

UNIVERSIDADE FEDERAL DE MINAS GERAIS
Instituto de Ciências Biológicas
Departamento de Genética, Ecologia e Evolução
Programa de Pós-Graduação em Ecologia Conservação
e Manejo da Vida Silvestre

Gabriela Moreira Ronzani

**DOES ENVIRONMENTAL DEGRADATION AFFECT TROPHIC NICHE OVERLAP
BETWEEN ECOLOGICALLY SIMILAR NATIVE AND NON-NATIVE FISH
SPECIES IN RIO DOCE BASIN?**

Belo Horizonte

2024

Gabriela Moreira Ronzani

**DOES ENVIRONMENTAL DEGRADATION AFFECT TROPHIC NICHE OVERLAP
BETWEEN ECOLOGICALLY SIMILAR NATIVE AND NON-NATIVE FISH
SPECIES IN RIO DOCE BASIN?**

Dissertação apresentada ao Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre da Universidade Federal de Minas Gerais, como requisito parcial à obtenção do título de Mestre em Ecologia Conservação e Manejo da Vida Silvestre.

Orientador(a): Prof. Dr. Rafael Pereira Leitão

Co-orientador(a): Prof. Dr. Gilberto
Nepomuceno Salvador

Belo Horizonte

2024

043

Ronzani, Gabriela Moreira.

Does environmental degradation affect trophic niche overlap between ecologically similar native and non-native fish species in Rio Doce basin? [manuscrito] / Gabriela Moreira Ronzani. – 2024.

51 f. : il. ; 29,5 cm.

Orientador(a): Prof. Dr. Rafael Pereira Leitão. Co-orientador(a): Prof. Dr. Gilberto Nepomuceno Salvador.

Dissertação (mestrado) – Universidade Federal de Minas Gerais, Instituto de Ciências Biológicas. Programa de Pós-Graduação em Ecologia Conservação e Manejo da Vida Silvestre.

1. Ecologia. 2. Água doce. 3. Degradação ambiental. 4. Ictiofauna. 5. Espécies Introduzidas. I. Leitão, Rafael Pereira. II. Salvador, Gilberto Nepomuceno. III. Universidade Federal de Minas Gerais. Instituto de Ciências Biológicas. IV. Título.

CDU: 502.7



UNIVERSIDADE FEDERAL DE MINAS GERAIS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS
PROGRAMA DE PÓS-GRADUAÇÃO EM
ECOLOGIA, CONSERVAÇÃO E MANEJO DA VIDA SILVESTRE



Ata da Defesa de Dissertação

Nº 460
Entrada: 2022/2

Gabriela Moreira Ronzani

No dia 21 de agosto de 2024, às 09:00 horas, sala 236, bloco I3, teve lugar a defesa de dissertação de mestrado no Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre, de autoria do(a) mestrando(a) Gabriela Moreira Ronzani, orientando(a) do Professor Rafael Pereira Leitão, intitulada: **“Does environmental degradation affect trophic niche overlap between ecologically similar native and non-native fish species in Rio Doce basin?”**. Abrindo a sessão, o(a) Presidente da Comissão, Doutor(a) Rafael Pereira Leitão, após dar a conhecer aos presentes o teor das normas regulamentares do trabalho final, passou a palavra para o(a) candidato(a) para apresentação de seu trabalho. Estiveram presentes a Banca Examinadora composta pelos Doutores: Luisa Resende Manna (UERJ), Patrícia Santos Fráguas (UFLA) e demais convidados. Seguiu-se a arguição pelos examinadores, com a respectiva defesa do(a) candidato(a). Após a arguição, apenas os senhores examinadores permaneceram no recinto para avaliação e deliberação acerca do resultado final, sendo a decisão da banca pela:

(X) Aprovação da dissertação, com eventuais correções mínimas e entrega de versão final pelo orientador diretamente à Secretaria do Programa, no prazo máximo de 30 dias;

() Reprovação da dissertação (marcar se é a primeira ou segunda reprovação): () *primeira reprovação () segunda reprovação

*Conforme o disposto no Artigo 80 da Resolução Complementar do CEPE/UFMG Nº 02/2017, de 04 de julho de 2017, caso seja a primeira reprovação, poderá ser concedido, a critério do Colegiado de Curso, um prazo para a realização de nova defesa de tese.

Nada mais havendo a tratar, o Presidente da Comissão encerrou a reunião e lavrou a presente ata, que será assinada por todos os membros participantes da Comissão Examinadora.

Belo Horizonte, 21 de agosto de 2024.

Assinaturas dos Membros da Banca Examinadora



Documento assinado eletronicamente por **Patrícia Santos Fráguas, Usuário Externo**, em 27/08/2024, às 10:30, conforme horário oficial de Brasília, com fundamento no art. 5º do [Decreto nº 10.543, de 13 de novembro de 2020](#).



Documento assinado eletronicamente por **Luísa Resende Manna, Usuária Externa**, em 27/08/2024, às 12:07, conforme horário oficial de Brasília, com fundamento no art. 5º do [Decreto nº 10.543, de 13 de novembro de 2020](#).



Documento assinado eletronicamente por **Rafael Pereira Leitao, Professor do Magistério Superior**, em 29/08/2024, às 13:25, conforme horário oficial de Brasília, com fundamento no art. 5º do [Decreto nº 10.543, de 13 de novembro de 2020](#).



A autenticidade deste documento pode ser conferida no site [https://sei.ufmg.br/sei/controlador_externo.php?](https://sei.ufmg.br/sei/controlador_externo.php?acao=documento_conferir&id_orgao_acesso_externo=0)

[acao=documento_conferir&id_orgao_acesso_externo=0](https://sei.ufmg.br/sei/controlador_externo.php?acao=documento_conferir&id_orgao_acesso_externo=0), informando o código verificador **3492355** e o código CRC **BF22169B**.

Referência: Processo nº 23072.219003/2024-52

AGRADECIMENTOS

Finalizando mais um ciclo incrível, repleto de desafios e aprendizados. Um percurso agradável, com companhias muito especiais. O medo que sentia no início se transformou em pertencimento e confiança. Cada passo revelou a certeza de que posso trabalhar com o que mais gosto. Tudo confluiu perfeitamente: desde a pesquisa e o estudo dos peixes, que é uma paixão que carrego desde criança, até as pessoas, os campos e o laboratório.

São muitos os agradecimentos que quero fazer neste momento, principalmente à minha família. Obrigada, mãe (Sanny), por ser essa mulher incrível e inspiradora, que sempre possibilitou e incentivou minhas escolhas. Obrigada, Mananna, minha irmã querida, que a todo momento me admirou, ouviu e me deu forças para continuar lutando e melhorar a cada dia. Ao Jay, meu irmão caçula, pela sensibilidade, por ter chegado ao mundo e demonstrado como a vida é linda e mutável, e por ter me apresentado o amor na sua forma mais pura.

Agradeço aos meus avós, Jane e Décio, por toda a estrutura, dedicação e apoio, por proporcionarem tudo que está ao alcance pelo bem da nossa família.

Agradeço ao Rafa, um orientador carinhoso, comprometido em ajudar, que incentiva o desenvolvimento de todos os seus alunos. Obrigada por ter me aceitado no laboratório em 2019, pois foi nesse espaço que cresci como profissional e me tornei mais humana.

Ao Laboratório de Ecologia de Peixes, agradeço tanto aos que já seguiram outros caminhos, quanto aos que ainda estão presentes e àqueles que chegaram para abrilhantar ainda mais esse ambiente de união e aprendizado. Agradeço à Camilinha, nossa IC querida, pela ajuda ao abrir os estômagos dos peixinhos, ao Dennys, que esteve ao meu lado o tempo todo, dando suporte nas identificações e nas conversas na varandinha. Ao meu coorientador Giba, por mais uma vez enriquecer meu trabalho, pela atenção, carinho e paciência em todos os momentos. Por me ensinar tanto sobre o trabalho de campo, assim como o Yoshi, com seu olhar sensível sobre todas as coisas. Admiro a dedicação na identificação dos peixes, o ensino de cada detalhe e as trocas filosóficas que acrescentaram ainda mais à experiência. Sou muito grata ao Carlitos, por ter dedicado seu tempo, mesmo estando longe, para desenvolver meus resultados da melhor maneira, ensinando coisas novas e desafiadoras. Obrigada, Enzo, por ter insistido em entrar como IC no laboratório e por ser uma companhia tão agradável e

inspiradora. E à Mari e Lucas, companheiros de laboratório e de turma, pelo carinho, paciência, trocas e experiências ao longo de todo o percurso.

Gostaria de agradecer à Professora Míriam Pilz Albrecht por ter me recebido no Laboratório de Ecologia de Peixes da Universidade Federal do Rio de Janeiro (UFRJ) e às suas alunas, Bella e Suzane, por todo o ensinamento, carinho e dedicação no treinamento de análise de conteúdo estomacal.

Agradeço à UFMG, por todo o percurso vivido e por ser minha casa nos últimos sete anos. Tenho muito orgulho de poder vivenciar a universidade e tudo que ela proporciona. A educação pública de qualidade é um direito de todos e transforma vidas. Gratidão ao Programa de Pós-graduação em Ecologia, Conservação e Manejo da Vida Silvestre por todas as oportunidades e aos professores que enriqueceram minha formação nesse período.

Obrigada, Vanessa, por ter me acompanhado em todo o processo, por ter me ajudado a entender que o mestrado pode ser um período tranquilo, de descobertas e amadurecimento.

Sou grata também ao Davi, um presente que ganhei no caminho, pelo incentivo, trocas, apoio, carinho, cumplicidade e amor. E por ter me apresentado à escalada, que fez toda diferença no período de finalização do trabalho.

Por fim, agradeço à FAPEMIG pela bolsa e o apoio à minha pesquisa e aos projetos do laboratório, tanto no Projeto IctioDoce (FAPEMIG - APQ-00401-19), quanto no Projeto de Biodiversidade e Funcionamento de Riachos da Cadeia do Espinhaço (FAPEMIG - APQ-01611-17).

Gratidão aos meus guias espirituais e a todos que fizeram parte desse processo maravilhoso.

