothesis I: Preparation for breeding in migratory birds begins on the wintering grounds and is influenced by winter habitat suitability.

Test I-1a: (March - April, 2007; Jan. - April, 2008, 2009, 2010) - As of May, 2010, over 350 male redstarts have been captured and sampled on the wintering grounds in both habitat types in Jamaica. Because of the truncated field 2007 season, no GnRH challenges were performed but in 2008-9, 120 male redstarts were captured and sampled for either baseline androgen levels or in response to GnRH injections, and samples were distributed across two sampling periods in two main habitat types. Further, approximately 300 individuals of other Neotropical migrants have also been similarly sampled since 2008. We found that circulating T levels in male redstarts on the wintering grounds approach, and in some cases overlap with, breeding levels as the season progresses towards departure on spring migration ($n=113$, $r^2=0.23$, $P<0.001$). There was no effect of habitat type on T-levels in 2008 or 2009, which were typical years, in terms of rainfall. However, in 2010, a severe drought year, males in scrub habitat did not show an increase in circulating androgen, while those in mangrove did. This indicates that high quality habitat may buffer individuals in stressful conditions. However, in all years, T levels in late winter, just prior to migratory departure, were positively related to condition ($n=42$, $r^2=0.25$, $P=0.001$). This indicates that variation, at the individual level, in territory quality may be playing a role in the ability of males to begin the transition to breeding.

Although CP development is not apparent before birds depart the wintering areas, male redstarts (and other species) increase circulating androgen levels before leaving the wintering areas. Plasma androgen levels in some birds prior to departure are comparable to those observed

during the arrival period on the breeding grounds. GnRH challenges administered during the wintering period did not elicit an additional increase in plasma androgen secretion suggesting that gonadal expression of HPG axis activity, as evidenced by the baseline androgen levels, was being observed at its true concurrent capacity.

Test I-1b: (Jan. - April, 2008-2010) Repeated sweep net samples for food abundance were collected for 60 male territories sampled for hormones with repeated counts on 42 total territories. The food abundance data are currently being analyzed. The associations among winter habitat occupancy, measures of food availability related to body condition, and hormone levels are being analyzed.

Test I-2a: (Jan. - April, 2009). We determined through several pilot studies that food reduction or enhancement is not feasible on these plots. Therefore, we extrapolated our interpretations from our captive studies to corroborate what we saw in the field.

Test I-2b: (Oct., 2008 - March, 2009)

The captive study to look at food availability, energy reserves, and breeding preparation was completed during Oct., 2008-March, 2009. Birds experienced either free access to food provided ad libitum or a "winter maintenance" diet, which was the amount of food the birds ate to maintain body mass before being photostimulated into migratory and breeding condition. The two groups on food limitation differed in the amount of time they spent on the maintenance diet during the period of migration. Regardless of food availability treatment, all birds underwent significant gonadal development by the end of the study but birds maintained on limited food throughout the study, and, as a consequence, were unable to fatten as part of the migratory state, showed the least amount of gonadal growth and hormone output compared to birds who had free access to food throughout and those restored to feeding ad libitum less than one week earlier. This latter group was able to compensate readily, becoming equal to controls within a few days of gaining energy reserves. These results illustrate that, while photoperiod initiates the cascade of neuroendocrine signals stimulating the hypothalamic-pituitary-gonadal axis, energy availability can influence the extent or rate of it. In spite of the inability to put on fat reserves, gonadal development can continue (except perhaps under starvation conditions, which our birds did not experience), even at the expense of energy reserves needed to complete migration. Our results are congruent with earlier field studies (Bauchinger et al. 2005, 2007) in that gonadal development does occur within the spring migratory period and may come at the expense of energy needed to support migration. We are developing further hypotheses to test hypotheses about the relationship between the HPG axis and migration. The results from the present study have been accepted upon revision in an international journal.

