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Essays and Perspectives

The benefits of evolution education for natural resources managers

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ABSTRACT

Managers are a strength of policy implementation in the changing and complex landscape of natural resources management. We argue future managers will require additional educational emphases such as coursework in evolution to confront emerging issues in this dynamic profession. An emphasis on more management-oriented evolution education at the collegiate level will help the next cohort of managers as they face changing management and policy realities. Our goal for this paper is to demonstrate the need for training in evolutionary theory for all natural resources professionals by (1) showing emerging needs for evolutionary theory in management, (2) detailing the strengths and uses for evolutionary theory, and (3) recommending strategies for increasing wildlife biologists' knowledge of evolution and its potential effect on wildlife management. Incorporating evolutionary thought and foresight into management decisions essentially forces managers to consider each of their actions and the complex set of consequences that may arise in both the short and long-term. We believe that through academic and post-graduate training, evolutionary theory can be understood and applied by managers in decision-making processes.

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Introduction

For over 20 years, natural resources professionals have emphasized that on-the-ground natural resources managers (e.g., state and federal biologists) can benefit from an understanding of genetics and evolutionary theory. As early as 1989, observers were noting that wildlife managers rarely explicitly incorporated theoretical concepts that included behavior and evolution into management programs (Gavin, 1991). The absence of evolutionary concepts in wildlife management occurred even as complex genetic and evolutionary considerations were incorporated into overarching natural resources management policies. Calls for improved evolution education and increased consideration of evolutionary consequences of management actions increased in the early 2000s (Bleich and Oehler, 2000; Crandall et al., 2000; Alters and Nelson, 2002; Ashley et al., 2003). Amidst these calls, we contend that more should be done to prepare future wildlife biologists and natural resource managers for the changing management landscape. This is not a criticism of current natural resources managers. Instead, we hope that emphasizing more management-oriented evolution education at the collegiate level will help the next cohort of managers as they face changing management and policy realities. Our goal for this paper is to demonstrate the need for training in evolutionary theory for all natural resources professionals by (1) showing emerging needs for evolutionary theory in management, (2) detailing the strengths and uses for evolutionary theory, and (3) recommending strategies for increasing wildlife biologists' knowledge of evolution and its potential effect on wildlife management.

There are many excellent treatises on the need for evolutionary thought in conservation biology and wildlife management and various strategies for integrating them (e.g., Gavin, 1991; Crandall et al., 2000; Wiens and Graham, 2005; Kinnison and Hairston, 2007). Rather than arguing these points we focus on the need for future natural resources managers to fundamentally understand evolutionary biology and integrate this knowledge into management planning. Therefore, we argue there is a need to provide

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practical illustrations of how evolutionary theory and thinking directly affect management. We offer this paper as a review of evolutionary principles and applications that students and current managers can consult to stimulate their own thinking on the role of evolution in management.

The basic theory of evolution is taught at multiple levels through the academic careers of students in the biological sciences. Moreover, evolution as a concept is repeatedly revisited in courses throughout undergraduate education curriculums and classes. However, we believe that universities can more effectively teach evolution for practitioners. Collectively, we have taught thousands of college students, from diverse backgrounds, in our roles as graduate assistants, teaching assistants, lecturers, professors, and as working scientists and wildlife managers. Yet, a common theme has emerged from our interactions with many of those students. Concepts in evolution and behavior, topics critical to natural resources management, consistently failed to interest students. In our discussions with students, evolution was often seen as extraneous to core lessons such as flora and fauna identification, wildlife-capture techniques, timber and range management, and population ecology. Additionally, students may often be interested in evolution, but fail to see its importance to on-the-ground natural resources management. Today's students are tomorrow's managers who help develop and implement wildlife management plans and policies. These policies increasingly contain genetics and evolutionary biology components; thus, underlining the need for an explicit understanding of these concepts and the consequences of not considering them (Gavin, 1991; Festa-Bianchet, 2013).