RESUMO

Invasões biológicas estão entre as principais causas de extinção da biodiversidade. Espécies não nativas podem interferir na estrutura das comunidades nativas, pois podem deter características biológicas que favorecem a ocupação do ambiente invadido. Entretanto, os mecanismos subjacentes ao processo de invasão, como a competição por recursos entre as espécies nativas e não nativas, ainda são pouco estudados para grande parte dos sistemas ecológicos. Considerando que o uso de recursos alimentares é uma das principais dimensões do nicho ecológico das espécies, quantificar o grau de sobreposição de nicho trófico entre espécies é um passo fundamental para a compreensão dos efeitos da invasão biológica. Espera-se que a competição seja mais intensa quando as espécies não nativas e nativas são taxonomicamente e/ou ecologicamente semelhantes. Aliado ao processo de introdução em ambientes naturais, a degradação ambiental parece facilitar o estabelecimento de espécies não nativas nos ecossistemas. Alterações de paisagem e uso do solo, geralmente ocasionam homogeneização do habitat e diminuem a disponibilidade e diversidade de recursos para os organismos, podendo aumentar a competição intra e interespecífica e potencialmente prejudicar as espécies nativas, visto que as espécies não nativas são mais tolerantes às mudanças das condições físicas do habitat. Devido ao histórico de degradação combinado a casos emblemáticos de introdução de espécies de peixes, a Bacia do Rio Doce é um modelo de estudo adequado para testar hipóteses sobre mecanismos de invasão biológica. Neste contexto, este estudo tem como objetivo descrever a dieta e quantificar a sobreposição de nicho trófico entre um par de espécies de peixe nativo (*Deuterodon cf. taeniatus*) e não-nativo (*Knodus moenkhausii*) na bacia do Rio Doce. Testamos a hipótese de que a sobreposição de nicho trófico entre este par de espécies de peixes aumenta em locais com nível mais elevado de degradação ambiental na bacia. Para testar tal hipótese, aplicamos protocolo de avaliação de habitat físico adaptado para rios, coleta de peixes, análise de conteúdo estomacal, cálculos de sobreposição de nicho trófico e de degradação ambiental. De acordo com nosso estudo, confirmamos que ambas as espécies possuem hábito alimentar onívoro, com alta plasticidade trófica e oportunismo alimentar. *Deuterodon cf. taeniatus* e *Knodus moenkhausii* apresentam alta sobreposição de nicho trófico na maioria dos locais analisados, indicando que a espécie não nativa possivelmente compete por recursos com a espécie nativa. Por outro lado, o nível de sobreposição de nicho trófico não foi afetado pelo nível de degradação ou por outras variáveis ambientais.

Palavras-chaves: Dieta; Invasão biológica; Interação ecológica; Variáveis ambientais; Ictiofauna; Água doce.

ABSTRACT

Biological invasions are among the main causes of biodiversity extinction. Non-native species can interfere with the structure of native communities, as they can possess biological characteristics that favor the occupation of the invaded environment. However, the mechanisms underlying the invasion process, such as competition for resources between native and non-native species, are still poorly studied for most ecological systems. Considering that the use of food resources is one of the main dimensions of the environmental niche of species, quantifying the degree of trophic niche overlap between species is a fundamental step toward understanding the effects of biological invasion. Competition is expected to intensify when non-native and native species are taxonomically and/or ecologically similar. In addition to the introduction process in natural environments, environmental degradation seems to facilitate the establishment of non-native species in ecosystems. Changes in landscape and land use generally cause habitat homogenization and decrease the availability and diversity of resources for organisms, which can increase intra- and interspecific competition and potentially harm native species, since non-native species are more tolerant of changes in the physical conditions of the habitat. Due to the history of degradation combined with emblematic cases of introduced fish species, the Rio Doce Basin is a model study well suited for testing hypotheses about biological invasion mechanisms. In this context, this study aims to describe the diet and quantify the trophic niche overlap between a pair of native (*Deuterodon cf. taeniatus*) and non-native (*Knodus moenkhausii*) fish species in the Rio Doce basin. We tested the hypothesis that the trophic niche overlap between this pair of fish species increases at higher levels of environmental degradation in the basin. To test this hypothesis, we applied a physical habitat protocol adapted for rivers, collected fish, analyzed stomach contents, and calculated trophic niche overlap and environmental degradation. According to our study, we confirmed that both species have omnivorous feeding habits, with high trophic plasticity and feeding opportunism. *Deuterodon cf. taeniatus* and *Knodus moenkhausii* show high trophic niche overlap in most of the sites analyzed, indicating that the non-native species possibly compete for resources with the native species. On the other hand, the level of trophic niche overlap was not affected by the level of degradation or the local environmental variables.

Key words: Diet; Biological invasions; Ecological interaction; Environmental variables; Ichthyofauna; Freshwater.

LISTA DE ILUSTRAÇÕES

1. Figura S1. Figura esquemática da sobreposição de nicho trófico entre o par de espécies nativa e não nativa.....15
2. Figura S2. Par de espécies nativa (*Deuterodon cf. taeniatus*) e não nativa (*Knodus moenkhausii*) na Bacia do Rio Doce.....17
3. Figura S3. Alguns pontos de coleta de dados da amostragem do projeto ICTIODOCE-ICB/UFMG em 2022.....18
4. Figura S4. Amostragem de peixes e obtenção de dados ambientais do projeto ICTIODOCE - ICB/UFMG, campanha de 2022.....19
5. Figura S5. Análise de conteúdo estomacal no laboratório de Ecologia de Peixes – UFMG, utilizando a lupa Zeiss Stemi DV4.....19
6. Figura S6. Trato gastrointestinal das espécies de peixes *Deuterodon cf. taeniatus* e *Knodus moenkhausii*.....20
7. Figura S7. Itens encontrados no conteúdo estomacal de exemplares das espécies de peixes *Deuterodon cf. taeniatus* e *Knodus moenkhausii* da Bacia do Rio Doce.....20
8. Figure 1. Map of the Rio Doce basin showing the sampling sites used in the IctioDoce Project and the 10 sites selected for our study.....27
9. Figure 2. Frequency of occurrence (Fo%) and Relative volume (Vo%) of the main food items consumed by the native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* from the Rio Doce Basin, Brazil.....33
10. Figure 3. Generic graph built based on the IAI (Feeding Index) of the items consumed by *Deuterodon cf. taeniatus* and *Knodus moenkhausii*, showing an overall change in the predominant food items used over the 10 sampling sites in the Rio Doce basin, Brazil.....34
11. Figure 4. Trophic niche overlap between native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* for the 10 sampling sites from Rio Doce basin, Brazil.....34
12. Figure 5. Relationship between Trophic niche overlap between the native fish species *Deuterodon cf. taeniatus* and non-native *Knodus moenkhausii* and Integrated Disturbance Index (IDI), and other local environmental variables (XCMG - mean total riparian cover; XDEPTH_S – mean depth in transect; XFC_NAT – mean natural fish cover) for all sampling sites, Rio Doce Basin, Brazil.....36

13. Figure A1. Demonstration of the 11 marginal plots where information on environmental variables and fish collection was obtained in river sites of the Rio Doce basin.....	49
14. Figure A2. Standard length (cm) of the native fish <i>Deuterodon cf. taeniatus</i> and the non-native fish <i>Knodus moenkhausii</i> from the Rio Doce Basin, Brazil.....	49
15. Figure A3. Gastrointestinal tract (cm) of the native fish <i>Deuterodon cf. taeniatus</i> and the non-native fish <i>Knodus moenkhausii</i> from the Rio Doce Basin, Brazil.....	50
16. Figure A4. The ratio between gastrointestinal tract size and standard length (cm) of the native fish <i>Deuterodon cf. taeniatus</i> and the non-native fish <i>Knodus moenkhausii</i> from the Rio Doce Basin, Brazil.....	50
17. Figure A5. Accumulation curves of food items consumed in each studied site in the Rio Doce basin, by the two characid fish species.....	51

LISTA DE TABELAS

1. Table 1. Frequency of occurrence (Fo%), Relative volume (Vo%), and Feeding Index (IAi) of items consumed by the native fish species *Deuterodon cf. taeniatus* and by the non-native fish species *Knodus moenkhausii* at the 10 sampling sites distributed in the Rio Doce Basin, Brazil.....30
2. Table 2. Trophic niche overlap (Pianka's index) between *Deuterodon cf. taeniatus* and *Knodus moenkhausii*, Integrated Disturbance Index (IDI), and other environmental variables (XCMG - mean total riparian cover; XFC_NAT - mean natural shelter cover; XDEPTH_S – mean depth in the transect), for the 10 sampling sites from Rio Doce basin, Brazil.....35

SUMÁRIO

Apresentação geral:	14
REFERÊNCIAS	21
1. Introduction	24
2. Methods	26
2.1 Study area	26
2.2 Data collection	27
2.2.1 Environmental data	27
2.2.2 Fish sampling	28
2.2.3 Stomach content analysis	28
2.3 Environmental degradation	29
2.4 Trophic niche overlap	29
3. Results	30
4. Discussion	36
5. Conclusion	40
REFERENCES	42
SUPPLEMENTARY MATERIAL	49

Apresentação geral:

Invasões biológicas são apontadas por muitos autores como uma das maiores ameaças à biodiversidade global (Meyerson et al., 2019). Espécies não nativas são capazes de interferir na estrutura das comunidades e ocasionar grandes alterações em processos ecológicos e no funcionamento de ecossistemas (Wang et al. 2021; Vitule e Prodocimo, 2012). Frequentemente, tais espécies detêm características biológicas que favorecem a ocupação do ambiente invadido, como rápido crescimento populacional, tolerância às mudanças das condições físicas, alta taxa de fecundidade e plasticidade alimentar (Wootton, 1998; Kolar e Lodge, 2000; Spínola e Ferreira Julio Junior, 2007). As espécies invasoras tendem a explorar os recursos disponíveis no ecossistema invadido, estabelecendo interações com as espécies nativas (David et al., 2017). O processo de invasão é geralmente dividido em cinco etapas (1) transporte de uma espécie para outra localidade diferente da sua área de distribuição nativa por ações antrópicas; (2) introdução em um novo ambiente; (3) estabelecimento (capacidade da espécie de se reproduzir no ambiente invadido); (4) disseminação; e (5) impactos (alterações causadas pelas espécies invasoras no ecossistema receptor) (Moyle&Light 1996; Blackburn et al. 2011; Bernery et al. 2022). Entender quais são os mecanismos subjacentes ao processo de invasão e como as espécies não nativas impactam a biodiversidade por meio de interações com as espécies nativas continua sendo uma lacuna importante do conhecimento (Bernery et al., 2022; Vitule and Prodocimo, 2012).