While we found that T is related to condition prior to migratory departure and arrival timing in male redstarts (Test II-1 below), we could not determine the causality of these relationships. Potential effects of androgens (testosterone, T) on migratory performance reported could indicate that T is playing a dual role (e.g. breeding role and a migration role) in the transition between wintering and breeding life history phases. Experimental work manipulating T during migratory preparation was necessary to examine this possibility. Thus Tonra devised two experiments to test the hypothesis that birds who elevate T early on in the transition from non-breeding to breeding are at an advantage in terms of migration phenology. First, Tonra performed a captive experiment using migratory dark-eyed junco (*Junco hyemalis*), in which T activity, via implanting subcutaneous Silastic capsules, was either inhibited (by blocking receptor binding and inhibiting conversion to estradiol by aromatase, hereafter referred to as "T-blocked?"), elevated with exogenous T, or left unchanged. To induce migratory preparation in captivity, we manipulated photoperiod. Tonra hypothesized that elevated androgen enhances migratory preparation and tested the following predictions: 1) birds with experimentally elevated T would reach peak migratory condition, as measured by mass and food intake, sooner than controls or T-blocked, 2) control birds would reach peak migratory condition sooner than T-blocked birds, and 3) this same pattern would hold for cloacal protuberance (CP) size as a measure of breeding preparation.

Testosterone-implanted birds reached peak mass and food intake approximately 6 days before controls (Tonra et al., ms in review). This same pattern held for CP diameter. Further, "T-blocked?" birds showed little increase in any of the response variables until the end of the study, and these birds never reached peak migratory condition. These results indicate that elevating T during migratory preparation could enable birds to increase the rate of hyperphagia and mass gain, and, thus, enhance migratory condition, while simultaneously stimulating the development of reproductive characters. While these results support our conceptual model, it must be acknowledged that juncos are very different in many aspects of their ecology from Paruline warblers. It would be ideal to replicate this experiment in a wild population of warblers during the pre-migratory period, and to begin to explore how robust these patterns are across other species. Further, a study in wild birds allows measurement of the effects of T on migration phenology, by estimating migratory departure dates.

A pilot test of the feasibility of using the small "pita" implants in small free-living birds was successful in 2009-10 and resulted in a full field study in 2011 in Jamaica. The use of the small "pita" implants allowed Tonra to design a second experiment, in free-living redstarts. Tonra tested the hypothesis that androgen activity plays an important role in preparing to migrate, and the timing of migration events, while birds are still on the wintering grounds. We predicted that, compared to procedural controls, male redstarts with experimentally elevated T prior to departure from Jamaica would: 1) prepare to migrate (i.e. increase in mass, fat, and breast muscle) faster, and 2) depart on migration earlier. During the first 10 days of April 2009 and 2010, we subcutaneously implanted male redstarts with either an implant packed with T or an empty implant. We then recaptured the birds 12-16 days later and measured change in condition. We determined departure dates as before.

We are analyzing the data from this experiment. Results thus far have shown that males, from early to late April, with elevated T increased in mass, fat score, and breast muscle score, while control males did not. Furthermore, males with elevated T departed earlier on spring migration than controls. These results, when considered in the context of the entire project, indicate that males who are able to elevate T early in the

transition into migration, most likely through the benefits of better habitat quality, are more likely to experience a fitness advantage through early arrival at breeding sites.

Hypothesis II: Winter habitat impacts breeding success through its influence on preparation for breeding and spring migration schedules.

In field studies, we looked for physiological carry-over effects from winter to summer mediated by winter habitat. We continued to capitalize on our ability to use stable isotopes as tracers of winter habitat to examine how winter events are related to several physiological variables, measured on arrival at breeding areas, associated with individual breeding performance (arrival time, condition on arrival, and breeding success).

Prediction II-1: Breeding readiness and energetic condition during arrival on the breeding grounds, acting together, influence breeding success and are linked with winter habitat suitability.

Test II-1: On the breeding grounds during the arrival period in May through July (2008, 2009) redstarts were measured for indicators of breeding readiness and energetic condition (plasma androgen concentration, CP development, and body condition) within 3 days of arriving at HB. Relationships among arrival time, energetic condition, and breeding readiness upon arrival, as well as stable-carbon isotope signatures of winter habitat occupancy were investigated and were ultimately linked with nesting success (onset of clutch initiation, fledging success).

On the breeding grounds, early arriving males had higher T upon arrival (Fig 1; $n = 39$, $r^2 = 0.20$, $P = 0.001$), were from wetter winter habitats ($n = 35$, $r^2 = 0.48$, $P < 0.001$), had earlier clutch initiation dates ($n = 23$, $r^2 = 0.23$, $P = 0.03$), and were more likely to successfully breed ($n = 34$, Wald $\chi^2 = 4.71$, $P = 0.03$) than late arrivers.

