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A Neutrosophic Model for Measuring Evolution, Involution, and Indeterminacy in Species: Integrating Common and Uncommon Traits in Environmental Adaptation

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Abstract: In 2017, Professor F. Smarandache introduced the Neutrosophic Theory of Evolution, Involution, and Indeterminacy (or Neutrality) (NToEIaI). He concluded that every theory of evolution is characterized by a certain degree of truth, indeterminacy, and untruth, as in neutrosophic logic. In this perspective, he raised several open questions on evolution, neutrality, and involution that required further research effort. Very recently, in 2024, Smarandache conducted research, from a soft sciences/philosophical viewpoint, on identifying and studying common parts in uncommon things and uncommon parts in common things emphasizing the complexity and interconnectedness of concepts within the context of neutrosophy. In this article, we propose a neutrosophic model that incorporates the ideas of finding common parts in uncommon things and uncommon parts in common things within the realms of NToEIaI. We attempt to provide a proper answer on how to measure the degree of evolution, involution, and indeterminacy (neutrality) of a species in a given environment and specific timespan. By employing our approach, we can explain how a species adapts, regresses, or remains neutral within a specific environment and timespan. This method acknowledges not only the clear changes in traits but also the uncertainty and ambiguity that may arise during the process of evolution or involution.

Keywords: Neutrosophy; Trait Analysis; Species Dynamics; Environmental Adaptation; Evolutionary Biology.

1. Introduction

In the scientific domains of evolutionary biology and environmental adaptation, the complexities of species dynamics can be difficult to classify. Traditional methods for understanding species evolution mostly include categorizing animals based on common traits or defining evolutionary stages [1-7]. However, these methods frequently overlook the complexities of species adaptation and the interplay of common and unusual traits.

Smarandache [8] investigated the concept of neutrosophy, which offers a distinct perspective by challenging conventional dichotomies and embracing the concept of indeterminacy, via a new approach, in which familiar traits might emerge in unusual conditions and vice versa. This method can be regarded as having the potential to lead to an integrated view of human knowledge and experience by encouraging innovative thinking and problem-solving across disciplines, thus expanding our understanding of both natural and social phenomena.

This philosophical framework extends into scientific research, as demonstrated by Smarandache [9-10], who proposed the notion of neutrosophic evolution. This theory proposes that species evolution may be defined not only by degrees of advancement (evolution) but also by degrees of regression (involution) and levels of uncertainty (indeterminacy). In this framework, evolution refers to a species' progress or adaptation over time in response to environmental changes. Involution, on the other hand, states to a species' regression or degeneration, potentially caused by environmental stress or maladaptation while indeterminacy denotes to a species' uncertain, neutral, or ambiguous state in terms of evolution or involution.

The current study was motivated by Smarandache's fundamental question about the "way to measure the degree of evolution, degree of involution, and degree of indeterminacy (neutrality) of a species in a given environment and a specific timespan" within the framework of NToEIaI [9]. In my perspective, this topic stimulates an investigation into species dynamics by recognizing common aspects in rare characteristics and vice versa. Such an approach can give more information on how beings adapt to changing surroundings while negotiating the intricate interplay of evolutionary advancement, regression, and indeterminacy (or neutrality). In this context, the purpose of this study is to establish a neutrosophic model for evaluating evolution, involution, and indeterminacy in species, as well as to synthesize common and unusual features of environmental adaption.

The study is structured as follows: The next section provides the necessary mathematical preliminaries and formulations that are utilized to build our conceptual model to measure the degree of evolution, involution, and indeterminacy in species. The results section applies the model to an illustrative example, demonstrating its practical utility in capturing the dynamic interplay of common, uncommon, and indeterminate traits across different timespans. Finally, the paper discusses the implications of the findings in the broader context of evolutionary theory and environmental adaptation, highlighting areas for future research and refinement of the model.

2. Materials and Methods

2.1 Proposed Methodology

In this subsection, we briefly describe the overall framework proposed in this article as a means to introduce the reader to the core methods used in our method. In Figure 1, our proposed "hybrid algorithm" for measuring the degrees of evolution, involution, and indeterminacy in species adaptation is depicted in the form of a flowchart.