A competição por recursos entre espécies nativas e não nativas é um dos mecanismos possíveis ao longo do processo de invasão. Quando espécies não nativas partilham requisitos ecológicos semelhantes e estão sujeitas às mesmas condições ambientais que as espécies nativas, podem reduzir a disponibilidade e a qualidade dos recursos utilizados pelas nativas (Firth et al., 2021; Britton et al., 2019). O nicho de uma espécie pode incluir o tipo de habitat que ocupa, suas exigências alimentares, tolerâncias às condições ambientais, requisitos reprodutivos, entre outras diversas dimensões (Hutchinson, 1959). Espera-se que espécies distintas sejam funcionalmente diferentes ao longo das dimensões de um espaço Hutchinsoniano (Rosenfeld, 2002), de tal forma que, sob condições de sobreposição mínima de nicho, deve haver aumento da exploração de recursos disponíveis após a introdução de espécies adicionais em uma comunidade (Tilman et al., 1997; Loreau et al., 2001; Cardinale et al., 2002). Considerando que o uso de recursos alimentares é uma das principais dimensões do nicho ecológico das espécies (Schoener, 1983; Toft, 1985), quantificar o grau

de sobreposição de nicho trófico interespecífico é um passo fundamental para a compreensão dos efeitos da invasão biológica (Figura S1). Espera-se que a competição seja mais intensa quando as espécies não nativas e nativas são taxonomicamente e/ou ecologicamente semelhantes (Dick et al., 2017).

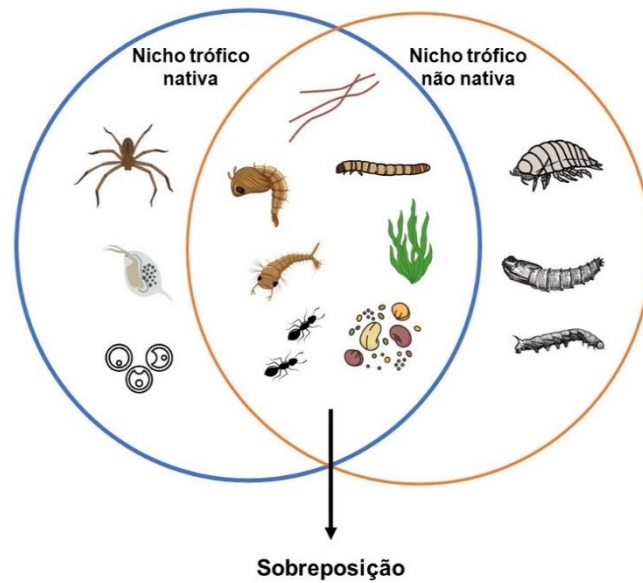


Figura S1. Figura esquemática da sobreposição de nicho trófico entre o par de espécies nativa e não nativa.

Aliado ao processo de invasão em ambientes naturais, a degradação parece facilitar o estabelecimento de espécies não nativas, visto que essas são geralmente mais tolerantes (Simberloff & Rejmánek, 2011). Alterações na paisagem modificam as condições ambientais e podem reduzir a disponibilidade de habitats e recursos alimentares, aumentando a competição intra e interespecífica e, potencialmente, prejudicando espécies nativas (Chapin et al., 2000; Souza, 2022). Particularmente para os sistemas de água doce, a agricultura e a urbanização são importantes fontes de mudanças no uso da terra que afetam o habitat físico, a qualidade da água e a entrada de energia no sistema (Mello et al., 2020). Tais alterações são responsáveis pelo aumento das cargas de sedimentos e nutrientes nos cursos d'água, bem como de poluentes tóxicos, resíduos orgânicos, coliformes fecais, fósforo e nitrogênio (Mello et al., 2020; Maia et al. 2022). Em relação aos efeitos nas condições físicas do habitat local, a alteração do uso do solo e a fragmentação fluvial, afetam a estabilidade do leito, reduzem o sombreamento local, diminuem a complexidade dos abrigos e reduzem a profundidade do canal (Leitão et al., 2017). Mesmo ocorrendo em

menor escala territorial, a mineração é outra pressão antrópica que resulta em altos impactos no ambiente aquático, contaminando águas superficiais e sedimentos com metais pesados e outros elementos tóxicos (Maia et al. 2022; Salvador et al. 2022; 2023). Investigar a correlação entre a degradação ambiental e a introdução de espécies através de interações ecológicas é crucial para compreender o funcionamento do sistema e como as espécies não nativas estão afetando as nativas.

O sistema do Rio Doce tem um histórico de introdução de espécies de peixes não nativos desde a década de 70 (Godinho, 1996). E, ao longo dos séculos, a bacia sofre com as atividades antrópicas, observando-se mudanças na paisagem e no uso do solo promovidas primeiramente pela mineração de ouro e, posteriormente, pela agropecuária, agroindústria do açúcar e do álcool, mineração de ferro, silvicultura e geração de energia elétrica (ANA, 2024). Além disso, em novembro de 2015, ocorreu o rompimento da barragem de rejeitos de Fundão, da mineradora Samarco, pertencente à Vale, e da empresa anglo-australiana BHP Billiton, localizada na cidade de Mariana (MG). A lama de minério atingiu o Rio Gualaxo do Norte, depois passou pelo Rio Carmo e atravessou a calha principal do Rio Doce, percorrendo aproximadamente 660 km até chegar ao mar (ANA, 2024). De acordo com Salvador et al. (2022), após o rompimento da barragem, as espécies não nativas aumentaram em abundância em todas as regiões de estudo da UHE Baguari, a montante do reservatório, no reservatório e a jusante. Tal resultado indicou que tais espécies podem ter sido beneficiadas, enquanto espécies nativas tiveram perda de abundância na região a montante do reservatório após o rompimento da barragem de Fundão.

Atualmente, existem cerca de 39 espécies não nativas na bacia do Rio Doce, dentre elas 14 são consideradas casuais, ou seja, com registros esporádicos, 10 são consideradas estabelecidas, e 15 já causam efeitos negativos no sistema (Bueno, et al. 2021). De acordo com o trabalho de Souza (2022), as espécies não nativas com maior número de ocorrências na bacia do Rio Doce são o lebiste *Poecilia reticulata*, a piabinha *Knodus moenkhausii*, o cascudo *Hoplosternum littorale*, o mandi *Pimelodus maculatus*, e a tilápia-do-Nilo *Oreochromis niloticus*. Dentre os vetores de introdução de espécies, o aquarismo tem maior número de registros, seguido pela aquicultura, pesca esportiva e isca-viva (Souza, 2022). Dentre as espécies não nativas, a piabinha *Knodus moenkhausii* (Eigenmann & Kennedy 1903) está amplamente distribuída na bacia do Rio Doce e em outras seis bacias hidrográficas do sudeste do Brasil (Bueno, et al. 2021). Além da alta pressão de propágulo (capacidade dos indivíduos de dispersar local ou regionalmente), é uma espécie oportunista

e tolerante a ambientes degradados (Vitule et al., 2009, Carvalho et al., 2017, 2019a, 2019b). Também amplamente distribuída na bacia, destaca-se a piabinha nativa *Deuterodon* cf. *taeniatus* (Jenyns 1842). Estas espécies, nativa (*Deuterodon* cf. *taeniatus*) e não nativa (*Knodus moenkhausii*), são filogeneticamente e ecologicamente relacionadas, possuem hábito alimentar onívoro e oportunista, com alta plasticidade alimentar (Manna et al., 2012; Carvalho et al., 2019a; Figura S2). Embora a dieta de ambas seja relativamente bem conhecida, o grau de sobreposição alimentar entre essas espécies quando partilham o mesmo ambiente ainda não foi investigado.

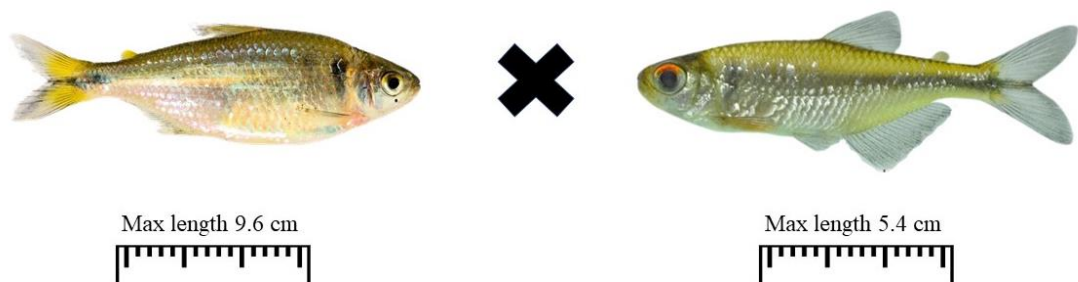


Figura S2. Par de espécies nativa (*Deuterodon* cf. *taeniatus*) e não nativa (*Knodus moenkhausii*) na Bacia do Rio Doce. Fotos: Gilberto Nepomuceno Salvador.

Investigar como as espécies não-nativas estão afetando as espécies nativas é crítico para a compreensão dos mecanismos fundamentais do processo de invasão biológica. Neste contexto, este estudo tem como objetivo central descrever a dieta e quantificar a sobreposição de nicho trófico entre o par de espécies de peixe nativo (*Deuterodon* cf. *taeniatus*) e não-nativo (*Knodus moenkhausii*) na bacia do Rio Doce. Adicionalmente, considerando a redução da disponibilidade e diversidade de recursos em ambientes degradados, testamos a hipótese de que a sobreposição de nicho trófico entre este par de espécies de peixes aumenta em níveis mais elevados de degradação ambiental na bacia.