T upon arrival was positively associated with winter habitat wetness, based on $\delta^{13}C$ in claws ($n = 35$, $r^2 = 0.19$, $P = 0.03$), and hematocrit on arrival ($n = 36$, $r^2 = 0.45$, $P < 0.001$). Successful males arrived, on average, 3.5 days earlier than unsuccessful males. However, T upon arrival was not a direct predictor of breeding success ($n = 28$, Wald $\chi^2 = 0.06$, $P = 0.80$), indicating that T measured during arrival may be more relevant to migration phenology than breeding. Earlier arriving males arrived with smaller CPs than late arriving males ($n = 25$, $r^2 = 0.64$, $P < 0.001$). The development of the CP, which serves as a sperm storage organ, may not be necessary for early arriving males if most females have yet to arrive.

Collectively, during the arrival period, independent of body condition, early arriving males are more likely to have higher T and higher hematocrit, which may enable them to better meet energetic demands and male-male competition for territories. There was no relationship between arrival T and latency of response to playback, a measure of aggressiveness ($n = 19$, $r^2 = 0.03$, $P = 0.73$). The lack of any direct relationship between arrival T and reproductive success does not rule out indirect effects. For instance, T could be acting through factors that affect arrival date to influence breeding success. This could indicate that arrival T is more relevant in a migration context as opposed to a reproductive one. Tonra is currently preparing a manuscript reporting these results for submission to a top tier journal.

While earlier studies have found that arrival time and/or arrival energetic condition is a reliable predictor of nest initiation, these variables often covary and few, if any, studies have attempted to separate them or to identify the factors that modify them. Our results thus far (captive and field studies) suggest that the trajectory of breeding readiness, which is ultimately initiated by photoperiod, can be modified by winter conditions, affecting not only departure schedules and, through them, arrival time, but also the degree of breeding preparation upon arrival. If arrival condition, in terms of body mass and fat reserves, which more likely reflect the more recent conditions experienced by birds prior to arrival, contribute less to the timing of breeding than actual physiological breeding readiness may, then we will have illustrated an important direct mechanism through which the wintering period influences population regulation in a Neotropical migratory bird, the major goal of this project. Furthermore, we have demonstrated the important role hormones, generally thought of as breeding steroids (T), can also be critical in migratory regulation and, ultimately, indirectly effect breeding success through effects on phenology.

Another outcome of this project has been the development of a novel method for creating implants for delivering steroids to a bird as small as the redstart.

Training and Development:

We are committed to disseminating knowledge gained from this research to enhance environmental awareness and scientific understanding. Our collaborative research program involved a national and international training component (post-docs, field assistants, wildlife biologists and governmental and NGOs in Jamaica) as well as graduate and undergraduate education. We worked with the National Environmental Protection Agency of Jamaica, training their wildlife officials in basic and applied research approaches to studies on migratory birds.

The activities of the project provided new experiences and opportunities to develop new skills for the doctoral student (C. Tonra) and

post-doctoral fellow (F. Angelier). Both of them developed their own ideas and incorporated them into the project's goals, significantly enhancing the research further. Tonra acquired over 100 hours experience performing radioimmunoassay to measure hormones in blood. In addition, Tonra fine-tuned a new implant design developed for this project by Holberton. He not only used this in laboratory studies under controlled conditions, but was the first to effectively and safely use this design in a tiny, free-living bird in the field. Tonra traveled to the Smithsonian Institute and learned how to perform mass spectrometry analysis on bird claws to determine $\delta^{13}C$. Angelier tested several hypotheses about winter habitat occupancy, adrenocortical sensitivity, and survival, as well as linking measures of chronic stress and aging (e.g. immune function, corticosterone secretion, telomere shortening) with winter habitat suitability. Angelier established collaborations with other researchers (R. Greenberg, C. Vleck) and traveled to Vleck's lab in Iowa to learn new techniques associated with measuring telomere length in redstarts. Two additional University of Maine students (Evan Adams, Adrienne Leppold) assisted with the captive study, learning how to collect, process, and analyze blood samples for plasma constituents, and to use implants for manipulating hormone activity. Four University of Maine undergraduates also assisted in this work and have participated in all phases of the captive study. Based on their experience on it, they have developed three additional studies on bird endocrinology and social behavior, which are currently underway. One undergraduate (Kayla Porcelli) is now proficient in doing radioimmunoassay and enzyme-based colorimetric assays and was instrumental in developing the new implant design. Opportunities for undergraduate research experience on the project came about through the University of Maine's Honor's program and the newly established S-cubed: Support for Science Students program, as well as BIO 387/388 Undergraduate Research Experience. UMaine undergraduates Doug Perez, Mellissa Kiermann, Kayla Porcelli, and Kristi Kennedy assisted with captive studies on testosterone, migration, and breeding preparation. They recently developed and completed a study on claw growth rates for standardizing stable isotope sampling and have helped design a new type of implant for delivering hormones in very small birds such as the redstart. One undergraduate (Doug Perez) was funded on a summer REU on this project at HB, and used his research experience on these studies to meet the requirements of his senior Capstone project.