In a nutshell, it can be observed that our methodology consists of the following steps that correspond to the respective methods used:

- *Input Species Data:* The first step involves collecting and inputting species data, including their traits and environmental factors that influence their adaptation.
- *Identify Common Traits:* Using set-theoretic approaches (Jaccard similarity coefficient), common features between species are determined.
- *Identify Uncommon Traits:* Using set-theoretic approaches (Jaccard similarity coefficient), identify uncommon traits that are unique to each species.
- *Determine Indeterminate Traits:* This step introduces indeterminate traits—those that cannot be classified as either common or uncommon due to uncertainty or incomplete data.
- *Apply Neutrosophic Logic:* The neutrosophic logic framework is used to determine the degrees of truth (evolution), falsehood (involution), and indeterminacy (neutrality) of traits based on the existence of common, rare, and indeterminate traits.
- *Calculate Evolution, Involution, and Indeterminacy:* The final step quantifies the degrees of evolution, involution, and indeterminacy of species dynamics over time by using the Jaccard similarity and relative complement formulas.
- *Output results:* The findings are then displayed, including the computed degrees of evolution, involution, and indeterminacy, which give information on how organisms adapt, regress, or remain neutral in their environment.

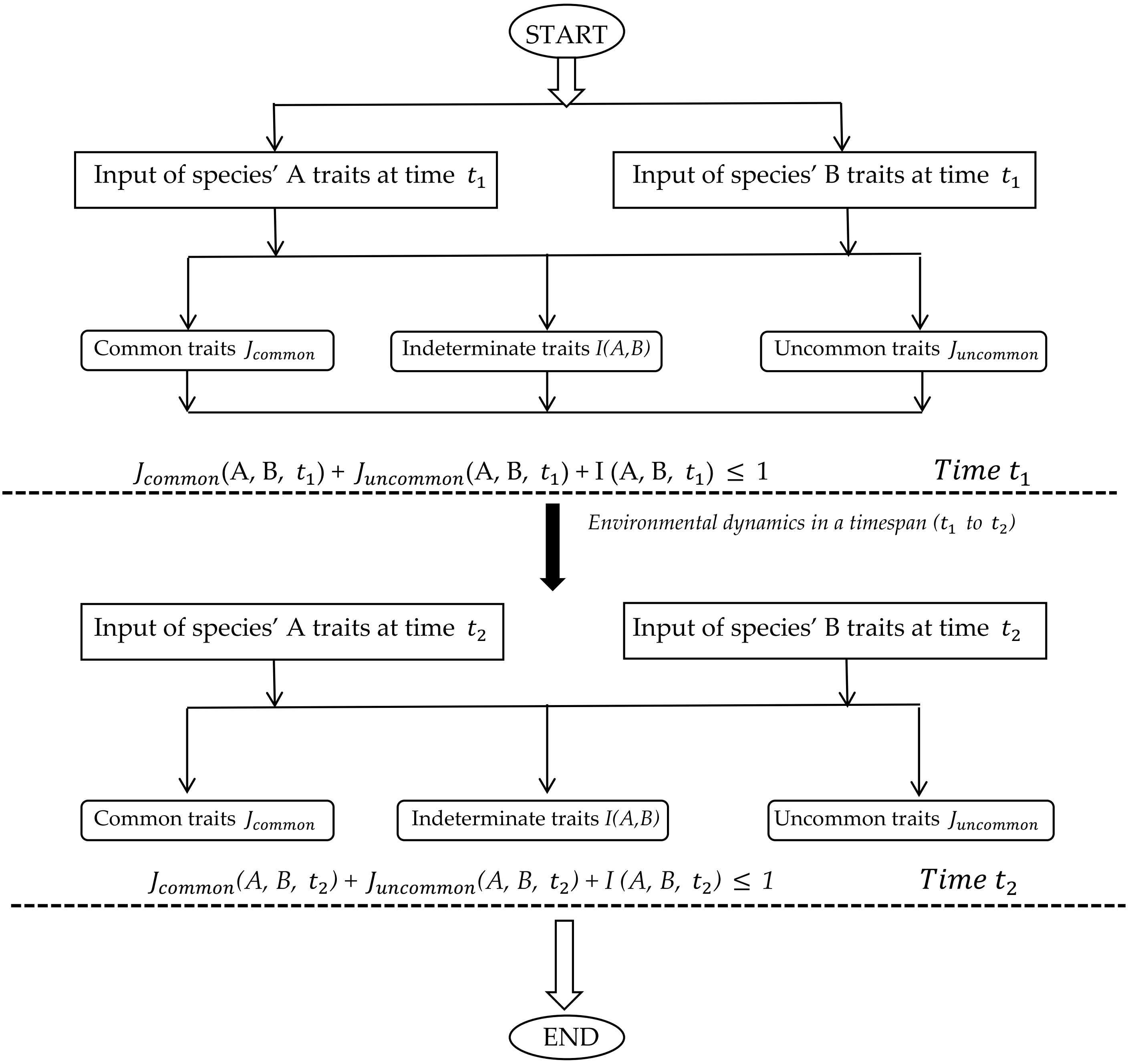

Figure 1. The framework of the proposed method

2.2 Neutrosophic framework of our study

Neutrosophy emphasizes the inclusion of truth (T), falsehood (F), and indeterminacy (I) to describe the uncertainty of knowledge, where each element can exist simultaneously in varying degrees.

In neutrosophic logic, a concept A is T% true, I% indeterminate, and F% false, with (T, I, F) ⊂ ||-0, 1+||3, where ||-0, 1+|| is an interval of hyperreals.

In this framework, a formula φ is characterized by a triplet of truth values, called the neutrosophic value defined as [11]:

NL(φ) = (T(φ), I(φ), F(φ)) where (T(φ), I(φ), F(φ)) ⊂ ||-0, 1+||^3

Let <A> be an item, concept, idea, proposition, theory, etc., and <anti-A> be the opposite of <A>. Analogously for <B> and it's opposite<anti-B>.