Este trabalho está vinculado ao projeto ICTIODOCE - ICB/UFMG, que tem como objetivos principais, investigar os efeitos do ambiente, em escala de bacia e de habitat local, sobre a distribuição e aspectos ecológicos das espécies de peixes do Rio Doce para entender como o desastre de Fundão levou à reestruturação da ictiofauna. E, além disso, investigar os efeitos do desastre sob o ponto de vista das espécies raras e ameaçadas de extinção, assim

como das espécies não nativas. O material biológico foi proveniente de amostragens realizadas em 46 pontos ao longo da Bacia do Rio Doce na estação seca de 2022. Os pontos foram distribuídos aleatoriamente na bacia em rios acima da 6ª ordem *sensu* Strahler (1957). Neste estudo, selecionamos apenas 10 do total de pontos amostrados (Figura S3), utilizando como critério a coocorrência de ambas as espécies e o número mínimo de indivíduos para uma análise robusta dos conteúdos estomacais e da sobreposição de nicho.



Figura S3. Alguns pontos de coleta de dados da amostragem do projeto ICTIODOCE-ICB/UFMG em 2022. IBIRD 11- Rio Santa Margarida; IBIRD 13 – Rio Tanque; IBIRD 23 – Rio Suaçuí pequeno; IBIRD 29 – Rio Suaçuí Grande; IBIRD 07 - Rio Suaçuí Grande; IBIRD 44 – Rio Doce. Fotos: Gilberto Nepomuceno Salvador.

O método utilizado nesse estudo envolveu aplicação de protocolo de avaliação de habitat físico adaptado para rios (EPA – US; Peck et al., 2006), coleta de peixes (Figura S4), análise de conteúdo estomacal em laboratório (Figura S5), cálculos de sobreposição de nicho trófico e de degradação ambiental.



Foto S4. Amostragem de peixes e obtenção de dados ambientais do projeto ICTIODOCE - ICB/UFMG, campanha de 2022.



Foto S5. Análise de conteúdo estomacal no laboratório de Ecologia de Peixes – UFMG, utilizando a lupa Zeiss Stemi DV4.

É possível visualizar a semelhança morfológica do trato gastrointestinal das espécies (Figura S6), com presença de cecos pilóricos, caractere típico de espécies com hábito alimentar onívoro. Além disso, observamos grande diversidade de itens nos estômagos dos exemplares examinados (Figura S7).

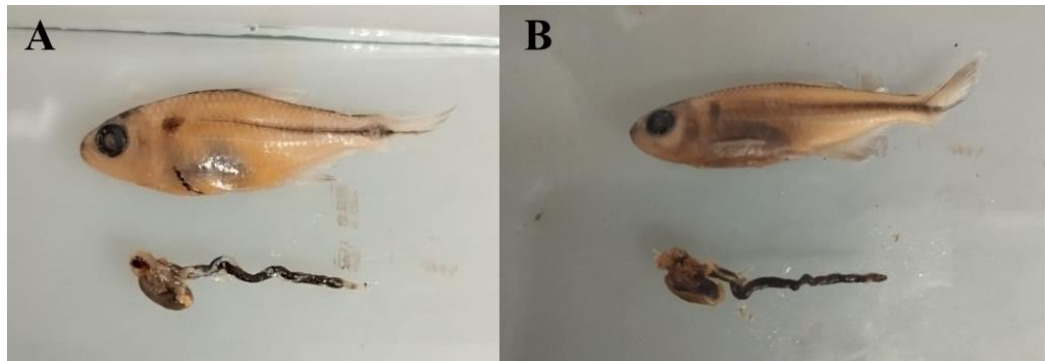


Foto S6. Trato gastrointestinal das espécies de peixe (A) *Deuterodon* cf. *taeniatus* e (B) *Knodus moenkhausii*.

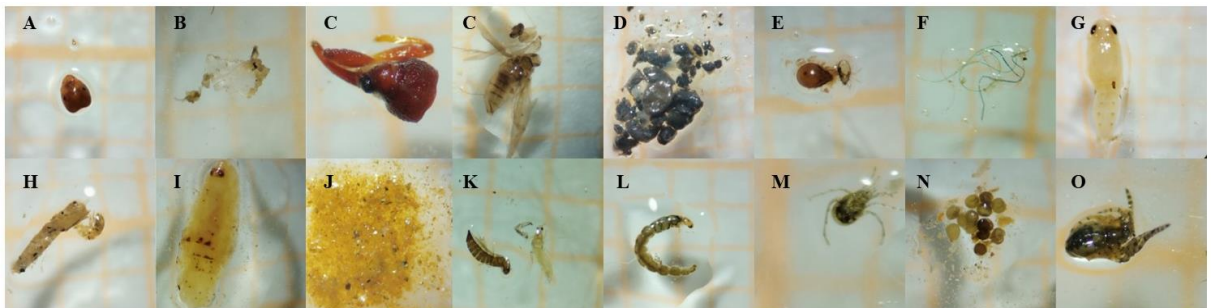


Foto S7. Itens encontrados no conteúdo estomacal de exemplares das espécies de peixes *Deuterodon* cf. *taeniatus* e *Knodus moenkhausii* da Bacia do Rio Doce. Em sequência: (A) Hymenoptera; (B) microplástico; (C) fragmentos de insetos alóctones; (D) detrito orgânico; (E) Acari terrestre; (F) fios de nylon; (G) Hemiptera; (H) Trichoptera; (I) Tipulidae; (J) detrito inorgânico; (K) Thysanoptera; (L) Chironomidae; (M) Acari aquático; (N) sementes; (O) Aranea.

Foi apresentado um panorama geral das teorias ecológicas, dos mecanismos e metodologias abordadas na dissertação, que contém apenas um capítulo e está apresentada em formato de artigo científico. Construímos o trabalho nesse formato, com objetivo de submeter ao periódico “Water Biology and Security” na edição especial “Mine Tailings Facility Disasters: Aquatic Ecological Effects and Policy”.

REFERÊNCIAS

- Bernery, C., Bellard, C., Courchamp, F., Brosse, S., Gozlan, R. E., Jaric, I., Teletchea, F., and Leroy, B. (2022). Freshwater Fish Invasions: A Comprehensive Review. *Annu. Ver. Ecol. Evol. Syst.* 53:427–56. <https://doi.org/10.1146/annurev-ecolsys-032522-015551>
- Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., et al. 2011. A proposed unified framework for biological invasions. *Trends Ecol. Evol.* 26(7):333–39. <https://doi.org/10.1016/j.tree.2011.03.023>
- Britton, J. R., Roberts, C. G., Trigo, F. A., Nolan, E. T., De Santis, V. (2019). Predicting the ecological impacts of an alien invader: Experimental approaches reveal the trophic consequences of competition. *J Anim Ecol.* 88:1066–1078. <https://doi.org/10.1111/1365-2656.12996>
- Bueno, M. L., Magalhães, A. L. B., Andrade Neto, F. R., Alves, C. B. M., Rosa, D. de M., Junqueira, N. T., Pessali, T. C., Pompeu, P. S., Zenni, R. D. (2021). Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. *Biol Invasions* 23:3021–3034. <https://doi.org/10.1007/s10530-021-02564-x>
- Cardinale, B. J., Palmer, M. A., & Collins, S. L. (2002). Species diversity enhances ecosystem functioning through interspecific facilitation. *Nature*, 415(6870), 426–429. doi:10.1038/415426^a
- Carvalho, D. R., Castro, D. M. P., Callisto, M., Chaves, A. J. M., Moreira, M. Z., Pompeu, P.S. (2019a) Stable isotopes and stomach content analyses indicate omnivorous habits and opportunistic feeding behavior of an invasive fish. *Aquat Ecol* 53(3):365–381. <https://doi.org/10.1007/s10452-019-09695-3>
- Carvalho, D. R., Flecker, A. S., Alves, C. B. M., Sparks, J., Pompeu, P. S. (2019b) Trophic responses to aquatic pollution of native and exotic livebearer fishes. *Sci Total Environ.* 681:503-515. <https://doi.org/10.1016/j.scitotenv.2019.05.092>
- Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405(6783), 234-242. doi: 10.1038/35012241
- David, P., Thébault, E., Anneville, O., Duyck, P. F., Chapuis, E., Loeuille, N. (2017). Chapter One - Impacts of Invasive Species on Food Webs: A Review of Empirical Data. *Advances in Ecological Research*, 56:1-60. <https://doi.org/10.1016/bs.aecr.2016.10.001>
- Dick, J. T. A., Laverty, C., Lennon, J. J., Barrios-O'Neill, D., Mensink, P. J., Robert Britton, J., Médoc, V., Boets, P., Alexander, M. E., Taylor, N. G., Dunn, A. M., Hatcher, M. J., Rosewarne, P. J., Crookes, S., MacIsaac, H. J., Xu, M., Ricciardi, A., Wasserman, R. J., Ellender, B. R., Weyl, O. L. F., Lucy, F. E., Banks, P. B., Dodd, J. A., MacNeil, C., Penk, M. R., Aldridge, D. C. and Caffrey, J. M. (2017). Invader Relative Impact Potential: a new metric to understand and predict the ecological impacts of existing, emerging and future invasive alien species. *J Appl Ecol*, 54: 1259-1267. <https://doi.org/10.1111/1365-2664.12849>
- Firth, B. L., Poesch, M. S., Koops, M. A., Drake, D. A. R., Power, M. (2021). Diet overlap of common and at-risk riverine benthic fishes before and after Round Goby (*Neogobius melanostomus*) invasion. *Biol Invasions*, 23:221–234. <https://doi.org/10.1007/s10530-020-02366-7>

