ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2026, 11 (1): 249-259 doi: 10.28978/nesciences.261018

Embedding Conservation Genetics and Invasion Biology into Undergraduate Curricula with Competency Based Framework for Biodiversity Literacy

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Abstract

Conservation genetics and invasion biology are important areas of conservation biology and biodiversity conservation, and are not well represented in current undergraduate curricula. This paper examines the incorporation of such key topics into undergraduate education in a competency-based education (CBE) framework, which is aimed at improving biodiversity literacy and developing a deeper understanding of problems facing conservation. The development of competency-based learning outcomes in conservation genetics and invasion biology, with a focus on practical skills such as genetic assessment of populations and management strategies to deal with invasive species, is outlined in the study. Assessment methods such as project-based work, case study, and field activities are designed to measure the competency and engagement of the students. The paper also assesses the effect of this integration on the performance of students and learning outcomes, illustrating the advantages of hands-on, real-world applications and how

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this can be useful in providing a better connection with the subject matter. Feedback from students and instructors indicates that competency-based education brings greater engagement of students, better retention of key concepts, and better practical application of theoretical knowledge. However, problems such as the adaptation of curricula and the lack of resources are mentioned. The paper ends with some recommendations for how these barriers can be overcome and competency-based education expanded within environmental science programs. The results show how the integration of conservation genetics and invasion biology into undergraduate courses using CBE can help students to be better trained to address critical global biodiversity challenges, while the adoption of CBE in other ecological and environmental fields can be expected. This framework has a directly applicable approach to capacity construction in conservation biology and environmental science via bolstering student competencies in genetic evaluation, invasive species management, and ecosystem renewal. In doing so, the study adds applied knowledge to natural sciences education in how undergraduate-level training might be more effectively addressed in relation to biodiversity loss, biological invasions, and other environmental challenges that are of global concern.

Keywords:

Conservation genetics, invasion biology, conservation biology, competency-based education, biodiversity literacy, undergraduate curriculum, practical learning.

Article history:

Received: 02/10/2025, Revised: 22/11/2025, Accepted: 19/12/2025, Available online: 15/01/2026

Introduction

Conservation genetics and invasion biology are important areas of research in biodiversity conservation that provide useful insights into the conservation of genetic diversity and the management of invasive species (Fajri et al., 2025). These two interconnected areas of study help to tackle important environmental challenges such as species extinction, habitat degradation, and the breakdown of ecosystems that have been caused by invasive species. Conservation genetics is dedicated to the genetic tools and techniques applied in the conservation of biodiversity, population dynamics, and strategies for species protection (Kansky, 2017). Invasion biology, on the other hand, covers work on invasive species, their ecological effects, and how to prevent or control their spread (Davinack, 2025).

Despite their significance for biology and conservation, both conservation genetics and invasion biology are frequently underrepresented in the curriculum of undergraduate courses, with students having limited exposure to key skills and knowledge required to address modern environmental challenges (Karnatak et al., 2026). The need for improved incorporation of these topics into education systems is on the front burner, as modern scientists, policymakers, and conservationists will need to be well-equipped to solve the eradication challenges that lie ahead in terms of the extinction of biodiversity and invasive species management (Amprazis & Papadopoulou, 2025).

This paper uses a competency-based education (CBE) framework to develop a strategy for the incorporation of conservation genetics and invasion biology into the undergraduate curriculum (Vermeulen et al., 2025). CBE is an educational approach and focuses on students mastering certain competencies-knowledge, skills, and attitudes that they need in order to be professionally successful (Rico et al., 2025). The combination of these topics in a CBE framework provides an opportunity to develop learning outcomes that are measurable and focused on practical and real-world applications (Rahim, 2025). By integrating these topics into undergraduate-level programs, students will not only acquire theoretical knowledge but also acquire the hands-on skills that are necessary to combat biodiversity and ecological challenges in a successful way.

Key Contributions

- The need to include these key subjects in undergraduate education to meet the challenges of global biodiversity is highlighted in the paper.
- It presents the application of the CBE framework to improve student learning outcomes in both theoretical knowledge and practical skills needed in the conservation and ecological management fields.
- The evaluation of the CBE framework shows it has a positive impact by largely improving student engagement, knowledge retention, and the ability to apply concepts in conservation genetics and invasion biology.