Outreach Activities:

The project's activities have been presented by both PIs to the general public in a variety of formats as invited talks by various organizations (Holberton: National Audubon, Maine Audubon, Acadia National Park Service, U.S. Fish & Wildlife Service, Univ. of Maine, Amherst College, Harvard University, Univ. of New Brunswick; Marra: Washington State University, University of Delaware, Hubbard Brook Annual Cooperators meeting, as well as local Audubon societies, University of Maryland). Holberton presented the results of this study as part of the NSF-funded MIGRATE program during its class in Brazil in 2010. Marra gave a keynote address in Bogota Colombia on redstarts as a model system for studying seasonal interactions. He was also one of two organizers of a course on studying migrants in the Neotropics offered to 35 students from all over South America. Marra also presented results from this project in a symposium on migration held at the 2010 meeting of the Society of Integrative and Comparative Biologists in Seattle. Marra also instructed a course on studying wood thrushes during the non-breeding season to more than 30 students from countries throughout Central America. The course was held in Veracruz, Mexico in 2010.

Public programs

- Holberton, Marra, and their students frequently give talks and demonstrations to the general public. In May, 2009, Holberton and a graduate student (A. Leppold) gave a banding demonstration and discussed this project at Maine Audubon's Field's Pond Nature Center in Holden, ME. Holberton and Leppold gave a public talk on migratory birds for the Penobscot Valley Chapter of Maine Audubon in Bangor, Maine in March, 2010. In October, 2009, Holberton and Leppold gave a talk on migratory birds and conservation, and held a banding demonstration on Metinic Island to schoolchildren (6-18 years old) from Matinicus Island, Maine.
- Throughout 2009, Holberton discussed this project and its findings to members of Maine's government and Maine's Governor's Ocean Energy Task Force group and subcommittees during the development of state regulations for offshore energy development.
- Holberton provided oral and written testimony to the Maine State legislature in April, 2011, on LD 872, a bill to reduce setbacks for migratory and breeding shorebirds and waterfowl.
- Holberton hosted a workshop 26 January, 2010 in Orono, Maine that together researchers at several institutions (Acadia Univ. in Nova Scotia; Univ. of Maine, Canisius College), and state and federal agencies (US Fish & Wildlife Service, Maine Inland Fisheries and Wildlife, National Park Service) to develop the Northeast Regional Migration Monitoring Network and a citizen science initiative, "Project Gulfwatch".
- In 2009 Tonra was invited to a meeting of the Rotary Club of Western Jamaica in which he presented aspects of his research and participated in a discussion with local business owners on migratory bird ecology and conservation
- In 2010 Tonra gave an invited seminar to the Biology Club of University of Maine in which he lectured on the migration ecology of birds to an audience of undergraduates.
- In 2011 Tonra participated in bird banding demonstrations and interpretation to the public at the International Migratory Bird Day celebration in Rock Creek National Park, Washington, D. C. This enabled him to discuss his research, and migration ecology in general, with a broad audience of all ages.
- Comments featured in articles on bird migration studies (in part):
- Dec. 10, 2010, Maine Birding News - Maine Business Press: "Coastal Owl and Falcon Migration Route Described By Scientists"
- Dec. 21, 2010, MPBN radio news story, "Bird Migration Study Could Impact Wind Power Siting Off Maine Coast" by Susan Sharon
- Dec. 21, 2010, MPBN report "Studies Document Bird Migration Routes Along the Maine Coast"