- Godinho, A. L. (1996). Peixes do Parque Estadual do Rio Doce. Belo Horizonte: Instituto Estadual de Florestas/Universidade Federal de Minas Gerais, 1, 48.
- Hutchison, G.E. (1959) Homage to Santa Rosalia, or Why Are There So Many Kinds of Animals? *The American Naturalist*, 93, 145-159. <https://doi.org/10.1086/282070>
- Kolar, C. S., Lodge, D. M. (2002) Ecological Predictions and Risk Assessment for Alien Fishes in North America. *Science* 298: 1233-1236. DOI: 10.1126/science.1075753
- Leitão, R.P., Zuanon, J., Mouillot, D., Leal, C.G., Hughes, R.M., Kaufmann, P.R., Villéger, S., Pompeu, P.S., Kasper, D., de Paula, F.R., Ferraz, S.F.B. and Gardner, T.A. (2018). Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. *Ecography*, 41: 219-232. <https://doi.org/10.1111/ecog.02845>
- Loreau, M. (2001). Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. *Science*, 294(5543), 804–808. doi:10.1126/science.1064088
- Maia, C., Salvador, G. N., Begot, T. O., Freitas, P. V., Nonato, F. A. S., Torres, N. R., Juen, L. & Montag, L. F. A. (2022). Fish functional responses to local habitat variation in streams within multiple land uses areas in the Amazon. *Neotropical Ichthyology*, 20(4):e220091. <https://doi.org/10.1590/1982-0224-2022-0091>
- Manna, L., Rezende, C., & Mazzoni, R. (2012). Plasticity in the diet of *Astyanax taeniatus* in a coastal stream from south-east Brazil. *Brazilian Journal of Biology*, 72(4), 919–928. doi:10.1590/s1519-69842012000500020
- Mello, K. de, Taniwaki, R. H., Paula, F. R. de, Valente, R. A., Randhir, T. O., Macedo, D. R., ... Hughes, R. M. (2020). Multiscale land use impacts on water quality: Assessment, planning, and future perspectives in Brazil. *Journal of Environmental Management*, 270, 110879. <https://doi.org/10.1016/j.jenvman.2020.110879>
- Meyerson, L. A., D. Simberloff, L. Boardman, J. L. Lockwood. (2019). Toward “Rules” for Studying Biological Invasions. *Bull Ecol Soc Am* 100(4):e01607. <https://doi.org/10.1002/bes2.1607>
- Moyle, P. B., Light, T. 1996a. Biological invasions of fresh water: empirical rules and assembly theory. *Biol. Conserv.* 78(1–2):149–61. [https://doi.org/10.1016/0006-3207\(96\)00024-9](https://doi.org/10.1016/0006-3207(96)00024-9)
- Peck, D., Herlihy, A., Hill, B., Hughes, R., Kaufmann, P., Klemm, D., Lazorchak, J., McCormick, F., Peterson, S., Ringold, P., Magee, T., & Cappaert, M. (2006). Monitoring and Assessment Program — Surface Waters Western Pilot Study: field operations manual for wadeable streams. EPA/620/R-06/003. Washington, DC: U.S.Environmental Protection Agency.
- Rosenfeld, J. S. (2002). Functional redundancy in ecology and conservation. *Oikos*, 98(1), 156–162. <https://doi.org/10.1034/j.1600-0706.2002.980116.x>
- Salvador, G. N., Hughes, R. M., Vieira, F., Ligeiro, R., Montag, L. F. A. (2023). Mine tailings storage dams modify upstream headwater fish assemblages. *Freshwater Biology*, 67:1708–1724. <https://doi.org/10.1016/j.watbs.2023.100136>

- Salvador, G. N., Montag, L. F. A., Hughes, R. M., Almeida, S. M., Prudente, B. S., Pessali, T. C., Barroso, T. A., Cianciaruso, M. V., Ligeiro, R., Juen, L., & Carlucci, M. B. (2022). Influences of multiple anthropogenic disturbances coupled with a tailings dam rupture on spatiotemporal variation in fish assemblages of a tropical river. *Freshwater Biology*, 67, 1708–1724. <https://doi.org/10.1111/fwb.13967>
- Schoener, T. W. (1983). Field Experiments on Interspecific Competition. *The American Naturalist*, 122(2), 240–285. <https://doi.org/10.1086/284133>
- Simberloff, D., & Rejmánek, M. (2011). *Encyclopedia of biological invasions*. California: University of California Press. First Edition, 792.
- Souza, C. P de. (2022). Alterações Da Paisagem São Indicadoras Da Ocorrência De Peixes Não Nativos Na Bacia Do Rio Doce? Dissertação De Mestrado, Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre do Instituto de Genética, Ecologia e Evolução da Universidade Federal de Minas Gerais.
- Spínola, L. A., & Ferreira Júlio Junior, H. (2007). Espécies invasoras: conceitos, modelos e atributos. *Interciencia*, 32(9), 580-585.
- Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology, *Eos Trans. AGU*, 38(6), 913–920. doi:10.1029/TR038i006p00913
- Tilman, D. (1997). The Influence of Functional Diversity and Composition on Ecosystem Processes. *Science*, 277(5330), 1300–1302. doi:10.1126/science.277.5330.1300
- Toft, C. A. (1985). Resource Partitioning in Amphibians and Reptiles. *Copeia*, 1985(1), 1. <https://doi.org/10.2307/1444785>
- Vitule, J. R. S., Prodocimo, V. (2012). Non-native species introduction and biological invasions. *Estud. Biol., Ambiente Divers*, 34(83), 225-237. <https://doi.org/10.7213/estud.biol.7335>
- Wang, Y., Tan, W., Li, B., Wen, L., & Lei, G. (2021). Habitat alteration facilitates the dominance of invasive species through disrupting niche partitioning in floodplain wetlands. *Diversity and Distributions*, 27, 1861–1871. <https://doi.org/10.1111/ddi.13376>
- Wootton, R. J. (1998) *Ecology of Teleost Fishes*. Kluwer. Dordrecht, Holanda. 386 pp.

1. Introduction

Biological invasions are among the main threats to biodiversity worldwide, leading to increasing levels of native species extinctions (Meyerson et al., 2019). Non-native species can affect the structure of biological communities and cause profound changes in ecological dynamics and processes, such as the erosion of native biodiversity and ecosystem functioning (Souza et al. 2021; Wang et al. 2021; Vitule and Prodocimo, 2012). These species often have biological characteristics that favor the colonization and establishment of new environments, such as rapid population growth, tolerance to changing physical conditions, high fecundity rates, and dietary plasticity (Spínola and Ferreira, 2007; Kolar and Lodge, 2000; Wootton, 1998).

Understanding the mechanisms underlying invasion success and the consequent biodiversity loss remains an important knowledge gap (Bernery et al., 2022; Vitule and Prodocimo, 2012). One of these mechanisms is the competition for resources between native and non-native species (Reference). When non-native species shared similar ecological requirements and are subject to the same environmental conditions of the native species, they may reduce the availability and the quality of food resources used by the latter (Firth et al., 2021; Britton et al., 2019). Considering that the use of food resources is one of the main dimensions of the ecological niche of species (Schoener, 1983; Toft, 1985), quantifying the degree of trophic niche overlap between species is a fundamental step toward understanding the effects of biological invasion on the native communities mediated by competition.

Environmental degradation seems to facilitate the establishment of non-native species, since they tend to be more tolerant to degraded conditions and opportunistic in the use of resources (Simberloff & Rejmánek, 2011). For instance, in a recent study using isotopic approach to understand energy assimilation from a pair of native and non-native freshwater fish from the Rio São Francisco basin, Southeast Brazil, Carvalho et al. (2019), found that the exotic species *Poecilia reticulata* can assimilate carbon directly from sewage, and when combined with its high survival rate in environments with low water quality and its reproductive strategy, it can establish itself successfully in heavily polluted areas.

Particularly to freshwater systems, agriculture and urbanization are important land use changes affecting local physical habitat, water quality, and energy inputs to streams and rivers (Mello et al., 2020). They are responsible for increasing sediment and nutrient loads in watercourses, toxic pollutants, organic waste, fecal coliforms, phosphorus, and nitrogen (Mello

et al., 2020; Maia et al. 2022). Regarding the effects on local physical habitat conditions, land use changes and riverscape fragmentation affect bed stability, reduce local shading, decrease shelter complexity, and reduce channel depth (Leitão et al., 2017). Even occurring on a smaller territorial scale, mining is another critical human-induced pressure to aquatic environment, contaminating surface waters with heavy metals and contributing to high amounts of fine sediment to the riverine systems (Maia et al. 2022; Salvador et al. 2022; 2023). These multitude of factors frequently lead to high habitat homogenization and lessening the availability and diversity of resources for the freshwater organisms (Leitão et al., 2017; Neves et al., 2023; Larentis et al., 2021). In this context, landscape changes can ultimately increase intra- and inter-competition and potentially harming native species (Chapin et al., 2000; Souza, 2022). Investigating the correlation between environmental degradation and species introduction through ecological interactions is thus a critical step to understanding how the system works and finding solutions for conserving native biodiversity.

The Rio Doce Basin is a suitable study model for testing hypotheses about biological invasion mechanisms coupled with environmental degradation, because this freshwater system has: (1) a marked history of non-native fish introductions, with reports dating back to the 1970s (Godinho, 1996); (2) a broad gradient of environmental degradation due to human activities associated with landscape changes; and (3) pairs of native and non-native species that are phylogenetically and ecologically close-related, such as the characid fishes *Deuterodon* cf. *taeniatus* (Jenyns 1842) and *Knodus moenkhausii* (Eigenmann & Kennedy 1903). *Knodus moenkhausii*, an invasive species in the Rio Doce basin (Bueno et al., 2021), has high propagule pressure (ability of individuals to disperse locally or regionally) and can thrive even in degraded environments (Vitule et al., 2009, Carvalho et al., 2017, 2019a, 2019b). It is also an opportunistic species in terms of the use of food resources, with the ability to change its trophic niche depending on environmental conditions (Carvalho et al., 2019a). *Deuterodon* cf. *taeniatus*, native to the Rio Doce basin, has an omnivorous and opportunistic feeding habit, with high dietary plasticity (Manna et al., 2012). Although the diet of both species is relatively well known, it is important to understand how these ecologically and morphologically similar species use feeding resources when they share the same environment.

Testing how non-native fish species are affecting native species is critical to improving our understanding of the fundamental mechanisms of the biological invasion process. In this context, this study aims to describe the diet and to quantify the trophic niche overlap between the native (*Deuterodon* cf. *taeniatus*) and the non-native (*Knodus moenkhausii*) fish species in

the Rio Doce basin. Additionally, considering the reduced availability and diversity of resources in degraded environments, we test the hypothesis that trophic niche overlap between this pair of fish species increases in higher levels of environmental degradation in the basin.

2. Methods

2.1 Study area

The Rio Doce basin is located in the Brazilian Southeast, covering a drainage area of 86,715 km², 86% of which belong to the state of Minas Gerais (MG) and the rest to the state of Espírito Santo (ES). The headwaters of the Rio Doce originate in the Mantiqueira and Espinhaço mountain ranges, and its waters travel around 850 km until reaching the Atlantic Ocean (ANA, 2024).

