Hypothesis Article

Nutrient-driven metabolic amplification (NDMA): A hypothetical extension of specific dynamic action in elasmobranchs

Thiruvengadam V.[1*]

Received: February 2026 Accepted: April 2026

Abstract

Specific Dynamic Action (SDA) has long been used to describe the postprandial increase in metabolic rate observed in animals following feeding. In elasmobranchs (sharks, rays, and skates), substantial variation in SDA responses has been reported, suggesting that factors beyond meal size alone may influence metabolic outcomes. This paper proposes Nutrient-Driven Metabolic Amplification (NDMA) as a hypothetical physiological framework that extends the traditional SDA concept by incorporating nutrient quality, endocrine regulation, feeding ecology, and environmental influences. NDMA is proposed as an integrative model through which nutrient composition may amplify metabolic responses beyond the energetic costs of digestion and assimilation alone. Existing literature on elasmobranch bioenergetics is reviewed to identify knowledge gaps and establish the conceptual basis for the framework. Potential physiological mechanisms, predicted outcomes, and future experimental approaches for testing NDMA are discussed. The framework is intended as a testable hypothesis requiring empirical validation through controlled laboratory and field-based studies.

Keywords: NDMA, Elasmobranchs, Specific Dynamic Action, Bioenergetics, Feeding Physiology, Metabolism, Nutrient Assimilation.

1-Operations Manager, Aquatic Gallery, Marinescape India Pvt Ltd, Ahmedabad, Gujarat, India

*Corresponding author's Email: squatlo69@gmail.com

Introduction

Elasmobranchs exhibit unique metabolic adaptations associated with intermittent feeding patterns and the consumption of energy-rich prey. Traditional bioenergetic models, particularly Specific Dynamic Action (SDA), describe the increase in metabolic rate following food consumption. Although SDA provides a useful framework for understanding postprandial metabolism, it may not fully account for variations associated with nutrient composition, feeding frequency, hormonal regulation, and environmental conditions.

Nutrient-Driven Metabolic Amplification (NDMA) is proposed here as a hypothetical extension of the SDA framework. The concept emphasizes nutrient quality and physiological regulation as potential determinants of metabolic amplification, rather than food quantity alone.

Harriet *et al*. (2024) reviewed the ongoing debate regarding the physiological basis of SDA in elasmobranchs. The authors examined two competing hypotheses: (1) the traditional interpretation that SDA primarily reflects the energetic costs of digestion and assimilation, and (2) the alternative hypothesis that a substantial proportion of SDA may represent the energetic costs associated with growth processes. Their review highlights the complexity of postprandial metabolic responses and underscores the need for broader integrative frameworks capable of incorporating multiple physiological mechanisms. A conceptual representation of the proposed NDMA framework and its hypothesized physiological pathways is presented in Figure 1.

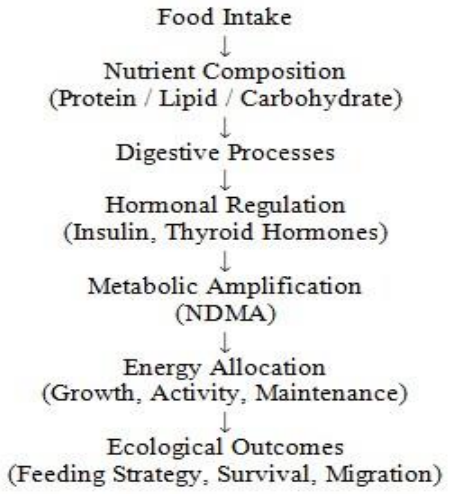

Figure 1: Conceptual Model Illustrating the Proposed Nutrient-Driven Metabolic Amplification (NDMA) Pathway in Elasmobranchs

Review of literature

The phenomenon of metabolic elevation following feeding has been extensively studied under the concept of SDA. McCue and Lillywhite (2002) provided a comprehensive review demonstrating that SDA is a widespread physiological response among vertebrates and varies according to meal size, nutrient composition, body size, and environmental conditions.

Studies involving elasmobranch species such as the lemon shark (*Negaprion brevirostris*), spinner shark (*Carcharhinus brevipinna*), blacktip shark (*Carcharhinus limbatus*), sicklefin lemon shark (*Negaprion acutidens*), whitetip reef shark (*Triaenodon obesus*), and bowmouth guitarfish (*Rhina ancylostoma*) have

reported prolonged SDA responses associated with protein-rich diets and intermittent feeding strategies.

Despite these advances, relatively few studies have simultaneously considered nutrient quality, endocrine regulation, and ecological feeding strategies within a unified conceptual framework. NDMA is proposed as a potential model that integrates these factors into a broader interpretation of postprandial metabolism.

History of SDA investigation

Specific Dynamic Action has been described using several terms throughout the history of physiological research, including "Darmarbeit" (von Mering and Zuntz, 1877), "metabolism of plethora" (Lusk, 1921; Mason, 1927), "generic dynamic action" (Wilhelmj, 1935), "heat increment" (Blaxter, 1989), and "postprandial calorigenesis" (McCue and Lillywhite, 2002; Marshall, 2006). The diversity of terminology reflects the complexity of the physiological processes associated with post-feeding metabolic elevation.

How NDMA differs from SDA

While SDA primarily describes the energetic costs associated with digestion, absorption, and assimilation of food, NDMA is proposed as a broader conceptual framework that incorporates additional physiological and ecological factors. Specifically, NDMA considers:

- Nutrient quality and biochemical composition of prey.
- Hormonal regulation, including insulin and thyroid-mediated pathways.
- Feeding ecology and intermittent feeding strategies.
- Environmental influences such as temperature and oxygen availability.