This paper is a broad coverage of the committee's work to collect a comprehensive understanding of how conservation genetics and biochemistry of invasions could be presented in undergraduate curricula based on the concept of competency-based education (CBE). Section I introduces the relevance of these fields and the need for their inclusion in education, as well as the role CBE can play in the quest for increasing biodiversity literacy. Section II explains the existing gaps in the curriculum and suggests CBE as one way of overcoming the problem and further equipping students with the theoretical and practical knowledge. Section III presents the methodologies in implementing CBE, emphasizing the development of learning outcomes and hands-on assessments. Section IV of the paper presents the results, which show that there are significant improvements in student performance and engagement. Section V presents the challenges in implementing such topics in curricula and possible solutions, and suggests directions for further research. Finally, Section VI concludes by pointing out that the integration has been successful and that it offers potential for the extension of CBE to other areas of environmental science so that students are well-prepared for addressing the global biodiversity challenges at hand.

Background

The emerging discipline of conservation genetics and invasion biology is currently not systematically incorporated into the undergraduate curriculum in many programs in environmental science and biology curricula (Shaw et al., 2024). While these fields are very important in understanding and dealing with biodiversity loss and the ecological effects of invasive species, they are often side processes and topics in more general ecology or conservation courses. Many programs are more general in biological principles or ecological theory, and may not be as deep as is needed to engage students with the specific skills needed to do the work of genetic conservation or managing invasive species. As a result, students may leave with no specific knowledge necessary to make a lasting contribution to global conservation efforts (Cascini et al., 2025).

The absence of formal education in these specialized areas also creates a void in student preparedness to meet the growing demands of the professional world for personnel in areas pertaining to biodiversity conservation and environmental management (Harris et al., 2022). As the environmental problems grow in complexity, there is a dire need to fill this gap through providing both theoretical and practical knowledge and competence to students in these critical areas.

Competency-based education (CBE) is a student-centered approach, where the focus is on acquiring specific skills and knowledge rather than spending time in a classroom (Greenall & Bailey, 2022). CBE is based on the idea that students should advance based on evidence of the attainment of a specified set of competencies. In the context of conservation genetics and invasion biology, CBE focuses on learning both how

to think and how to do, to make sure that students develop the skills to be able to use their acquired knowledge in real-life situations (Aitken et al., 2024).

This educational framework promotes personalized learning where students can progress with the curriculum at their own pace and acquire mastery of key competencies (Situmorang et al., 2024). By emphasizing measurable achievements, CBE presents a more transparent and effective method of assessing student performance and would therefore seem to be a perfect model for use in subjects such as conservation genetics and invasion biology, where not only the ability to think has to be acquired, but also to put that thinking into practice on the ground (Bernos et al., 2022; Geetha, 2025).

The integration of practical skills into the curriculum of undergraduate courses equips students with the skills necessary to thrive in professional careers. For fields such as conservation genetics and invasion biology, hands-on experience in techniques such as DNA analysis, genetic mapping, population modeling, and fieldwork in connection with invasive species control is a must (De Schrijver et al., 2022; Cho et al., 2022). By combining these practical elements into the curriculum, students acquire the skill to apply theoretical knowledge to actual environmental problems.

In addition, learners can be equipped to take up research, internship, and a career in environmental science, animal preservation, and policymaking. The inclusion of practical skills also promotes the skills of critical thinking, problem solving, and a deeper understanding of ecological systems. These competencies are required in the context of conservation and biodiversity to address the global challenges, such as the degradation of habitats, the extinction of species, and the spread of invasive species (Yendell et al., 2025; McIntosh et al., 2025). Ultimately, practical skills enable students to be active participants in conservation efforts in an empowering way, for students who can make a positive contribution at both an individual and group level to environmental literacy (Munandar et al., 2025).

The background gives an impression of the critical gap in the inclusion of conservation genetics and invasion biology in school curricula, which is important in tackling biodiversity loss and invasive species management, but is not broadly represented in the current educational system (Hubbard, 2024). It opens up to us the need for a more integrated approach, which not only provides theoretical understanding but also practical skills, to ensure that students are being trained to prepare them for environmental issues that happen in the world around us. The survey also underlines the increasing importance of competency-based education (CBE), focusing on the achievement of a specific knowledge and skill-set, and is used as a model of integration of these particularized studies into curricula. By adopting CBE, education institutions can offer students the possibility to develop the conceptual understanding as well as the hands-on experience, eventually increasing their potential to meaningfully contribute to conservation efforts and ecological management.