According to [8], neutrosophy means to find: (i) common parts to uncommon things (that is, <A>and <anti-A> have something in common, or their intersection <A>∩<anti-A> is not empty), and vice versa: (ii) uncommon parts to common things (the two equal items <A> = <B> have also uncommon parts, either<A>∩<anti-B> is not empty, or <anti-A>∩<B> is not empty).

To develop a mathematical model around this principle using neutrosophy, we can define key terms and relationships mathematically in line with the concepts mentioned in the work of [8].

- *Common Parts to Uncommon Things*: This refers to commonalities or shared characteristics between seemingly unconnected or different objects.
- *Uncommon Parts to Common Things*: These are the unique characteristics or distinctions found in objects that are otherwise thought to be comparable or related.

In this context, the *common parts of two sets A and B* can be represented by their intersection A∩B

Analogously, the *uncommon parts* are their differences or elements not shared between A and B, represented by their relative complements A\B and B\A.

By utilizing the Jaccard similarity coefficient which was originally developed as a metric for comparing the similarity of different species' distributions in ecological studies but further applied in many scientific areas [12-20], we can define a "*common part to uncommon thing*" equation as the following:

$$J_{common}(\mathrm{A, B}) = \frac{|A \cap B|}{|A \cup B|} \tag{1}$$

where:

$|A \cap B|$ denotes the number of elements in the intersection of sets A and B and

$|A \cup B|$ Denotes the number of elements in the union of sets A and B (i.e., the total number of unique elements in both sets, counting each element only once).

In this study, the ratio defined in (1), measures the *degree of truth (T)* in terms of how much A and B share common features despite being uncommon or different objects.

Similarly, we can define the *"uncommon parts to common things"* formulation as:

$$J_{uncommon}(\mathrm{A, B}) = \frac{|(A \setminus B) \cup (B \setminus A)|}{|A \cup B|} \tag{2}$$

where:

$(A \setminus B)$ denotes the number of elements in A but not in B,

$(B \setminus A)$ denotes the number of elements in B but not in A and

$|A \cup B|$ Denotes the number of elements in the union of sets A and B (i.e., the total number of unique elements in both sets, counting each element only once).

This ratio represents the *degree of falsehood (F)* or the extent to which objects differ, despite being otherwise perceived as related.