- Dec. 26, 2010, Portland Press Herald, "Can Wing Power Thrive Amid Wind Power Growth?" By Beth Quimby
- Dec. 26, 2010: UMaine Press Release, "Comments from UMaine Prof. Rebecca Holberton, leader of the Gulf of Maine's Northeast Regional Migration Monitoring Network, were included in a Maine Public Radio report about a new report documenting the migratory patterns of certain bird species off the Maine coast. Holberton notes that the study is important to helping scientists identify the species that could be affected by offshore wind power generation technology.?"
- Dec. 27, 2010, The Times Record, Monday Meter "THUMBS UP & DOWN - Offshore Raptor Migrations?"
- Dec. 28, 2010, Offshore Wind Wire, "MORNING ROUNDUP: Monitoring Birds to Guide Offshore Wind Development?"
- Articles related to discovery of previously undocumented major flyway in the Gulf of Maine region:
- Oct. 7, 2010 ? USF&W Press Release "Researchers Work to Reveal Bird Migration Pathways in the Gulf of Maine?"
- Oct. 15, 2010 Univ. of Maine press release: "UMaine Among Leaders of Groundbreaking Research Into Bird Migration in Gulf of Maine?"
- Oct. 21, 2010, Acadia University press release "Acadia's Phil Taylor Collaborates with UMaine Researchers on Bird Research?"
- Nov. 1, 2010, "An Innovative Strategy for Monitoring Bird and Bat Migration in the Gulf of Maine?", USF&W report.
 - Nov. 27, 2010, Portland Daily Sun "Research on the Wing" By David Carkhuf
 - Winter, 2010, The Wildlife Professional, pg 16-17. Northeast region/Maine overview.
- UMaine Today, Winter 2010: "Migration Monitoring?"
- UMaine Today, Spring 2010: "Songbird shortcut?"
- UMaine Today, Spring 2011: "Maine's Super Flyway: Can Mass Migrations Survive a Changing Gulf of Maine Coast?"

Presentations/seminars to the general public

- (2011) "What's Blowing in the Wind?" ? Dirigo Pines Retirement Community (2010) Wildlife Society Student Forum career discussion (2009-10) outreach and public education in a multi-agency activity initiated by the Farnsworth Museum and the Matinicus Island School District, leading to the 2010 exhibition at the Julia's Gallery for Young Artists at the Farnsworth Art Museum: A Bird's Eye View: Journeying through 21st Century Climate Change, a multimedia, interdisciplinary, collaborative exhibition exploring the intersection of art and science through the eyes of thirty-five students from the Matinicus Island School, Julia's Gallery for Young Artists and Unity College.
- (2009) NE Wildlife Conclave at SERC ? bird-banding demonstration
- (2009) Field's Pond Migratory Bird Day ? bird-banding demonstration

Journal Publications

Angelier, F; Holberton, RL; Marra, PP, "Does stress response predict return rate in a migratory bird species? A study of American redstarts and their non-breeding habitat", PROCEEDINGS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES, p. 3545, vol. 276, (2009). Published, 10.1098/rspb.2009.086

Angelier, F.; Tonra, C.M.; Holberton, R.L.; Marra, P.P., "How to capture wild passerine species to study baseline corticosterone levels.", Journal of Ornithology, p. 415, vol. 151, (2009). Published, DOI 10.1007/s10336-009-0471-6

Tonra, C.M.; Marra, P.P.; Holberton, R.L., "Migration phenology and winter habitat quality are related to circulating androgen in a long-distance migratory bird.", Journal of Avian Biology, p. , vol. , (2011). Published, 10.1111/j.1600-0587.2011.05333.x

Tonra, C.M., Marra, P.P., Holberton, R.L., "Early elevation of testosterone advances migratory preparation in a songbird.", Journal of Experimental Biology, p. , vol. , (2011). Accepted,

Angelier, F. Tonra, C.M., Holberton, R.L., Marra, P.P., "Short-term changes in body condition in relation to habitat and climate in American redstarts during the non-breeding season.", Journal of Avian Biology, p. , vol. , (2011). Accepted,

Angelier, F., Ballentine, B. Holberton, R.L., Marra, P.P. and Greenberg, R., "What drives variation in the corticosterone stress response between subspecies?: a common garden experiment of Swamp sparrows (*Melospiza georgiana*).", Journal of Evolutionary Biology, p. 1160, vol. 24, (2011). Published, 10.1111/j.1420-9101.2011.02260.x

Books or Other One-time Publications

Web/Internet Site**URL(s):**

<http://sbe.umaine.edu/avian/>

Description:Other Specific Products**Product Type:**

presentations at meetings or invited seminars

Product Description:

25th International Ornithological Congress, 22-28 August, 2010 -

SYMPOSIUM: STUDYING BIRDS IN THE CONTEXT OF THE ANNUAL CYCLE: CARRY-OVER EFFECTS AND SEASONAL INTERACTIONS.