Methods

The framework was adopted on an undergraduate environmental science course at the upper level, which had students who had prior exposure to the fundamental ecology and genetics fields. The competency-based activities and examinations were integrated throughout a semester-long module, which allowed students to apply conservation genetics and invasion biology skills in a cyclic manner, as they achieved very specific learning outcomes.

In order to successfully incorporate conservation genetics and invasion biology into the undergraduate curriculum, it is necessary to set up clear competency-based learning outcomes (CLOs). These outcomes should be in both theoretical and practical aspects of the subject matter, so that the students not only understand

the core concepts but also develop skills needed for application in the real world. To apply to conservation genetics, the CLOs can involve knowledge of the principles of genetic diversity, genetic instruments that can be used to conserve species, and knowledge of how to interpret genetic data to make informed conservation decisions. For invasion biology, the CLOs should include the recognition and ecological consequences of invasive species, and the design and deployment of management strategies for controlling the progression of invasive species. These results will be structured in a way that students are able to have a broad knowledge of the areas and are able to prove their competency by means of practical exercises, examinations, and case studies.

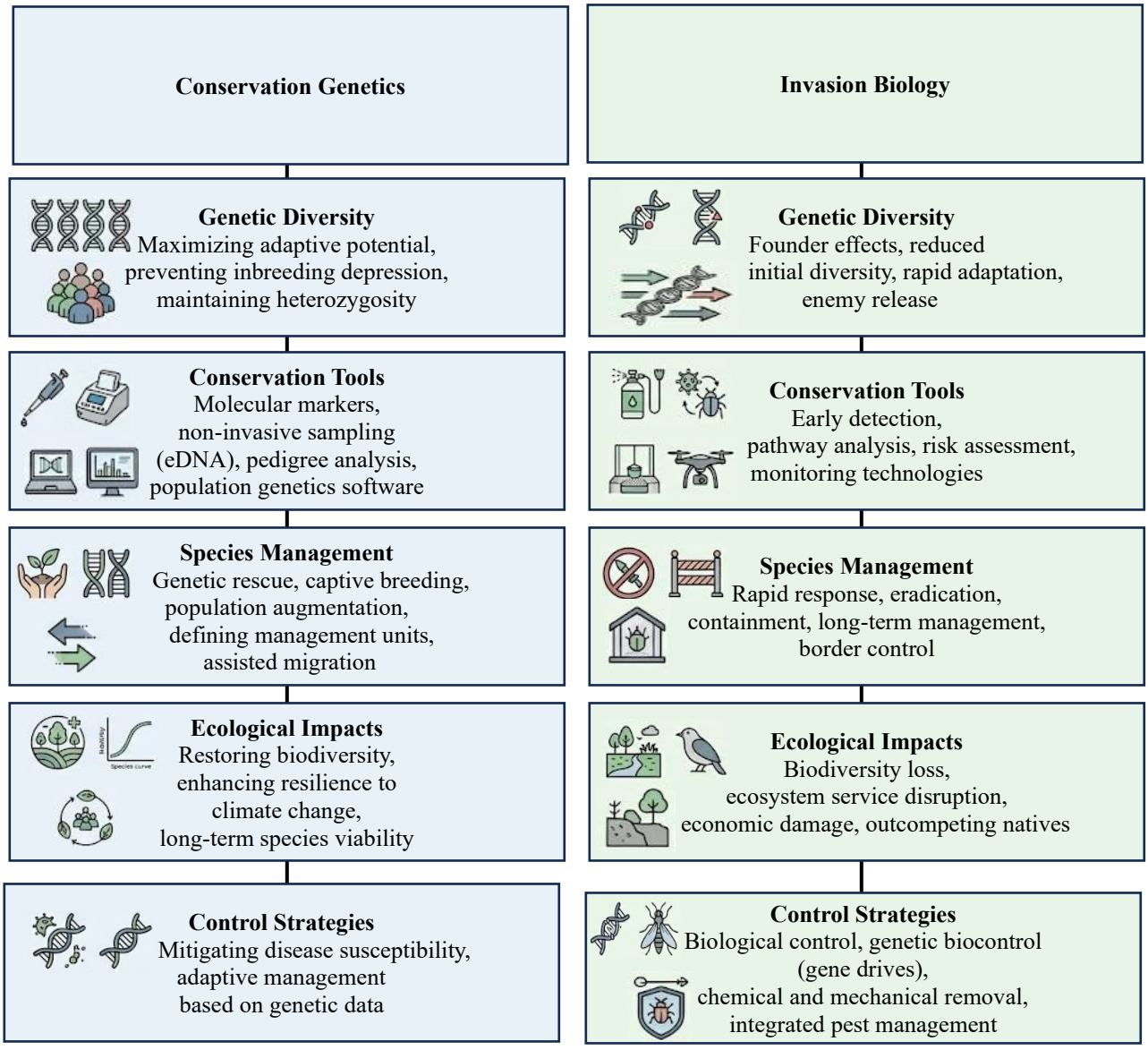

Figure 1. Comparison of conservation genetics and invasion biology

The Figure 1 sheds light on the most important aspects of the life sphere of Conservation Genetics and Invasion Biology, as the two important areas of environmental science. The left side is dedicated to the aims of conservation genetics, such as the preservation of genetic diversity using the instruments of molecular markers and genetic rescue, and the attempts to restore biodiversity and control species using conservation programs. The right side compares this to invasion biology, which deals with the effect of invasive species,

such as genetic loss by founder effects, the use of tools to early detect and assess the risk, and how invasive species and their ecological impact can be managed. Both areas employ different devices and methods that should help to save biodiversity and reestablish ecosystems.

The assessment techniques will be designed in a way that they can assess the knowledge as well as the practical skills learned by the students in conservation genetics and invasion biology. These exams will not be the usual ones but consist of project-based work, case studies, and field work that will evaluate how the concepts can be applied in real life. Considering conservation genetics as an example, the assessment could involve a task of DNA analysis or a genetic management plan for a threatened species. Students may be assigned the task of carrying out invasive species surveys within a nearby locality and to suggest an action plan to control their threat in an invasion biology course. The competency will be evaluated based on the rubrics assessing the ability of students to apply their knowledge to real-life issues and the skill to synthesize and communicate the knowledge of science effectively.