Natural resources professionals have diverse educational backgrounds covering a multitude of management, ecological, and theoretical emphases (Peek, 1989). They represent on-the-ground caretakers of natural resources and range from state and federal government employees to consultants and private lands managers. Increasingly, managers are confronted with problems and objectives that require broad scientific understanding to resolve. What are species? Does humanity preserve species or lineages? Do we save what we have or manage to provide the most evolutionary potential? How do we plan habitat management from a system perspective? Understanding the short and long-term evolutionary impacts of management actions allows managers to determine the best course of action. This contention is based on a few conceits: (1) we (humanity) desire certain species, ecosystems, ecosystems services and products to exist in perpetuity, (2) continued existence of these systems requires management even when direct action is not considered (non-management is a management strategy), (3) all organisms pass genetic heritage to their offspring, and (4) organisms and the ecosystems they inhabit impact each other (often in complex and unforeseen ways).

Natural resources managers are increasingly tasked with developing synthesized short-term management strategies with potentially long-term implications. Managers are directly impacting future generations of populations, species and ecosystems whether they understand evolutionary principles or not. Thus, coming to terms with evolution is not a luxury for managers, but a necessary tool they must develop and consider with each management action or plan. The manager should have a broad understanding of the genetic impacts on managed species due to the consequences of management actions (e.g., changes due to hunting; Harris et al., 2002) and the increasing role of genetics and evolution in wildlife policy. For example, Coltman et al. (2003) found that trophy hunting of big horn sheep (*Ovis canadensis*) rams resulted in population declines for weight and horn size in mean breeding males. Agriculturalists have practiced this for millennia as they cultivate various crops and livestock with an eye toward maximizing hardiness, efficiency, and production. Management actions invariably have consequences (good and bad). Sometimes evolutionary implications of management actions on target and non-target species are overlooked or not recognized.

Academic institutions and management agencies strive for comprehensive syntheses of ecological principles that guide management. However, comprehensive principles and direct illustrations must be increased throughout undergraduate education (Jacobson, 1990). We encourage the full return to the path of long-term, sustainable, and integrative thinking prescribed by management and conservation scions such as Aldo Leopold and John Muir (Leopold, 1949; Harte, 1996; Kessler and Booth, 1998). Comprehensive evolutionarily-based management strategies address many current and arising challenges in natural resources management (e.g., endangered species conservation, habitat loss and fragmentation). Such a management strategy should foremost attempt to identify and preserve adaptive diversity and evolutionary processes, be proportionate to need, and create strategies based on sound science (Crandall et al., 2000). Incorporating evolutionary thought and foresight into management decisions essentially forces managers to consider each of their actions and the complex set of consequences that may arise in both the short and long-term. We believe that through academic and post-graduate training, evolutionary theory can be understood and applied by managers in decision-making processes.

Evolutionary theory in wildlife management

Futuyma (1986) defines the theory of biological evolution as genetic change inherited from one generation to the next. Recent literature is expanding on the traditional view of evolution as solely slow progressive change over millions of years (Stockwell et al., 2003; Kinnison and Hairston, 2007). Rapid or contemporary evolution (i.e., evolution occurring within a relatively few number of generations) might commonly occur. In essence, while common evolutionary examples occur on time scales too long for a human to observe over a lifetime, evolution also occurs rapidly such as resistance to pesticides, herbicides, antibiotics, or response to changes in habitat, climate, or exotic species (Stockwell et al., 2003). This concept is popularly demonstrated by the complex of Darwin's finches (Geospizinae) on a Galápagos island in which a group of closely related finch species evolved radically different beak morphology in response to abrupt climatic changes. Each species adapted to utilize different feeding strategies and food resources as a result (Grant and Grant, 1993).

Palumbi (2001) called humans the "greatest evolutionary force" on earth due to the recurring impacts humans have on these processes (e.g., antibiotic or herbicide resistance). Managers often make decisions that counteract, manipulate, or accentuate anthropogenic impacts. This means that managers can impact the evolution of wildlife through any number of strategies even as larger anthropogenic actions (e.g., climate change, national policies) add more complexity. These environmental pressures highlight the increasing role of humanity in shaping the course of evolution for many species. Furthermore, humans are not just impactors of other species but competitors for water, air, space, and nutrients (Futuyma et al., 2001).