The Rio Doce system has introduced non-native fish species since the 1970s (Godinho, 1996). The introduction of species into many lakes in the region has caused significant changes in native communities, resulting in several cases of local extinctions (Fragoso-Moura et al., 2016; Souza et al., 2021; Souza, 2022). Moreover, over the centuries, faced multiple human activities which led to profound landscape changes, firstly by gold mining, and then by farming, sugar and alcohol agro-industry, iron mining, forestry, and electricity generation (ANA, 2024).

In addition, this scenario, in November 2015, the Fundão tailings dam of the Samarco mining company, which belongs to Vale, and the Anglo-Australian company BHP Billiton, located in the city of Mariana (MG), collapsed. The ore sludge reached the Rio Gualaxo do Norte, then passed through the Rio Carmo and crossed the main stem of the Rio Doce, running for approximately 660 km until reaching the sea (ANA, 2024).

This study is part of the ICTIODOCE - ICB/UFMG project and the biological material came from sampling carried out at 46 sites along the basin in dry season of 2022. These sites were randomly distributed using “spsurvey: Spatial Sampling Design and Analysis” package for R (Dumelle et al. 2023; R Development Core Team, 2023), encompassing rivers above the 6th order *sensu* Strahler (1957) (Fig. 1). In our study, we selected 10 of the total sampled sites, using as criteria the co-occurrence of both focal species (*Deuterodon cf. taeniatus* and *Knodus moenkhausii*) and the minimum number of specimens for a robust analysis of stomach contents and niche overlap.

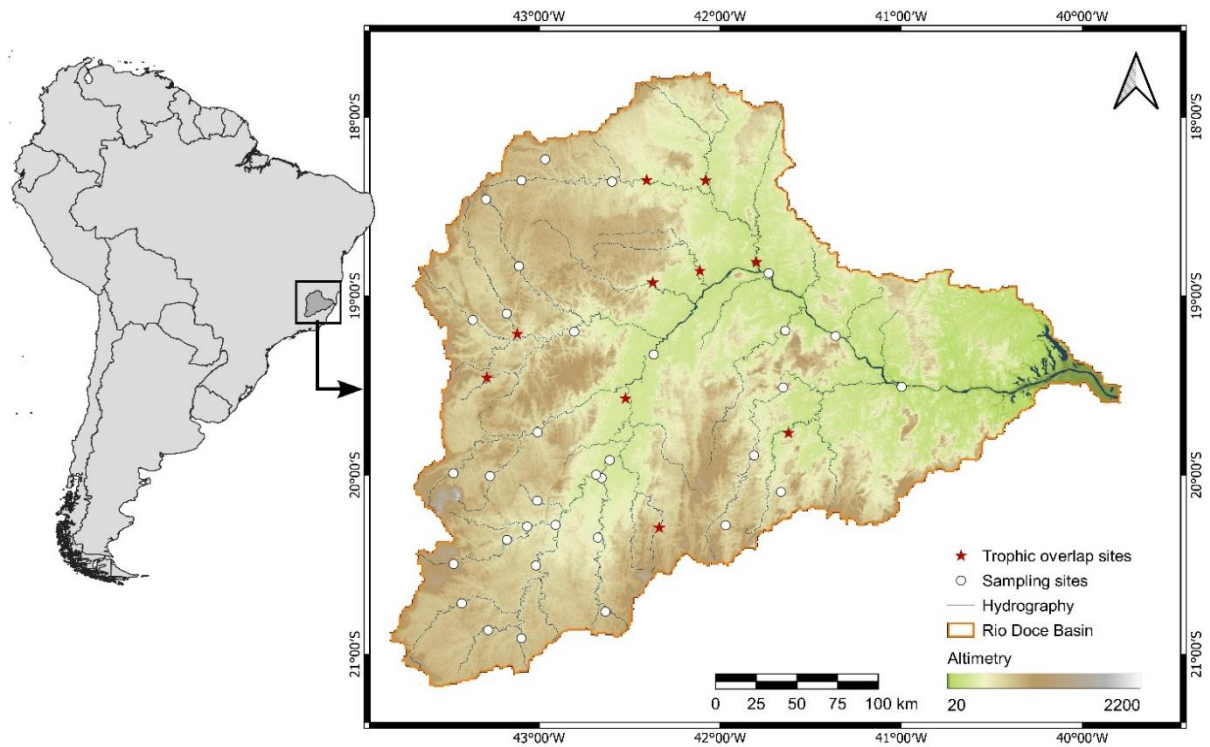


Figure 1. Map of the Rio Doce basin showing the sampling sites used in the IctioDoce Project (white dots) and the 10 sites selected for our study (red stars).

2.2 Data collection

2.2.1 Environmental data

At each of the 10 sampling sites, with an extension of 1.0 to 2.0 km of the river (depending on the wetted width), we characterize the local physical habitat by using the boatable habitat assessment protocol - adapted from Environmental Protection Agency of US (EPA) (Peck et al., 2006). We surveyed environmental variables in 11 marginal 10x20 m plots (Figure A1), obtaining information for: substrate type and depth (cm); bank angle classes; counts of large pieces of wood; visual estimates of the riparian zone (riparian vegetation cover and human influence); shelter for fish; and estimation of shading on the margins. For more details on how to obtain the metrics, see Peck et al. (2006). From the set of habitat variables obtained, we used three that indicate availability of food resources for river fish and habitat use, which are: mean total riparian cover (XCMG); mean natural shelter cover (XFC_NAT), and mean water column depth (XDEPTH_S) (Kaufmann et al., 1999). These variables had low correlation between each other (XCMG vs XFC_NAT = 0.55; XCMG vs XDEPTH_S = -0.24; XFC_NAT vs XDEPTH_S = -0.15).

2.2.2 Fish sampling

We collected fish specimens in 11 marginal 10x20 m plots (Figure A1), using semicircular sieves (80 cm diameter, 0.5 mm of mesh size) and trawls (4 m long, 2 m high and 0.5 mm of mesh size). The effort was standardized over two hours (12 min per plot) of sampling by two people along each sampling point. In the field, all the fish were anesthetized with a lethal dose of eugenol solution and then fixed in formaldehyde 10%, following the Ethics Committee on the Use of Animals in Research of the Federal University of Minas Gerais (CEUA process 339/2022). In the laboratory, the fish were preserved in alcohol 70% and identified to species level using identification keys and consultation with specialists. The Brazilian Government authorized this research through license number SEI/GOVMG 48.834.009.

2.2.3 Stomach content analysis

The stomach contents of the specimens of *Deuterodon* cf. *taeniatus* and *Knodus moenkhausii* were identified and quantified in the laboratory using a stereo microscope (model Zeiss Stemi DV4). The stomachs were placed on a glass plate (1 x 1 x 1.5 mm) containing an alcohol solution (70%), the degree of repletion was registered, and the food items (except plant material, algae, seeds, and eggs) were identified to order and/or family category, when possible. Each food item was quantified according to the method of Kawakami and Vazzoler (1980), considering the relative volume (Vo%) occupied in each stomach and its frequency of occurrence (%) among all the stomachs analyzed for each species. Based on this information, we calculate the Importance Alimentary Index (IA_i – also called Feeding Index): $IA_i = \frac{Fi \times Vi}{\sum_{i=1}^n (Fi \times Vi)}$ for each food item to describe the diet. We then constructed a generic graph by ordering the sites along the first axis of a Principal Coordinate Analysis (PCoA) to verify the general pattern of food resources used among sites by the two species.

We measured and weighed all fish specimens (mean of 3.5 cm) and, to avoid ontogenetic biases in dietary patterns, we chose only specimens of similar sizes in further analysis (Figure A2). The length of the gastrointestinal tract (GI tract) and stomach (cm) was also measured using a digital caliper, and the stomach was weighted (g) using a precision scale (MW 0,001g resolution), to compare the internal morphology of the gastrointestinal tract of the species. We observed a larger gastrointestinal tract in the native species *Deuterodon* cf. *taeniatus* than in the non-native *Knodus moenkhausii* (Figure A3). We also calculated the ratio between the gastrointestinal tract (cm) and the body standard length (cm) as complementary information on possible differences in feeding habits (Figure A4). During the analyses, we constructed

accumulation curves of the food items for each species and found that they reached the asymptote for almost all sites (Figure A5), which means that the number of stomachs analyzed was satisfactory to obtain a good representation of the species' diet.

2.3 Environmental degradation

We used the area of all the drainage upstream from each site to calculate land use categories. This classification is made using MAPBIOMAS data with a 10 m resolution based on the SENTINEL 2 satellite. From that, we calculated the Catchment Disturbance Index (CDI; Ligeiro et al., 2013; Rawer-Jost et al., 2004), as follows: $CDI = (4 \times \% \text{ urban areas}) + (2 \times \% \text{ agricultural areas}) + (1 \times \% \text{ pasture areas})$. Each category was given a weight corresponding to the type of land use and its impact on the rivers. The values range from 0 (complete natural vegetation cover) to 400 (basin completely occupied by urban areas).

To taking into account the level of local degradation (i.e., human activities in the riparian zone closer to sampled sites), we quantified the Local Disturbance Index (LDI). To that, we used the metric W1H_HALL, which is obtained from 11 metrics related to visible impacts caused by human activities, such as buildings, trash, pipes, roads, pasture and others (Kaufmann et al.; 1999). The LDI ranges from 0 (no anthropogenic disturbance observed at the local scale) to 16.5 (several types of disturbance observed close to each of the marginal plots). Finally, we calculated an integrated disturbance index (IDI; Ligeiro et al., 2013), which joins the information of the CDI and LDI, as follows:

$$IDI = \left[\left(\frac{LDI}{5} \right)^2 + \left(\frac{CDI}{300} \right)^2 \right]^{1/2}$$

High IDI values indicate rivers with higher levels of disturbance in both local and catchment scales (Ligeiro et al., 2013; Drager, 2022).

2.4 Trophic niche overlap

Based on the relative volume (Vo%) of organic food items found in the stomachal analysis (Hyslop, 1980) of *Deuterodon cf. taeniatus* and *Knodus moenkhausii*, we calculate the trophic niche overlap using Pianka's index:

$$O_{jk} = \frac{\sum_1^n p_{ij} p_{ik}}{\sqrt{\sum_1^n p_{ij}^2 \sum_1^n p_{ik}^2}},$$

O_{jk} measures niche overlap between species j and k , where p_{ij} is the proportion of the i th resource for species j , p_{ik} is the proportion of the i th resource for species k and n is the number of resource categories (Pianka, 1973). The metric ranges from zero (no overlap) to 1 (total overlap). We obtained the niche overlap values using the package 'spaa' (Zhang, 2016). We established the trophic niche overlap (Pianka's index) values at the following levels: high (>0.6), intermediate (0.4 - 0.6), or low (<0.4) (adapted from Grossman, 1986).