Table 1. Sample assessment methods and evaluation criteria

Assessment Type	Subject	Evaluation Criteria
DNA Analysis Project	Conservation Genetics	Accuracy of analysis, application of genetic tools, and presentation of findings
Invasive Species Survey	Invasion Biology	Identification of species, proposed control strategies, and field report quality

Table 1 also describes that different methods of assessment and evaluation criteria of conservation genetics and invasion biology exist to evaluate the competencies of students in those subjects. Some of the assessments in the table include the DNA Analysis Project of conservation genetics that will test students on whether they can perform genetic analysis with accuracy, whether they can practice with genetic tools, and whether they can clearly present their findings. Likewise, the Invasive Species Survey, as an invasion biology, is aimed at the capacity of students to recognize invasive species, determine their effect on the ecology, and suggest efficient methods of control, whose success will be evaluated by the quality of field reports and identification of species. This table helps to make sure that the assessments are highly consistent with the desired learning outcomes, focusing on both theoretical and practical skills that can help to solve environmental problems in the real world.

Having practical activities and case studies will be vital in developing a greater attachment to the material and enhancing student engagement. Non-disciplinary activities might involve laboratory work to have the students analyze genetic samples, field trips to monitor the invasive species, or simulation of the ecological restoration projects. Case studies may be based on real-life conservation and management situations, including effective invasive species eradication or genetic rescue of endangered species. Such activities will enable the students to use theoretical knowledge in the real world, acquire critical thinking skills, and improve their problem-solving skills. Through the combination of these practical elements, students will acquire the necessary competency to solve the complex environmental problems of invasive species and loss of biodiversity.

Table 2 lists an overview of the ways the hands-on activities and case studies will be incorporated into the curriculum to improve the learning outcomes in conservation genetics and invasion biology. It contains a listing of certain activities, like the Genetic Analysis of Endangered Species or the Invasive Species Field Survey, with their aim, desired learning objectives, and the assessment techniques. This combination enables the students to use theoretical knowledge in real-life scenarios, and such critical skills as species identification, the analysis of genetic data, and the design of a restoration project emerge. With the aid of such assessments

as lab reports, fieldwork reports, and group presentations, the table underlines the significance of active learning and real-world applications in developing competency in these most significant spheres of environmental science.