Humanity's ever growing presence on the planet causes complex, sometimes intractable problems for natural resources managers that further highlights the necessity of comprehensive training in evolution (Western, 2001). The new human-dominated biosphere leads to "biotic destruction" highlighted by high extinction rates coupled with degraded or retarded evolutionary processes such as speciation (Erwin, 1991; Dirzo et al., 2014). Evolution spurred by intensive selective pressure has proven incapable of adapting quickly enough to substantially counteract extinction rates (Parmeson, 2006). Comprehensive and complex conservation programs have arisen to mitigate these sobering predictions.

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Some researchers suggest that preservation of processes like evolution is more important than protecting intraspecific phenotypes (Moritz, 1999). The question, therefore, is do we work to preserve current species and processes or do we attempt to protect lineages that allow evolutionary adaptation (Myers and Knoll, 2001). This tug-of-war is apparent in species conservation legislation (e.g., Endangered Species Act [ESA]). Endangered species are often a component of what Babbitt (1995) described as the compartmentalization of the American landscape. Although undeniably often focused on phenotypes, increasingly many conservation initiatives such as the ESA are trying to maintain adaptive species diversity in perpetuity such as in the form of evolutionarily significant units (ESU) or distinct population segments (DPS) outlined in the ESA (Crandall et al., 2000). ESU and DPS, which range from a single population to entire species, are attempts to recognize distinct taxa with distinct evolutionary trajectories as well as specific ecological roles where organisms are co-adapted with other organisms in specific systems. Differences among populations or significant units may emerge from simple founder effects caused by geographic or temporal isolation from conspecifics or by selective processes that lead to reproductive isolation and local adaptation (e.g., Liles et al., 2015).

While some ESUs are easily identified discrete entities (such as salmon populations returning to different watersheds) others are indistinct. For instance, black bears (*Ursus americanus*) are found throughout North America, although their range is fragmented due to habitat loss and other anthropogenic causes. Habitat fragmentation has resulted in many isolated populations, some of which underwent dramatic population declines. During the middle part of the 20th century approximately 250 bears were translocated (over 10-year period) into Arkansas from Minnesota and Manitoba and 160 bears were translocated (over 3-year period) from Minnesota into eastern Louisiana. The long term genetic effects of these programs on the southern bear populations have been debated but a large study by Van Den Bussche et al. (2009) showed closer genetic affinities between samples collected in Minnesota/Manitoba and Arkansas compared to those from areas geographically closer while samples from eastern Louisiana were significantly different from the northern populations. While the Louisiana population is federally listed, the Arkansas population is not, although some portions of it are also quite distinct. This study also highlights how two successful translocations can have different impacts on the receiving population. Managers need to consider implications of introducing genes from different populations, and the fact that these can have long term implications (i.e., Arkansas's bear population is not protected and adding protection may meet resistance due to the genetic similarity to bears occurring in more northern areas which do not currently warrant protection). In fact, by translocating bears from a geographically distant portion of the population a unique lineage of bears was replaced by a genetically common and widespread bear. While in some instances this may be unavoidable (i.e., the population in a region is too low to be viable) it is important to understand the ramifications of these types of translocations.

There are also some wildlife translocation examples that demonstrated how a lack of consideration for evolutionary relationships caused projects to fail. Stuwe and Nievergelt (1991) showed that translocated Ibex (*Capra ibex*) that hybridized with captive goats (*Capra aegagrus hircus*) give birth in a season with few food resources. Thus, due to outbreeding through hybridization, recruitment failed when they were decoupled from the growing season they had evolved to exploit. Additionally, Hodder and Bullock (1997) described that large blue butterflies were thought to use the dens of several species of ants and brooding chambers. During translocation all reproduction failed because they were obligate commensals with only one ant species and without its presence they could not survive. Such highly co-evolved systems are relatively common but managers need to better understand their mechanisms to identify and manage them.