Finally, to test our hypothesis that trophic niche overlap between this pair of fish species increases in higher levels of environmental degradation in the basin we correlated IDI and other local environmental variables (mean total riparian cover (XCMG); mean natural shelter cover (XFC_NAT), and mean water column depth (XDEPTH_S) with trophic overlap (Pianka's index) between *Deuterodon cf. taeniatus* and *Knodus moenkhausii* using linear regression. The level of significance in all analyses was 0.05. All analyses were performed in the R statistical environment (version 4.3.2) (R Development Core Team, 2023).

3. Results

We analyzed 325 fish stomachs, being 158 (mean of 15.8 ± 8.6 per site) from *Deuterodon cf. taeniatus*, and 167 (mean of 16.7 ± 7.2 per site) from *Knodus moenkhausii*. Overall, 41 items were found in the fish stomachs, with the main ones being: autochthonous and allochthonous insects, plant material, microplastics, and inorganic debris (Table 1).

Table 1. Frequency of occurrence (Fo%), Relative volume (Vo%), and Feeding Index (IAi) of items consumed by the native fish species *Deuterodon cf. taeniatus* and by the non-native fish species *Knodus moenkhausii* at the 10 sampling sites distributed in the Rio Doce Basin, Brazil.

Species	<i>Deuterodon cf. taeniatus</i>			<i>Knodus moenkhausii</i>		
Number of stomachs	158			167		
Standard body length range (cm)	1.7 – 5.6			1.8 – 4.2		
ITEMS	Fo	Vo	IAi	Fo	Vo	IAi
PLANTS						
Plant Material	91.77	24.95	0.36	66.67	11.07	0.13
Filamentous Algae	62.03	10.40	0.10	66.67	13.90	0.16
Seeds	36.08	3.76	0.02	19.21	3.48	0.01
Microalgae	1.90	0.90	<0.01	0.00	0.00	0.00

ALLOCHTHONOUS

Terrestrial insect

Hymenoptera	36.08	4.53	0.03	14.12	2.15	0.01
Diptera	41.14	1.60	0.01	18.64	0.91	<0.01
Coleoptera Adult	13.29	1.08	<0.01	3.95	0.27	<0.01
Blattodea	0.63	0.01	<0.01	0.00	0.00	0.00
Isopoda	0.00	0.00	0.00	0.56	0.03	<0.01
Siphonaptera	0.63	0.01	<0.01	0.56	0.01	<0.01
Thysanoptera	6.96	0.20	<0.01	0.00	0.00	0.00
Fragments of terrestrial insects	71.52	14.66	0.16	34.46	4.97	0.03

Other terrestrial invertebrates

Aranea	1.90	0.44	<0.01	0.00	0.00	0.00
Acari	15.82	0.34	<0.01	3.39	0.10	<0.01

AUTOCHTHONOUS

Aquatic insects

Ceratopogonidae	15.19	0.49	<0.01	11.30	0.55	<0.01
Chironomidae	72.15	4.90	0.06	64.41	8.52	0.10
Coleoptera larvae	3.80	0.28	<0.01	2.82	0.22	<0.01
Dixidae	0.00	0.00	0.00	0.56	0.01	<0.01
Elmidae	0.63	0.01	<0.01	0.00	0.00	0.00
Empididae	5.06	0.49	<0.01	4.52	0.70	<0.01
Ephemeroptera	27.22	1.64	0.01	53.67	5.55	0.05
Hemiptera larvae	3.16	0.18	<0.01	1.69	0.31	<0.01
Odonata	0.63	0.07	<0.01	0.56	0.07	<0.01
Plecoptera	1.90	0.03	<0.01	0.00	0.00	0.00
Diptera pupae	21.52	1.05	<0.01	31.64	1.80	0.01
Simulidae	9.49	0.24	<0.01	5.65	0.21	<0.01
Tabanidae	0.00	0.00	0.00	0.56	0.01	<0.01
Tipulidae	3.16	0.47	<0.01	4.52	0.90	<0.01
Trichoptera	18.35	0.95	<0.01	24.86	1.28	0.01

Lepidoptera Larvae	0.63	0.02	<0.01	0.56	0.06	<0.01
Fragments of aquatic insects	78.48	14.33	0.18	81.92	22.63	0.33
<u>Fish</u>						
Scale	13.29	0.69	<0.01	18.64	1.35	<0.01
<u>Other aquatic invertebrates</u>						
Daphnia	1.90	0.03	<0.01	0.00	0.00	0.00
Collembola	1.90	0.04	<0.01	0.00	0.00	0.00
Eggs	23.42	0.62	<0.01	16.95	0.53	<0.01
NON-ORGANIC MATERIAL						
Microplastic	37.97	0.77	<0.01	25.42	0.70	<0.01
Mineral	2.53	0.01	<0.01	0.00	0.00	0.00
Glass	0.00	0.00	0.00	0.56	0.01	<0.01
Cotton string	0.63	0.01	<0.01	0.00	0.00	0.00
Detritus	39.24	8.92	0.06	50.28	17.53	0.15
UNDETERMINED						
Organic detritus	5.70	0.85	<0.01	0.56	0.17	<0.01

Considered only organic items (i.e., excluding microplastics, sand and others), the diet of *Deuterodon cf. taeniatus* consisted of 37 items, and the most representative (based on IAI values) were: plant material (36%), fragments of aquatic insects (18%), fragments of terrestrial insects (16%), filamentous algae (10%), and chironomidae (6%) (Table1; Figure 2). *Knodus moenkhausii* consumed 31 items, and the most relevant items were: fragments of aquatic insects (33%), filamentous algae (16%), plant material (13%), chironomidae (10%), and ephemeroptera (5%) (Table1; Figure 2). Only items with an IAI value higher than 5% are identified in the figure.

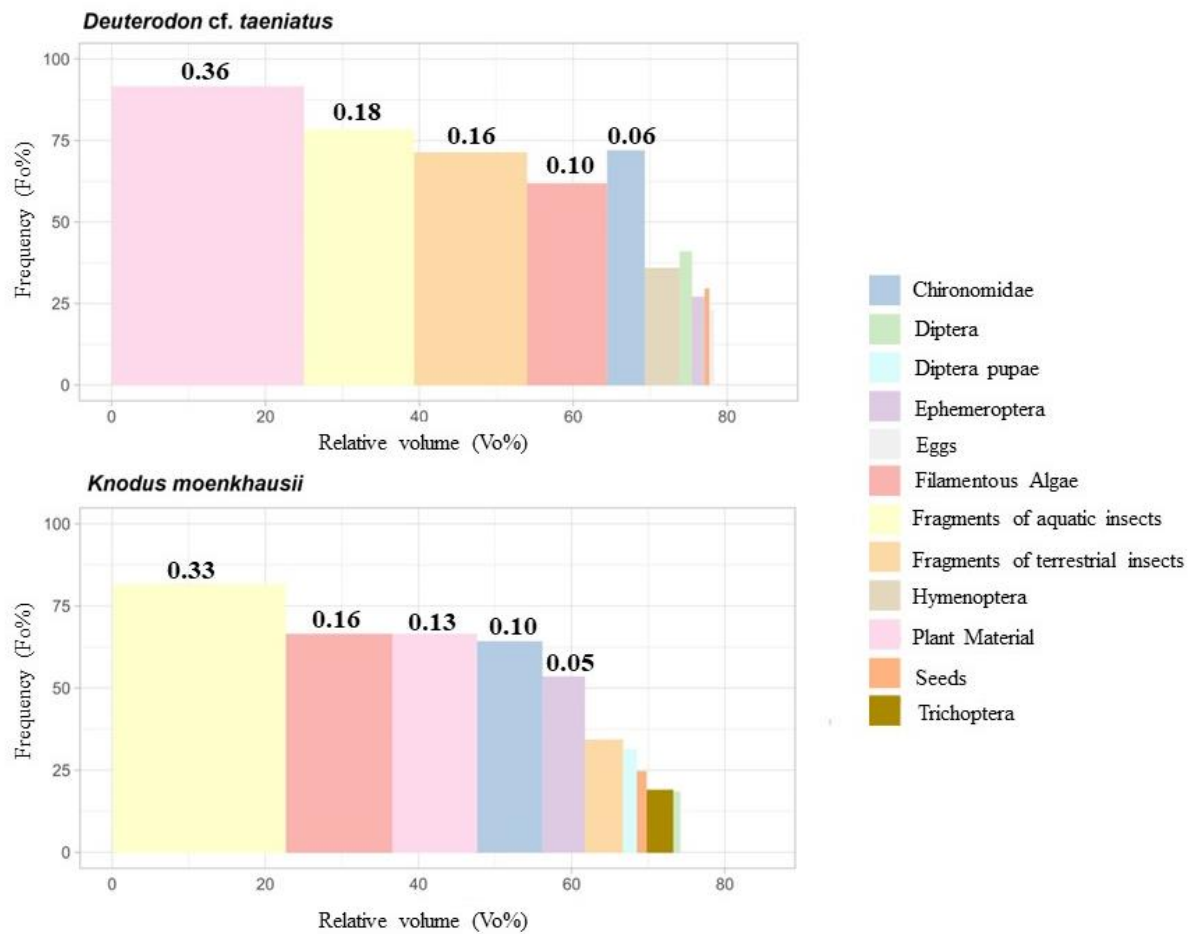


Figure 2. Frequency of occurrence (Fo%) and Relative volume (Vo%) of the main food items consumed by the native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* from the Rio Doce Basin, Brazil. Numbers above bars are the Feeding index (IAi) values for each food item.

Overall, the predominant items consumed by each fish species changed across the 10 sites (Figure 3), and some items are shared by the species at each site, such as Hymenoptera, Ephemeroptera and Filamentous algae (at IBIRD19), Diptera, Trichoptera and Simuliidae (at IBIRD 26), Acari and Fragments of aquatic insects (at IBIRD41) and Inorganic detritus, Scales and Eggs (at IBIRD29).