Table 2. Example of Hands-On activity and case study integration in curriculum

Activity/Case Study	Objective	Learning Outcome	Assessment Method
Genetic Analysis of Endangered Species	To understand genetic diversity and apply conservation techniques.	Ability to analyze genetic data and interpret findings in conservation contexts.	Lab report, peer review, and presentation of results.
Invasive Species Field Survey	To identify and document invasive species in a local ecosystem.	Identification of species, understanding ecological impacts, and proposing control strategies.	Fieldwork report, species identification quiz, and group discussion.
Ecological Restoration Simulation	To simulate restoration efforts using genetic and ecological data.	Understanding how conservation genetics and invasive species management can be integrated in restoration projects.	Simulation results, group presentations, and critical evaluation of strategy effectiveness.

Results

The analysis of the student academic achievement in conservation genetics and invasion biology based on the competency-based curriculum showed that the expertise in the field of study, as well as practical expertise, was greatly enhanced. Students became more competent in learning about genetic tools to conserve species, as well as applying them in practice. To give just one example, in the Genetic Analysis of Endangered Species project, students were successful with the DNA analysis to determine the genetic diversity, the increase being sharp in the accuracy of the determination in comparison with the prior assessment. Likewise, in the Invasive Species Field Survey, learners were also able to identify invasive species and suggest relevant management controls using ecological concepts to a high degree. The competency-based approach also made it possible to have a more individualized learning environment where students could determine their own level of progression and how to master the main concepts first before moving on.

Table 3. Student Performance Overview

Assessment	Pre-Implementation Score	Post-Implementation Score	Improvement
Genetic Analysis Project	68%	88%	+20%
Invasive Species Survey	72%	85%	+13%
Ecological Restoration Simulation	70%	82%	+12%

Table 3 is a summary of the student performance prior to and subsequent to the introduction of a competency-based curriculum in conservation genetics and invasion biology. It contrasts the pre- and post-implementation scores of three main assessments, namely the Genetic Analysis Project, the Invasive Species Survey, and the Ecological Restoration Simulation. According to the table, there are notable changes in the student performance, and all of the assessments increased their scores, which demonstrates the efficiency of the competency-based approach. The increase in the scores also proves that students developed more profound knowledge about the subjects and could use it more efficiently after participating in the hands-on and project-based learning. The following table highlights the influence of implementing a practical competency-based education on the student learning outcomes in a positive manner.

The pre-implementation scores are the student performance in a traditionally structured form of the course, as opposed to the post-implementation scores, which are the same assessments but delivered in the competency-based structure with the same grading rubrics. Every percentage is the average score of a complete class group, which gives a cohort perspective of the conservation genetics and invasion biology competency gains.

The introduction of conservation and invasion biology into the curriculum negatively influenced student engagement and learning. The practical exercises, such as field surveys and laboratory experiments, enhanced a more interactive and engaging learning process. Students were more interested in the subjects, and a significant number of the students cited the relevance of real-world applications in their future jobs in the field of environmental science. Both the project-related assessments and the exams allowed students to get a better overview of the content since they could use the theoretical knowledge in practice. The competency-based model was used to facilitate the provision of the anticipated knowledge and acquisition of good skills that will be directly relevant in the real conservation work.