With this dawning awareness of the importance of genetic variability in the conservation of species and habitats, managers must understand and apply evolutionary theory to identify and manage the evolutionary consequences of their actions. The manager is often cast in the difficult role of triage coordinator deciding which foci are in urgent need of scarce conservation resources. This has contributed to creating fragmented management strategies that tax the skills and knowledge of individual managers. Poorly planned management programs (e.g., hunting impacts on population genetics; Festa-Bianchet, 2013), accidental introductions (e.g., red imported fire ant (*Solenopsis invicta*) impacts on biodiversity; Wojcik et al., 2001), extirpations and extinctions (e.g., future role of climate change in extinctions; Brook et al., 2008), habitat destruction and fragmentation (e.g., changes in wildlife competitive coexistence based on patch dynamics; Nee and May, 1992), wildlife behavioral changes (e.g., urban impacts on animal behavior; Ditchkoff et al., 2006), and resulting genetic and demographic problems (e.g., revised reserve creation for biodiversity and sustainability; Margules and Pressey, 2000) can have important impacts on target populations. More to the point, the alteration of ecosystem processes, both subtle and overt, can alter the evolution of a variety of native species and the costs of poor planning can be high. Managers undertake management strategies that impact population genetics (Wedekind, 2002) and, thus, understanding the connection between population genetics and species viability and conservation is a central reason for in-depth education in evolutionary theory (Lande, 1988).

Many examples exist that demonstrate the unexpected and far-reaching management impacts (e.g., elk in Yellowstone National Park, deer on the Kaibab plateau, wolf control in North America). Researchers have increasingly recognized the importance of hybridization in wildlife evolution such as the case of hybrid speciation (DeMarais et al., 1992; Allendorf et al., 2001). Hybridization of wildlife species occurs both naturally and anthropogenically (e.g., in captivity, due to habitat loss). This creates a series of legal and practical issues in wildlife management. Hybrids inhabit uncharted seas under the ESA as species-level conservation depends on consistent species delineation. Agencies and management personnel determine acceptable amounts of anthropogenic hybridization (e.g., coastal cutthroat trout [*Oncorhynchus clarki clarki*] hybridizing with rainbow trout [*O. mykiss*]) (Allendorf 2001), but these difficult decisions impact uniquely and locally adapted species and retention of genetic variation (DeMarais et al., 1992). Management practices greatly impact hybridization (e.g., habitat destruction, non-native species introductions). These strategies have impacted the evolutionary potential, genetic well-being, and current population status of many wildlife species. Conversely, community and ecosystem level management strategies are often difficult or impossible to implement due to artificial development. When possible, these strategies often take the form of metapopulation systems and corridor creation. For instance, an important goal of wildlife conservation and management is connecting different populations to promote gene flow, increase habitat availability, and increase realized population size (disconnected smaller populations are more susceptible to genetic drift and demographic and environmental stochasticity). Therefore, the connection of populations through corridors or the maintenance of networks of subpopulations in metapopulations are common management goals and are related to genetic health and species persistence (Amos and Harwood, 1998). Decisions made in reintroductions, conservation, metapopulation dynamics, among many others have significant impacts on short and long-term evolution.

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Evolution-based management and education

Managers facing modern problems are tasked with more than simply managing populations. At the local or regional level the threats of habitat fragmentation, mutations originating from pollution, and wide-ranging impacts of global climate change must be anticipated. The increasing pressures of a rapidly urbanizing and industrializing landscape has increased the complexity of management programs as they try to account for a changing world with changing expectations (Parker et al., 2008). Research has indicated that humans are a major impactor on evolution in non-human species (Darimont et al., 2009), thus, interminably connecting humanity, management, and evolution. Managers must plan or react to everything from relatively short-term actions like depredation hunts, beach cleanups, and funding changes to more long-term issues like dam building, sea-level rise from climate change, and changes in social views (e.g., hunting approval). For example, maintaining maximum genetic heterogeneity in a population can aid in adaptation to future climate and environmental changes. The form this management takes is entirely up to the manager or managing apparatus. Increasingly, management recommendations are in the language of genetics and evolution (Lande, 1988; Crandall et al., 2000). This is the idea of "look before you manage".

The most important components of successful management are a thorough understanding of the ecosystem in question, knowledge of the management "toolbox" available to managers, and the education to use the appropriate tools correctly (Shea, 1998; Kroll, 2007). Unfortunately, evolution education varies wildly amongst universities and programs and is sometimes seen as extraneous to practical management concerns (e.g., population dynamics, nutrition habits, habitat and vegetation) (Johnson et al., 2009). Natural resources management departments will often have a natural history course (e.g., Natural History of the Vertebrates at New Mexico State University) that includes an evolution component. However, dedicated courses in evolution are often electives rather than core curriculum and reside predominantly in biology or related departments rather than wildlife or agriculture departments. Furthermore, the integration of evolution into natural resources courses is uneven and varies amongst teachers and results in many college graduates lacking a fundamental understanding of evolution (Smith et al., 1995; Alters and Nelson, 2002). This lack of instruction often begins at the high school level, thus, producing students with a wildly varying understanding of an intrinsic natural resource principle (Scott and Branch, 2003; Catley, 2006). This is complicated by the intransigent controversy of evolution education in the U.S. (hotbed of anti-evolution activism) which threatens to undermine high school and college education.