More attention should be drawn to model indeterminacy (or neutrality) in common and uncommon parts. To model indeterminacy, we need to account for parts where it is unclear whether they belong to A, B, both, or neither. In practical terms, these could be ambiguities, uncertain relationships, or overlapping properties that are not fully understood. In this manner, we need a definition of indeterminacy, I(A, B), that measures the parts where it's unclear whether elements belong to A, B, or neither. So, we have the following definition:

$$\mathrm{I}\,(\mathrm{A, B}) = \frac{|I(A,B)|}{|A \cup B|} \tag{3}$$

where |I(A, B)| represents the number or proportion of elements with indeterminate status, meaning their degree of membership in A and B is uncertain or ambiguous.

Given Equation (3), we can state the following properties of indeterminacy:

High indeterminacy: when there is a great deal of uncertainty or when the distinctions between common and rare elements are not clearly defined, I(A, B) will be high. This could happen when there are complex characteristic overlaps or when there are gaps in the data for A and B.

Low indeterminacy: I (A, B) will be low when the common and uncommon parts are well-defined, and there is little or no ambiguity about which traits belong to each category.

If we consider the representation and meaning of a neutrosophic set, we can depict it in an analogous way but concerning the common, uncommon, and indeterminate formulas as defined previously.

$$S(A, B) = (J_{common}(A, B), I(A, B), J_{uncommon}(A, B)) \quad (4)$$

The total of truth, falsity, and indeterminacy in a neutrosophic set may, under certain conditions, be larger than, less than, or equal to 1. Thus, the following can be used to express the requirement for the total of the common, uncommon, and indeterminate parts:

$$J_{common}(A, B) + J_{uncommon}(A, B) + I(A, B) \leq 1 \quad (5)$$

The above inequality reflects the flexibility in neutrosophic logic, where elements can exist with overlapping or uncertain membership. It comes from the nature of neutrosophic logic, where we deal with partial truth, partial falsity, and partial indeterminacy. It is also valid from a (neutrosophic) biological point of view wherein for each being, over a long time, there is a process of partial evolution, partial indeterminacy or neutrality, and partial involution concerning the being's body parts and functionalities.

We extend now Equation (5) with the notion of time to be able to examine temporal changes in a dynamic environment or a given timespan since species' evolution, involution, and neutrality vary over time.

$$J_{common}(A, B, t) + J_{uncommon}(A, B, t) + I(A, B, t) \leq 1 \quad (6)$$

Incorporating time t into the equation emphasizes that the relationships between sets A and B are not static but are subject to change and evolution. It introduces a temporal dimension that reflects how the state of the system can vary, making the equation more flexible and applicable to dynamic processes.

3. Results

Let's consider species A and species B, which evolved from a common ancestor and have since diverged. Our objective is to simulate their interaction over two time periods to illustrate the temporal evolution of their qualities. At each time point, we determine the amount of:

Common traits: qualities that both species share and inherited from a common ancestor.

Uncommon traits: features that are unique to either species A or species B and evolved independently.

Indeterminate traits: traits where it remains unclear whether they belong to species A, species B, or both, due to incomplete data or ongoing evolutionary complexity.

To quantify this, we define the following functions:

- J_{common} (A, B, t_i): The proportion of common traits at the time t_i.
- $J_{uncommon}$(A, B, t_i): The proportion of uncommon traits at the time t_i.
- I(A,B,t_i): The proportion of indeterminate traits at the time t_i. .

At any given time t_i, the sum of these three components is constrained by:

$$J_{common}(A, B, t) + J_{uncommon}(A, B, t) + I(A, B, t) \leq 1$$

This inequality reflects that a portion of traits may remain undefined or unexplored due to gaps in knowledge or incomplete research, a common feature in evolutionary biology.

We model the evolution of two species across two-time points: from t_1 (based on fossil records), to t_2 (present-day genetic research). The species' shared, exclusive, and indeterminate traits vary with each stage, representing the continual process of evolution and scientific breakthroughs.