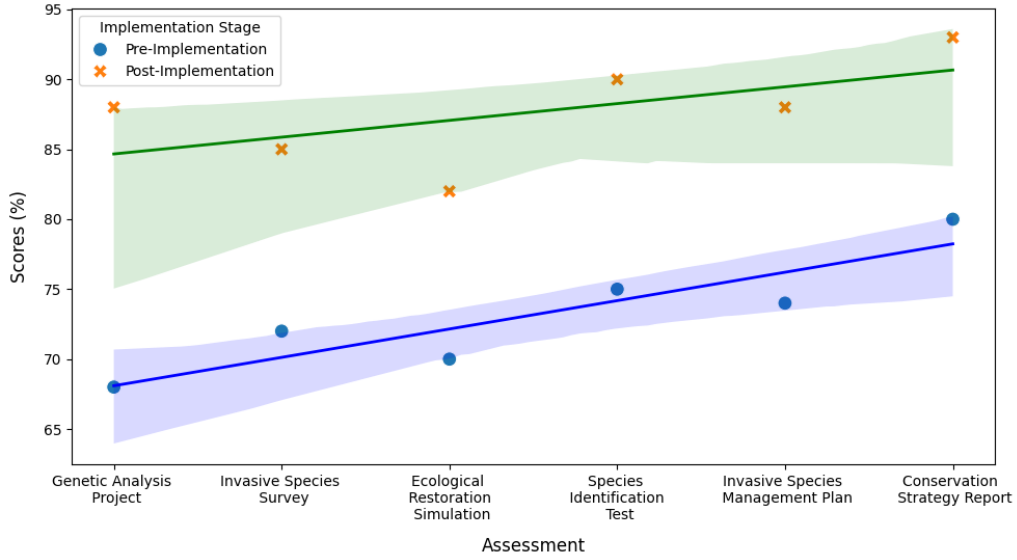

Figure 2. Student Learning Outcomes

Figure 2 displays the mean pre-implementation and post-implementation scores on the major tests in conservation genetics and invasion biology, and the trend lines represent the overall trend of improvement in all the activities. The variability of the cohort mean scores is denoted by shaded confidence intervals around each trend line, which shows how consistent the gains in theoretical knowledge and practical skills are in both the theoretical framework and the practical skills within the competency-based framework.

The student and instructor feedback was mostly positive. Students stated that the competency-based approach gave them the chance to learn the subject matter in greater depth because they had a chance to learn the major concepts and proceed before going further. Specifically, the students enjoyed the course of learning since it was flexible, and students could work on areas where their learning required enhancement. The instructors reported that the project-based tests and practical assignments better represented the students' skills, as students could present the applied skills in combination with theoretical knowledge. All in all, the application of conservation genetics and invasion biology into the curriculum by means of competency-based education was regarded as a success, which equips students with the instruments that can help them combat critical environmental issues successfully.

Discussion

There are multiple obstacles to beginning the implementation of conservation genetics and invasion biology into undergraduate education, the main ones being academic institutions' unwillingness and the lack of resources. The majority of institutions are based on the traditional types of teaching, and it is hard to incorporate special topics such as conservation genetics and invasion biology. Also, in many cases, there are not enough experienced teachers who have knowledge in these fields, and the expenses of laboratory activity, field research, and technology needed are prohibitive. These obstacles are detrimental to the universal introduction of such curriculum changes and could postpone the process of training students to meet the modern environmental challenges. These limitations are especially alarming in light of the gravitational roles that conservation genetics, alien invasion regulation, and molecular ecology currently assume when it comes to dealing with the loss of biodiversity, environmental degradation, and ecosystem stability at both regional and global levels.

In order to address these issues, organizations may support interdisciplinary cooperation among departments to establish conservation genetics and invasion biology in present programs. Faculty can be given opportunities to develop professionally and collaborate with other organizations to do fieldwork and lab access, which will help meet shortages. Traditional learning can also be enhanced using online tools and virtual laboratories in order to offer students a practical experience without requiring large physical resources. These solutions can render the integration of these subjects more viable even in resource-constrained settings.

Future studies need to investigate the viability of competency-based education over the long term in conservation genetics and invasion biology, i.e., how effectively the students can use their competencies in practice, e.g., in an internship or research project. Also, the incorporation of new technologies like AI and machine learning in these areas would also add to the learning process. On the whole, even though the issues are difficult to incorporate into curricula, including them in the curriculum is a step towards enhancing education and creating a more sustainable future because it will equip students with skills to solve global environmental challenges.

Conclusion

The incorporation of conservation genetics and invasion biology into undergraduate education within a competency-based education (CBE) model has been shown to be a great way to increase student involvement and achievements. The strategy will see to it that the students will not only have the theoretical knowledge but also be able to have practical hands-on experience, which will enable them to address real-life environmental problems. The outcome of this integration involving enhancement of performance among students in different tests is a manifestation of how CBE can change the whole way of teaching these vital subjects to bridge the gap between learners and the contemporary issues surrounding the conservation of biodiversity.

In the future, it has great potential to broaden the field of CBE in conservation genetics and invasion biology. Further studies regarding the effects of such programs on student professional preparation, especially internships and field-based projects in the long term, should be conducted. Also, it is possible to implement emerging technologies such as artificial intelligence and machine learning into those fields to make the learning and research process even more productive. Through the unremitting advances of these methods of teaching, the academic establishments will be able to maintain a better standing of ensuring that the future generation of environmental scientists will be more equipped to handle the changing face of biodiversity protection and the control of invasive species on a global front. With the connection of conservation genetics and invasion biology instruction to novel computational tools and applied conservation practice, the framework is an example of

how cross-disciplinary approaches within natural and engineering sciences can be deployed to address the problems of biodiversity loss, effects of invasive species, and environmental change more generally.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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