Often, natural history courses such as the Natural History of the Vertebrates at North Carolina State University do explicitly state they cover evolution. In truth, these courses are still often overlooked in current university curriculums and in need of expansion and synthesis with other areas such as conservation biology (Bury, 2006). Non-core courses struggle for inclusion in already crowded schedules as many university curriculums have reduced plan-hour requirements. There are simply too many courses competing for too few slots in undergraduate degree plans. Probably more importantly, in our experience, many of the available courses fail to emphasize evolution as critical in on-the-ground management scenarios. Even less management-oriented programs such as ecology and evolutionary biology or biology programs often fail to synthesize management realities with other areas such as conservation biology and evolutionary theory (Bury, 2006). As such, graduating students expected to move into management positions lack critical information about the connection between management action and genetic and evolutionary consequences.

We propose a multi-fold response to this need. First, we argue that undergraduate natural resources management programs should urge students to take a management-oriented genetics course (e.g., Introduction to Conservation Genetics, University of Florida) or an evolution course. We realize that modern curriculums are relatively filled with required courses but students should be strongly encouraged to include such a course as an elective. This requires a strong cross-disciplinary component in program thinking as students must feel encouraged to take upper division courses outside the confines of their department. That may require reducing departmental course loads. We acknowledge that departments have individual educational goals and also often receive money based on student hours. They might, therefore, hesitate to expand core curriculum classes outside the department. Increased cooperation amongst departments might include revenue sharing agreements, special integrated programs between departments, and interdepartmental team-teaching may help to ameliorate some of these concerns. Second, we recommend that instructors of existing natural resources courses place management actions within the context of greater management goals and consequences. Even traditionally, method-driven courses (e.g., wildlife techniques) could devote more time to the nuances of evolution and management as they discuss methods (e.g., population estimation, forest basal area calculation). Third, we agree with Alters and Nelson (2002) that educators can incorporate more efficient teaching methods into courses; thus, increasing the effectiveness of general content retention. This includes more active learning rather than uninterrupted lecturing and an emphasis on critical thinking. Techniques may include student-driven discussions, problem-solving activities, and field work. This may seem far afield but we feel it dovetails well with what Gavin (1991) was describing as he extolled the benefits of teaching evolution to wildlife managers. Finally, we recommend that universities create distance learning and workshop opportunities for current natural resources managers. Partnerships with university-affiliated research institutes and extension programs could help facilitate outreach to public and private land managers as part of continuing evolution education.

Conclusion

We believe that future natural resources managers would benefit from more extensive training in genetics and evolutionary theory. The expanded education would allow greater engagement with researchers and policy-makers and more effective short-term and long-term management of natural resources. We admire past and current natural resources managers; however, shifts in policy and management directions (e.g., ESUs) require some changes in education for incoming managers. Changes in university curriculums will not be easy but we believe the potential benefits could maintain high-level management of natural resources in a changing world.

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References

Allendorf, F.W., Leary, R.F., Spruell, P., Wenburg, J.K., 2001. The problems with hybrids: setting conservation guidelines. Trends Ecol. Evol. 16, 613–622.

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Alters, B.J., Nelson, C.E., 2002. Perspective: teaching evolution in higher education. Evolution 56, 1891–1901.

Amos, W., Harwood, J., 1998. Factors affecting levels of genetic diversity in natural populations. Philos. Trans. R. Soc. Biol. Sci. 353, 177–186.

Ashley, M.V., Willson, M.F., Pergams, O.R.W., O'Dowd, D.J., Gende, S.M., Brown, J.S., 2003. Evolutionary enlightened management. Biol. Conserv. 111, 115–123.