Time t_1: *initial fossil evidence*

Let species A and B have the following traits:

- A={trait1,trait2,trait3,trait4}
- B={trait2,trait3,trait5}

Common, Uncommon, and Indeterminate traits

1. Common Traits:
- A∩B={trait2,trait3}
- Number of common traits: |A∩B|=2
2. Uncommon Traits:
- A\B={trait1,trait4} (2 traits)
- B\A={trait5} (1 trait)

Total uncommon traits: |A\B|+|B\A|=2+1=3

3. Indeterminate Traits:

Let's introduce an indeterminate trait {trait6} found in some individuals of both species but whose classification is uncertain.

To include the indeterminate trait in our model we need to slightly modify and extend Equations (1), (2), and (3) in the following way respectively:

$$J_{common}(\text{A, B}) = \frac{|A \cap B|}{|A \cup B \cup Indeterminate|} \tag{7}$$

$$J_{uncommon}(\text{A, B}) = \frac{|A \setminus B| + |B \setminus A|}{|A \cup B \cup Indeterminate|} \tag{8}$$

$$\text{I (A, B)} = \frac{|Indeterminate|}{|A \cup B \cup Indeterminate|} \tag{9}$$

It is observed that in this way, the above formulae provide a quantitative method for analyzing the overlap (commonality), differences (uncommonality), and neutrality (indeterminacy) of sets A and B in a wider context that includes an indeterminate category.

By substituting the above data in Equations (7), (8), and (9) we get:

J_{common}(A, B) = 2/6 = 0.33

$J_{uncommon}$(A, B) = 3/6 = 0.5

I (A, B) = 1/6 = 0.17

The neutrosophic set representing the relationship between species A and B with indeterminacy is:

S(A,B, t_1) = (J_{common}(A, B, t_1),I(A,B, t_1), $J_{uncommon}$(A, B, t_1))=(0.33,0.17,0.50), i.e.

Common traits: 33%

Uncommon traits: 50%

Indeterminate traits: 17%

Time t_2: *present genetic research*

- A={trait1,trait2,trait3,trait4,trait7} (new trait added)
- B={trait2,trait3,trait5,trait8}
- Indeterminate traits: {trait6,trait9} (new indeterminate trait added))

Again, by applying Equations (7), (8), and (9) we have the following neutrosophic set:

S(A,B, t_2) = (J_{common}(A, B, t_2),I(A,B,t_2), $J_{uncommon}$(A, B, t_2))=(0.22,0.22,0.56), i.e.

Common traits: 22%

Uncommon traits: 56%

Indeterminate traits: 22%

Remark: We could also utilize the proposed neutrosophic model to quantify the evolutionary dynamics of species A in comparison to their ancestors, offering a potential solution to the question posed in [9] about how to calculate the levels of similarity, dissimilarity, and indeterminate similarity-dissimilarity to ancestors.

To accomplish this, we could adjust Equations (7), (8), and (9) to determine the (i) degree of similarity to ancestors, (ii) degree of dissimilarity to ancestors, and (iii) degree of indeterminate similarity-dissimilarity to ancestors. This can be done through the following formulas respectively:

$$J_{similarity}(\text{A, ancestor}) = \frac{|A \cap ancestor|}{|A \cup ancestor \cup Indeterminate|}$$

$$J_{dissimilarity}(\text{A, ancestor}) = \frac{|A\backslash \text{ancestor}|+|\text{ancestor}\backslash \text{A}|}{|A \cup ancestor \cup Indeterminate|}$$

$$\text{I (A, ancestor)} = \frac{|\text{I (A}\cap\text{ancestor)+I(A}\backslash\text{ancestor)+I(ancestor}\backslash\text{A)}|}{|A \cup ancestor \cup Indeterminate|}$$

or in a neutrosophic context:

$$J_{similarity}(\text{A, ancestor}) = \frac{T(A \cap ancestor)}{T(A)+T(ancestor)+I(A \cap ancestor)} \tag{10}$$

$T(A \cap ancestor)$: degree of truth for common traits
$T(A)$: total truth for traits in species A
$T(ancestor)$: total truth for traits in the ancestor
$I(A \cap ancestor)$: degree of indeterminacy for the common traits

In the same way, and with a similar meaning, we get:

$$J_{dissimilarity}(\text{A, ancestor}) = \frac{\text{F}(A\backslash\text{ancestor})+\text{F(ancestor}\backslash\text{A)}}{\text{F(A)+F}(ancestor)+I(A \cup ancestor)} \tag{11}$$

$$\text{I (A, ancestor)} = \frac{|\text{I (A}\cap\text{ancestor)+I(A}\backslash\text{ancestor)+I(ancestor}\backslash\text{A)}|}{\text{T(A}\cup\text{ancestor)+I(A}\cup\text{ancestor)}} \tag{12}$$

Thus, the proposed neutrosophic model proves to be a versatile and powerful tool for comprehensively analyzing complex evolutionary dynamics.