Convenors: Peter P. Marra, Smithsonian Migratory Bird Center, National Zoological Park, Washington, DC., USA, and Jennifer Gill, School of Biological Sciences, University of East Anglia, United Kingdom

Keynotes speakers:

Peter P. Marra ? Carry-over effects in migratory birds: consequences for individual performance on breeding areas.

Jennifer Gill - Carry-over effects in migratory birds: individual-based drivers and population-scale patterns

Symposium Abstract

Migratory and resident birds either spend different periods of the annual cycle in geographically disparate places or must cope with changing environmental conditions. The conditions and selective pressures during one period undoubtedly affect individual performance during a subsequent season. This simple fact has important implications for the ecology, evolution, and conservation of birds. Such inter-seasonal effects are especially poorly understood within most bird migration systems, primarily because it has been difficult to determine the connections between specific summer and winter populations and during migration. Ringing observations, satellite telemetry and stable isotopes have contributed to our ability to link events in the annual cycle and we are only beginning to uncover the ecological and evolutionary significance of these connections. Events on the wintering grounds affect both arrival time and body condition of individual birds on the breeding grounds, and these impacts are likely to have important consequences for breeding behavior, natal dispersal and population dynamics. In this symposium, we will highlight and describe through examples across diverse taxa how understanding carry-over effects and seasonal interactions are essential to a fundamental understanding of bird biology. Topics to be covered in the symposium include modeling annual cycle routines, population dynamics and density-dependent effects, physiological underpinnings of carry-over effects, life history evolution and conservation.

Sharing Information:

This symposium was scheduled as part of the program of events at the meeting, which has an international audience with an expected registration of 2000-3000 participants.

Product Type:

presentations

Product Description:

-Presentations at meetings relative to this project

(2010) Balancing the demands of migration and the physiological transition to breeding in Neotropical songbirds: a dual role for testosterone? C.M. Tonra (presenter), P.P. Marra, and R.L. Holberton. Ecological Society of America Annual Conference, Aug 1-6, Pittsburgh, PA

(2010) Carry-over effects and the relevance of studying migration in the context of the entire annual cycle. P.P. Marra. Annual meeting of the Society for Integrative and Comparative Biology, January 4-7, Seattle, WA

(2009) The physiological underpinnings of seasonal interactions in a Neotropical migrant songbird. C.M. Tonra (presenter), P.P. Marra, and R.L. Holberton. Annual meeting of the American Ornithologists? Union, August 12-15, Philadelphia, PA

(2009) ?Preparation for breeding on the non-breeding grounds in Neotropical migrants: Does elevated testosterone enhance migratory preparation??. C.M. Tonra, presenter, P.P. Marra, R.L. Holberton. Annual meeting of the American Ornithologists? Union, August 12-15, Philadelphia, PA

(2009) ?A novel ?pita? design for hormone manipulations in small birds.?. R.L. Holberton, presenter, K.N. Porcelli, C.M. Tonra, co-authors. Annual meeting of the American Ornithologists? Union, August 12-15, Philadelphia, PA

(2009) The role of breeding hormones in seasonal interactions in a Neotropical migrant songbird. C.M. Tonra (presenter), P.P. Marra, and R.L. Holberton. Hubbard Brook Ecosystem Study Annual Conference, North Woodstock, NH

(2008) Navigating the Trail to the Grail: A Physiological Codex in Search of Body Condition. AOU/CSO/COS Portland, OR. R. L. Holberton, presenter; E. M. Adams, S. M. Agius, K. M. Covino, A. J. Leppold, C. M. Tonra, W. A. Wright, co-authors; Symposium "Body condition of birds: the search for the Holy Grail", organized by S. R. McWilliams, C. G. Guglielmo.