Babbitt, B., 1995. Science: opening the next chapter of conservation history. Science 267, 1954–1955.

Bleich, V.C., Oehler Sr., M.W., 2000. Wildlife education in the United States: thoughts from agency biologists. Wildl. Soc. Bull. 28, 542–545.

Brook, B.W., Sodhi, N.S., Bradshaw, C.J.A., 2008. Synergies among extinction drivers under global change. Trends Ecol. Evol. 23, 453–460.

Bury, R.B., 2006. Natural history, field ecology, conservation biology and wildlife management: time to connect the dots. Herpetol. Conserv. Biol. 1, 56–61.

Catley, K.M., 2006. Darwin's missing link – a novel paradigm for evolution education. Sci. Educ. 90, 767–783.

Coltman, D.W., O'Donoghue, P., Jorgenson, J.T., Hogg, J.T., Strobeck, C., Festa-Bianchet, M., 2003. Undesirable evolutionary consequences of trophy hunting. Nature 426, 655–658.

Crandall, K.A., Bininda-Edmonds, O.R.P., Mace, G.M., Wayne, R.K., 2000. Considering evolutionary processes in conservation biology. Trends Ecol. Evol. 15, 290–295.

Darimont, C.T., Carlson, S.M., Kinnison, M.T., Paquet, P.C., Reimchen, T.E., Wilmers, C.C., 2009. Human predators outpace other agents of trait change in the wild. Proc. Natl. Acad. Sci. 106, 952–954.

DeMarais, B.D., Dowling, T.E., Douglas, M.E., Minckley, W.L., Marsh, P.C., 1992. Origin of *Gila seminuda* (Telestei: Cyprinidae) through introgressive hybridization: implications for evolution and conservation. Proc. Natl. Acad. Sci. 89, 2747–2751.

Dirzo, R., Youngy, H.S., Galetti, M., Ceballos, G., Isaac, N.H.B., Collen, B., 2014. Defaunation in the anthropocene. Science 345, 401–406.

Ditchkoff, S.S., Saalfeld, S.T., Gibson, C.J., 2006. Animal behavior in urban ecosystems: modifications due to human-induced stress. Urban Ecosyst. 9, 5–12.

Erwin, T.L., 1991. An evolutionary basis for conservation strategies. Science 253, 750–752.

Festa-Bianchet, M., 2013. Exploitative wildlife management as a selective pressure for life-history evolution of large mammals. In: Fest-Bianchet, M., Apollonio, M. (Eds.), Animal Behavior and Wildlife Conservation. Island Press, Washington, D.C., USA.

Futuyma, D.J., 1986. Evolutionary Biology, Second edition. Sinauer Associates, Sunderland, MA, USA.

Futuyma, D.J., Meagher, T.R., Donoghue, M.J., Langley, C.H., Maxson, L., Bennett, A.F., Brockmann, H.J., Feldman, M.W., Fitch, W.M., Godfrey, L.R., Hanken, J., Jablonski, D., Lynch, C.B., Real, L., Riley, M.A., Sepkoski, J.J., Smocovitis, V.B., 2001. Evolution, science, and society: evolutionary biology and the national research agenda. Calif. J. Sci. Educ. 1, 19–32.

Gavin, T.A., 1991. Why ask "why": the importance of evolutionary biology in wildlife science. J. Wildl. Manag. 55, 760–766.

Grant, B.R., Grant, P.R., 1993. Evolution of Darwin's finches caused by a rare climatic event. Proc. Biol. Sci. 251, 111–117.

Harris, R.B., Wall, W.A., Allendorf, F.W., 2002. Genetics consequences of hunting: what do we know and what should we do? Wildl. Soc. Bull. 30, 634–643.

Harte, J., 1996. Confronting visions of a sustainable future. Ecol. Appl. 6, 27–29.

Hodder, K.H., Bullock, J.M., 1997. Translocation of native species in the UK: implications for biodiversity. J. Appl. Ecol. 34, 547–565.

Jacobson, S.K., 1990. Graduate education in conservation biology. Conserv. Biol. 4, 431–440.

Johnson, J.B., Adair, M., Adams, B.J., Fairbanks, D.J., Itamura, V., Jeffery, D.E., Merrell, D., Ritter, S.M., Tolman, R.R., 2009. Evolution education in Utah: a State Office of Education-university partnership focuses on why evolution matters. Evol. Educ. Outreach 2, 349–358.