4. Applications

In examining the evolutionary dynamics of species A and B between timespan t_1 and t_2, as described in the previous section the results reveal significant observations of the shared and divergent traits of these species.

At time point $\boldsymbol{t_1}$, the shared traits of species A and B were represented by J_{common}(A, B,t_1) = 0.33, indicating a significant overlap in behaviors and habitats, consistent with ecological theories that emphasize the role of niche overlap in species interaction and coexistence. The presence of three rare qualities, resulting in $J_{uncommon}$ (A, B , t_1) = 0.50, suggests that both species possess unique characteristics essential for survival and adaptation within their respective environments.

By time point $\boldsymbol{t_2}$, the introduction of new features in both species led to J_{common}(A, B,t_2) = 0.22 and $J_{uncommon}$(A, B, t_2) =0.56. The decrease in shared traits, along with an increase in total traits, indicates a likely divergence in evolutionary paths as each species adapts differently to its surroundings. The balance between common and uncommon traits, coupled with a rise in indeterminate traits from t_1 to t_2, underscores the complexities of evolutionary dynamics, where each species may be following distinct adaptive strategies.

Furthermore, the rising value of indeterminate traits emphasizes times of ambiguity when it is unclear whether specific features belong to one species, the other, both, or neither. This demonstrates the dynamic nature of species adaptation, in which traits arise or disappear in response to changing environmental circumstances, interspecies competition, or genetic mutations.

5. Conclusions

In this study, we employed the neutrosophic framework in a novel way by integrating the concepts of common parts in uncommon things and uncommon parts in common things in the context of NToEIaI. In this way we were able to analyze species' evolution, involution, and indeterminacy, demonstrating its use in capturing the complex interplay between common and atypical traits during environmental adaptation.

Our study primarily focuses on the evolution, involution, and indeterminacy of a species in a specific environment and timeframe without exploring the potential neutrality that may arise from NToEIaI. This occurs when a trait remains unchanged from one generation to the next. To address this, as a future work, we plan to use a quadruple neutrosophic set (T, I1, N, F), where indeterminacy I is divided into two parts: I1, representing pure indeterminacy, and N, representing neutrality. This approach will provide a more comprehensive neutrosophic "toolkit" for analyzing multiple aspects of adaptation, allowing us to better understand the complexity of species adaptation over time.

However, because our suggested conceptual framework is a first step in this direction, more testing and validation in real-world scenarios are required. Future research should look at actual applications and develop the model based on empirical data.

For example, our proposed model could be applied outside evolutionary biology, notably in the social sciences, economics, and artificial intelligence, where systems display uncertainty, adaptation, and regression. For example, applying the concept to human cultural evolution or technology development might give useful insights into how societies and systems evolve in response to changing environmental or technological challenges.

Furthermore, our model could be extended to study more complex temporal and geographical dynamics in species adaptation. This would include investigating how evolutionary and revolutionary tendencies emerge across different geographical locations or periods and possibly combining geospatial data and climatic factors into the neutrosophic framework.

Lastly, our conceptual framework could find applications in healthcare and medical research. For example, we could integrate our proposed methodology in related research, as in [21], by modeling key factors like symptoms, disease severity, and treatment effectiveness as traits, with common, uncommon, and indeterminate characteristics identified using set-theoretic approaches. Neutrosophic values—truth, falsehood, and indeterminacy—are then applied to linguistic terms, enabling more accurate assessments of patient conditions and treatment outcomes.

Declarations

Ethics Approval and Consent to Participate

The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher. All the material is owned by the authors, and/or no permissions are required.

Consent for Publication

This article does not contain any studies with human participants or animals performed by any of the authors.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare no competing interests in the research.

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Author Contribution

All authors contributed equally to this research.

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