(2008) Symposium - Physiological Underpinnings of Seasonal Interactions. AOU/CSO/COS Portland, OR. R. L. Holberton, P.P. Marra, co-presenters

(2007) "The Role of Food Availability in Driving Physiological Carry-over Effects from the Non-breeding to the Breeding Season?". Association of Field Ornithologists? Mtg., Orono, ME, R.L. Holberton, presenter; Peter P. Marra, co-author

(2007) "The Role of Food Availability in Driving Physiological Carry-over Effects from the Non-breeding to the Breeding Season?". Wilson Ornithologists? Society Mtg., Boston, MA, R.L. Holberton, presenter; Peter P. Marra, co-author

Invited Seminars

(2011) "Parallels, Circles, and Triangles: The Geometry of Migration Studies in a Major Flyway System, the Gulf of Maine?". Smithsonian Migratory Bird Center and National Zoo, Washington, DC, AJ Leppold, co-author, R Holberton, presenter

(2011) "The Northeast Regional Migration Monitoring Network: Building Bridges with Partners and Public Participation?". AJ Leppold, co-author, R Holberton, presenter, US Fish & Wildlife Service, Craig Brook Fish Hatchery, Orland, ME

(2007) "Glucose, Goals and Gonads: Understanding the Basis of Seasonal Interactions and Their Links to Survivorship and Reproduction in Migratory Birds?", Amherst College, R. Holberton, presenter

Sharing Information:

These public presentations were made to a broad general audience as well as at professional meetings.

Product Type:

presentations at professional meetings

Product Description:

Presentations at meetings by Tonra (2009-10 ONLY)

(2010) Carry-over effects and the relevance of studying migration in the context of the entire annual cycle. P.P. Marra. Annual meeting of the Society for Integrative and Comparative Biology, January 4-7, Seattle, WA

(2009) "Preparation for breeding on the non-breeding grounds in Neotropical migrants: Does elevated testosterone enhance migratory preparation?". C.M. Tonra, presenter, P.P. Marra, R.L. Holberton. Annual meeting of the American Ornithologists' Union, August 12-15, Philadelphia, PA

(2009) "A novel "pita" design for hormone manipulations in small birds?". R.L. Holberton, presenter, K.N. Porcelli, C.M. Tonra, co-authors. Annual meeting of the American Ornithologists' Union, August 12-15, Philadelphia, PA

(2009) Hubbard Brook Ecosystem Study Annual Conference, North Woodstock, NH (2009) The role of breeding hormones in seasonal interactions in a Neotropical migrant songbird. (C.M. Tonra, presenter, P.P. Marra and R.L. Holberton, co-authors)

Sharing Information:

All of these presentations have been made at national or international meetings that have a broad audience.

Contributions

Contributions within Discipline:

This project is the first to study underlying mechanisms (integrating physiological, ecological, behavioral) of seasonal interactions in a migratory bird. The study has provided a framework for understanding how events during one stage of the annual cycle are inextricably linked with events occurring during other stages. The model is now being extended to other avian species across a diversity of life history patterns, including other migratory landbirds and several species of seabirds, including terns (Common and Arctic tern) and alcids (Atlantic puffin and Razorbill).

The work from this project was presented in a larger context within the symposium organized by Marra and Gill (see below) for the 25th International Ornithological Congress, 22-28 August, 2010 in Brazil.

SYMPOSIUM: STUDYING BIRDS IN THE CONTEXT OF THE ANNUAL CYCLE: CARRY-OVER EFFECTS AND SEASONAL INTERACTIONS.

Convenors: Peter P. Marra, Smithsonian Migratory Bird Center, National Zoological Park, Washington, DC., USA, and Jennifer Gill, School of

Biological Sciences, University of East Anglia, United Kingdom. Peter P. Marra ? Carry-over effects in migratory birds: consequences for individual performance on breeding areas.

Jennifer Gill - Carry-over effects in migratory birds: individual-based drivers and population-scale patterns

Plenary and Keynotes

British Ornithological Union March 2011:

Invited speaker Peter P. Marra ? Carry-over effects in migratory birds: consequences for individual performance on breeding areas.

This project is the first to approach the study of seasonal interactions in songbirds. Holberton is now introducing this approach to several federal and state agencies as a way to help them develop effective management plans for a diversity of species, including seabirds and shorebirds, in the region. Holberton hosted a workshop 26 January, 2010 in Orono, Maine to bring together researchers at several institutions (Acadia Univ. in Nova Scotia; Univ. of Maine, Canisius College), and state and federal agencies (US Fish & Wildlife Service, Maine Inland Fisheries and Wildlife, National Park Service) to develop the Northeast Regional Migration Monitoring Network. This entity had its second annual meeting and now comprises several federal agencies, institutions, and NGOs including US Fish & Wildlife offices in Maine, New Hampshire, Massachusetts and Rhode Island, the National Park Service - Acadia National Park, Maine Inland Fisheries and Wildlife, Canadian Wildlife Service, New Jersey Audubon, Appledore Island Banding Station, Manomet Bird Observatory, Acadia University in Nova Scotia and many others. The Network now has annual meetings, a newsletter, and many activities that support environmental education.