Kessler, W.B., Booth, A.L., 1998. Professor Leopold, what is education for? Wildl. Soc. Bull. 26, 707–712.

Kinnison, M.T., Hairston Jr., N.G., 2007. Eco-evolutionary conservation biology: contemporary evolution and the dynamics of persistence. Funct. Ecol. 21, 444–454.

Kroll, A.J., 2007. Integrating professional skills in wildlife student education. J. Wildl. Manage. 71, 226–230.

Lande, R., 1988. Genetics and demography in biological conservation. Science 241, 1455–1460.

Leopold, A., 1949. A Sand County Almanac. Oxford UP, Oxford, UK.

Liles, M.J., Peterson, M.J., Seminoff, J.A., Altamirano, E., Henríquez, A.V., Gaos, A.R., Gadea, V., Torres, P., Urteaga, J., Wallace, B.P., Peterson, T.R., 2015. One size does not fit all: importance of adjusting conservation practices for endangered hawksbill turtles to address local nesting habitat needs in the eastern Pacific Ocean. Biol. Conserv. 184, 405–413.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

Moritz, C., 1999. Conservation units and translocations: strategies for conserving evolutionary processes. Hereditas 130, 217–228.

Myers, N., Knoll, A.H., 2001. The biotic crisis and the future of evolution. Proc. Natl. Acad. Sci. 98, 5389–5392.

Nee, S., May, R.M., 1992. Dynamics of metapopulations: habitat destruction and competitive coexistence. J. Anim. Ecol. 61, 37–40.

Palumbi, S.R., 2001. Humans as the world's greatest evolutionary force. Science, 1786–1790.

Parker, I.D., Lyons, E.K., Licona, M.M., Scoggin, A.K., Sumrall, S.A., Sutton, A.E., 2008. Dinosaur evolution: student response to dinosaur ramblings. J. Wildl. Manage. 72, 1453–1455.

Parmeson, C., 2006. Ecological and evolutionary responses to recent climate change. Ann. Rev. Ecol. Evol. Syst. 37, 637–669.

Peek, J.M., 1989. A look at wildlife education in the United States. Wildl. Soc. Bull. 17, 361–365.

Scott, E.C., Branch, G., 2003. Evolution: what's wrong with 'teaching the controversy'. Trends Ecol. Evol. 10, 499–502.

Shea, K., 1998. Management of populations in conservation, harvesting and control. Trends Ecol. Evol. 13, 371–375.

Smith, M.U., Siegel, H., McInerney, J.D., 1995. Foundational issues in evolution education. Sci. Educ. 4, 23–46.

Stockwell, C.A., Hendry, A.P., Kinnison, M.T., 2003. Contemporary evolution meets conservation biology. Trends Ecol. Evol. 18, 94–101.

Stuwe, M., Nievergelt, B., 1991. Recovery of alpine ibex from near extinction: the result of effective protection, captive breeding, and reintroductions. Appl. Anim. Behav. Sci. 29, 379–387.

Van Den Bussche, R.A., Lack, J.B., Onorato, D.P., Gardner-Santana, L.C., McKinney, B.R., Villalobos, J.D., Chamberlain, M.J., White, D., Hellgren, E.C., 2009. Mitochondrial DNA phylogeography of black bears (*Ursus americanus*) in central and southern North America: conservation implications. J. Mammal. 90, 1075–1082.

Wedekind, C., 2002. Sexual selection and life-history decisions: implications for supportive breeding and the management of captive populations. Conserv. Biol. 16, 1204–1211.

Western, D., 2001. Human-modified ecosystems and future evolution. Proc. Natl. Acad. Sci. 98, 5458–5465.

Wiens, J.J., Graham, C.H., 2005. Niche conservatism: integrating evolution, ecology, and conservation biology. Annu. Rev. Ecol. Evol. Syst. 36, 519–539.

Wojcik, D.P., Allen, C.R., Brenner, R.J., Forys, E.A., Jouvenaz, D.P., Lutz, R.S., 2001. Red imported fire ants: impact on biodiversity. Am. Entomol. 47, 16–23.