Consequently, NDMA is intended as an integrative hypothesis that may explain variations in metabolic responses that are not fully accounted for by traditional SDA models alone. The major conceptual differences between the traditional SDA framework and the proposed NDMA framework are summarized in Table 1.

Table 1: Comparison between the traditional specific dynamic action (SDA) framework and the proposed nutrient-driven metabolic amplification (NDMA) framework.

Parameter	SDA	NDMA
Primary focus	Digestion cost	Nutrient-driven metabolic response
Meal size effect	Included	Included
Nutrient quality	Limited	Central factor
Hormonal regulation	Usually excluded	Included
Ecological context	Limited	Included
Predictive capability	Descriptive	Hypothesis-driven
Environmental modulation	Partial	Explicitly considered

Predicted physiological outcomes

If the NDMA framework is supported by future experimental evidence, the following outcomes may be expected:

- Protein-rich diets may produce greater metabolic amplification than diets with lower protein content.
- Larger-bodied elasmobranchs may exhibit longer amplification periods following feeding.
- Endocrine regulation may influence the magnitude and duration of metabolic responses.
- Environmental variables, including temperature and dissolved oxygen, may affect NDMA scaling relationships.

Discussion

The proposed NDMA framework expands upon existing SDA concepts by incorporating nutrient-driven variability and physiological regulation. Unlike SDA, which primarily describes observed metabolic responses, NDMA seeks to provide a broader mechanistic context for understanding interspecific and environmental variation.

The framework may be particularly relevant for species exhibiting feast-and-famine feeding strategies, where nutrient composition and physiological regulation could influence energy allocation patterns. However, the proposed framework remains hypothetical and requires rigorous experimental validation before definitive conclusions can be drawn.

Scientific justification

The present concept was developed partly from long-term behavioral observations of captive elasmobranchs maintained under aquarium conditions for more than three years. Although these observations provide insights into feeding-associated behavioral patterns, the study was not designed to directly quantify metabolic responses through oxygen-consumption measurements, respirometry, or SDA curve analysis. Accordingly, the observations should be regarded as exploratory and hypothesis-generating rather than direct evidence supporting the NDMA framework. Captive environments nevertheless provide valuable opportunities for long-term behavioral monitoring under controlled husbandry conditions that are difficult to achieve in wild populations.

Limitations

Several limitations should be acknowledged:

- Observations were conducted under captive conditions and may not fully represent natural environmental variability.
- Sample sizes were limited and restricted to aquarium-held individuals.
- Direct metabolic measurements were not obtained.
- Feeding regimes differed from those encountered in natural ecosystems.
- Behavioural observations alone cannot establish causal relationships between feeding and energetic expenditure.

- Behavioral patterns observed in captivity may differ from those expressed during migration, foraging, reproduction, and other activities in free-ranging populations.

Future research direction

Future studies should combine behavioral observations with quantitative bioenergetic measurements, including intermittent-flow espirometry, oxygen-consumption monitoring, accelerometry, and biologging technologies. Such approaches would allow estimation of metabolic costs associated with digestion, activity, and recovery following feeding.

Comparative investigations involving multiple elasmobranch species under standardized feeding protocols would further improve understanding of species-specific bioenergetic strategies. In addition, field-based studies using acoustic telemetry, accelerometer tags, and satellite-linked biologgers may help determine whether patterns observed under captive conditions are also expressed in free-ranging populations.

Conclusion

NDMA is proposed as a novel and testable conceptual framework linking nutrition, metabolism, and ecological adaptation in elasmobranchs. By integrating nutrient quality, physiological regulation, and environmental influences, the framework extends beyond traditional interpretations of SDA and provides new hypotheses for future investigation. Although empirical validation remains necessary, NDMA may offer a useful foundation for advancing research in elasmobranch bioenergetics and feeding physiology.

Recommendations

- Experimentally evaluate NDMA across multiple elasmobranch species.
- Integrate physiological, behavioural, and environmental variables into future bioenergetic studies.
- Assess the potential application of NDMA concepts in captive husbandry and aquaculture systems.

References

Blaxter, K.L., 1989. Energy metabolism in animals and man. Cambridge University Press, Cambridge. 290 P.

Harriet, R.G., Wood, C.M., Wilson, R.W., Clark, T.D., Last, K.B. and Wang, T., 2024. Specific dynamic action: the energy cost of digestion or growth. *Journal of Exp. Biol.,* 227(**7**), jeb246722. https://doi.org/10.1242/jeb.246722

Lusk, G., 1921. The behavior of various intermediary metabolites upon the heat production. *Journal of Biological Chemistry*, 49, 453-478.

Marshall, D.M., 2006. Specific Dynamic Action: A Century of Investigation. 150P.

Mason, E.H., 1927. Abnormal specific dynamic action of protein, glucose, and fat associated with under-nutrition. *Journal of Clinical Investigation*, 4, 353-387.

McCue, M.D. and Lillywhite, H.B., 2002. Oxygen consumption and the energetics of island-dwelling Florida cottonmouth snakes. *Physiological and Biochemical Zoology,* 75, 165-178.

Von Mering, J. and Zuntz, N., 1877. In Wiefern beeinflusst Nahrungszufuhr die thierischen Oxydationsprocesse? *Pflugers Archiv fur die gesamte Physiologie des Menschen und der Tiere*, 15, 634-636.

Wilhelmj, C.M., 1935. The specific dynamic action of food. *Physiological Reviews*,15, 202-220.