Contributions to Other Disciplines:

The principles underlying seasonal interactions are broadly applicable beyond avian taxa. This project illustrates the success that can be realized by in integrating several disciplines such as ecology, behavior, and physiology.

Contributions to Human Resource Development:

We are committed to disseminating knowledge gained from this research to enhance environmental awareness and scientific understanding. Our collaborative research program involves a national and international training component (post-docs, field assistants, wildlife biologists and governmental and NGOs in Jamaica) as well as graduate and undergraduate education. We continue to work with officials at the National Environmental Protection Agency of Jamaica, training wildlife officials in basic and applied research approaches to studies on migratory birds. The activities of the project provide new experiences and opportunities to develop new skills for the doctoral student (C. Tonra) and post-doctoral fellow (F. Angelier). Both of them developed their own ideas and incorporated them into the project's goals, thus enhancing the research further. Tonra's dissertation includes hypotheses about density-dependent factors during the arrival period on the breeding grounds. Tonra traveled to the Smithsonian Institute and learned how to perform mass spectrometry analysis on bird claws to determine $\delta^{13}C$. Angelier tested several hypotheses about winter habitat occupancy, adrenocortical sensitivity, and survival, as well as linking measures of chronic stress and aging (e.g. immune function, corticosterone secretion, telomere shortening) with winter habitat suitability. Angelier established collaborations with other researchers (R. Greenberg, C. Vleck) and traveled to Vleck's lab in Iowa to learn new techniques associated with measuring telomere length in redstarts. Two additional University of Maine students (Evan Adams, Adrienne Leppold) assisted with the captive study, learning how to collect, process, and analyze blood samples for plasma constituents, and to use implants for manipulating hormone activity. Four University of Maine undergraduates also assisted in this work and have participated in all phases of the captive study. Based on their experience on it, they have developed three additional studies on bird endocrinology and social behavior, which are currently underway. One undergraduate (Kayla Porcelli) is now proficient in doing radioimmunoassay and enzyme-based colorimetric assays. Opportunities for undergraduate research experience on the project has been offered through the University of Maine's Honor's program and the newly established S-cubed: Support for Science Students, as well as BIO 387/388 Undergraduate Research Experience. UMaine undergraduates Doug Perez, Mellissa Kiermann, Kayla Porcelli, and Kristi Kennedy assisted with captive studies on testosterone, migration, and breeding preparation. They developed and completed a study on claw growth rates for standardizing stable isotope sampling and have helped design a new type of implant for delivering hormones in very small birds such as the redstart. One undergraduate (Doug Perez) was funded on a summer REU on this project and used his research experience on these studies to meet the requirements of his senior Capstone project. Nissa Marione used her experience on this project to develop an independent study for her Honor's Thesis, which she successfully defended. Altogether, this project fostered the interaction among individuals at different stages of career development and from different disciplines. Students and post-docs learned new skills, and were encouraged to develop novel techniques and approaches. The project provided many opportunities for community involvement and public education.

Contributions to Resources for Research and Education:

The data from this project will be incorporated in the extensive Migratory Bird Database at the Laboratory of Avian Biology at University of Maine (Holberton). Plans are underway to make this an online searchable database, comprising ecophysiological data for over 3500 birds, available to the public.

Contributions Beyond Science and Engineering:

Throughout 2009-2011, Holberton discussed this project and its findings to members of Maine's government and Maine's Governor's Ocean Energy Task Force group and subcommittees during the development of state regulations for offshore energy development. Holberton continues to contribute to the development of policy and environmental monitoring plans related to the University's DeepCWind Consortium for offshore wind development and to work with federal and state wildlife agencies in developing their long-term comprehensive resource management plans. Holberton relies on the outcomes of this project when preparing written and oral testimony she presents in the Maine state legislature.

Conference Proceedings

Categories for which nothing is reported:

Any Book

Any Conference