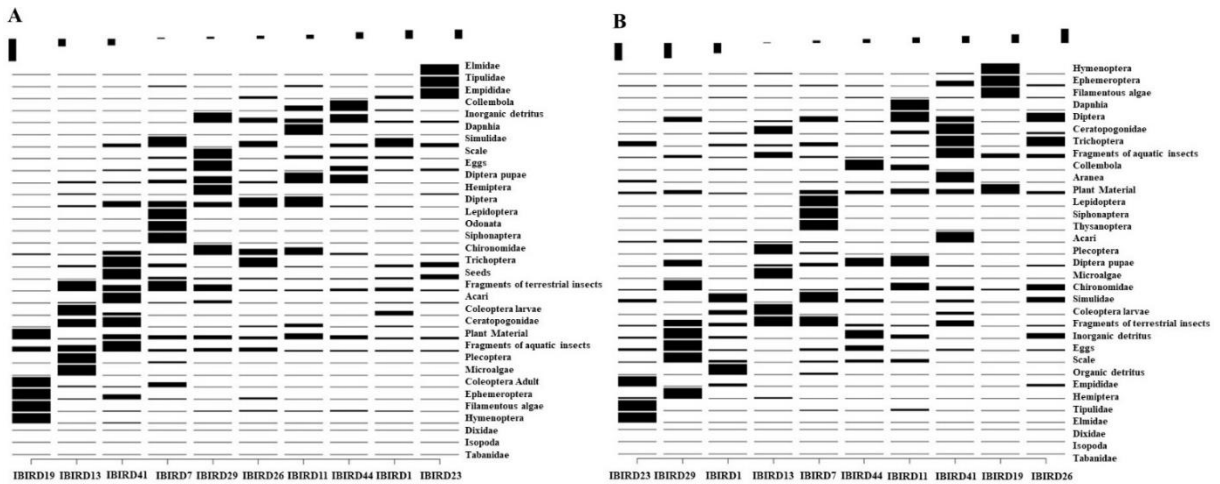


Figure 3. Generic graph built based on the IA_i (Feeding Index) of the items consumed by *Deuterodon cf. taeniatus* (A) and *Knodus moenkhausii* (B), showing an overall change in the predominant food items used over the 10 sampling sites in the Rio Doce basin, Brazil.

We found high trophic niche overlap (> 0.6) between *Deuterodon cf. taeniatus* and *Knodus moenkhausii* at 70% of the sampled sites, and intermediate overlap (0.4 - 0.6) at the other 30% (Figure 4). The integrated disturbance index (IDI) and other environmental variables showed low variation among sites (Table 2).

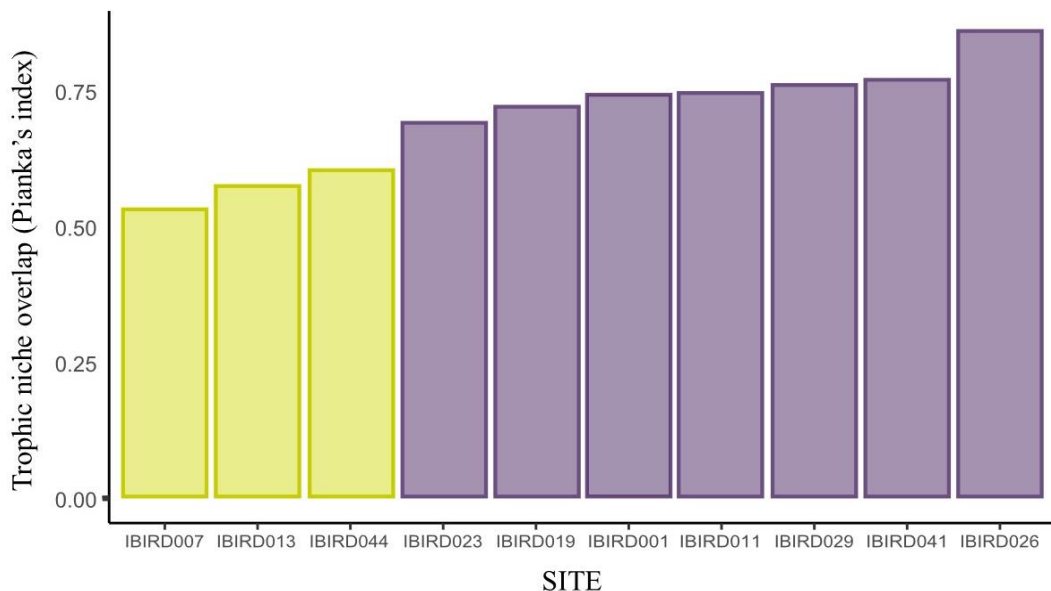


Figure 4. Trophic niche overlap between native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* for the 10 sampling sites from Rio Doce basin, Brazil. In yellow are the intermediate values of trophic niche overlap (0.4-0.6), and in purple are the high values (>0.6).

Table 2. Trophic niche overlap (Pianka's index) between *Deuterodon* cf. *taeniatus* and *Knodus moenkhausii*, Integrated Disturbance Index (IDI), and other environmental variables (XCMG - mean total riparian cover; XFC_NAT - mean natural shelter cover; XDEPTH_S – mean depth in the transect), for the 10 sampling sites from Rio Doce basin, Brazil.

RIVER	SITE	PIANKA'S INDEX	IDI	XCMG	XFC_NAT	XDEPTH_S
Suaçuí grande	IBIRD007	0.5285	0.0381	25.4545	2.0909	0.5364
Tanque	IBIRD013	0.5714	0.0186	42.9545	5.4545	0.5236
Doce	IBIRD044	0.6005	0.0412	53.2955	3	0.8291
Suaçuí pequeno	IBIRD023	0.6878	0.0226	31.5909	2.7273	0.6227
Urupoca	IBIRD019	0.7174	0.0358	50	2.4545	0.2836
Corrente grande	IBIRD001	0.7395	0.0299	29.8864	2.2727	0.6873
Santa Margarida	IBIRD011	0.7426	0.1163	32.1591	1.1818	0.6118
Suaçuí grande	IBIRD029	0.7573	0.0324	35.1136	2.5455	0.3873
Peixe	IBIRD041	0.7669	0.0263	42.2727	3.3636	0.4891
José Pedro	IBIRD026	0.8567	0.0657	38.5227	1.3636	0.5855

The level of trophic overlap between the native and non-native fish species is not affected by the environmental degradation (IDI) or other local environmental variables (Figure 5). The correlation between trophic niche overlap and the level of degradation may have been influenced by environmental variables not analyzed in this study.

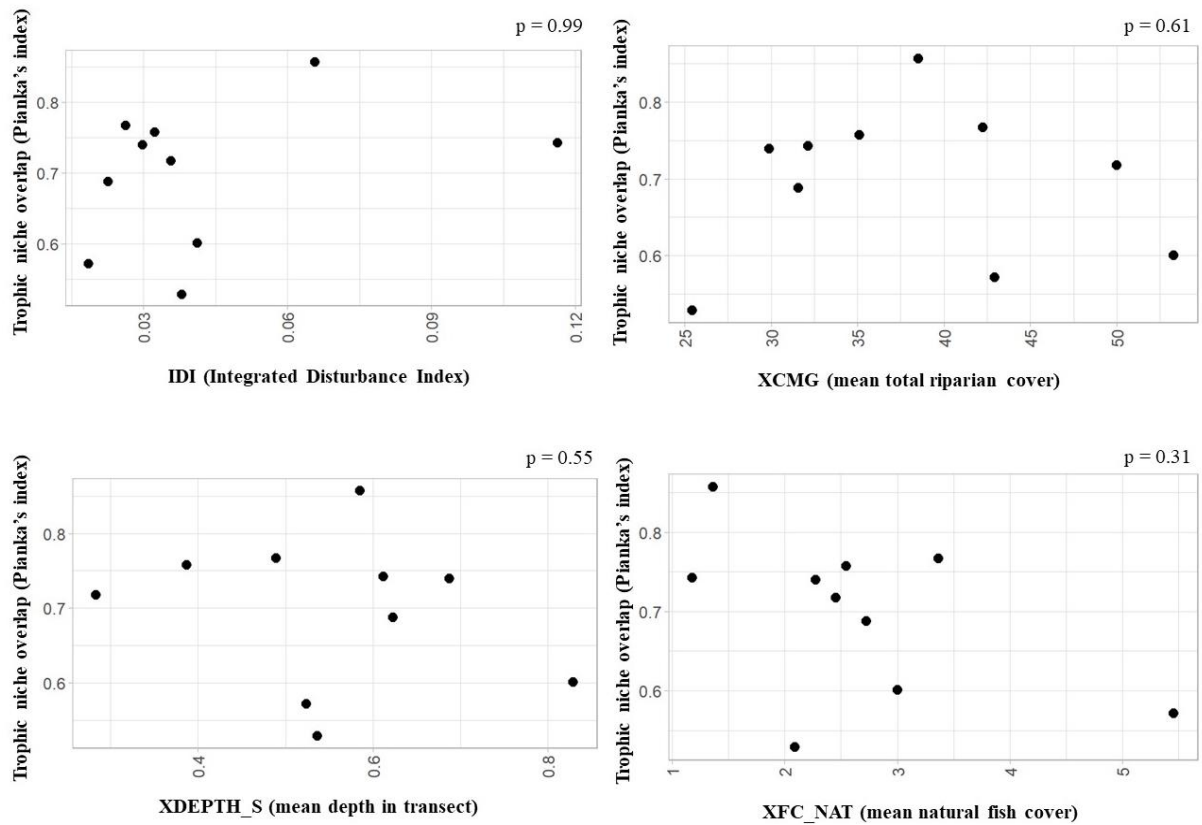


Figure 5. Relationship between Trophic niche overlap between the native fish species *Deuterodon* cf. *taeniatus* and non-native *Knodus moenkhausii* and Integrated Disturbance Index (IDI), and other local environmental variables (*XCMG* - mean total riparian cover; *XDEPTH_S* – mean depth in transect; *XFC_NAT* – mean natural fish cover) for all sampling sites, Rio Doce Basin, Brazil.

4. Discussion

Here we describe the diet and quantify the trophic niche overlap between a native (*Deuterodon* cf. *taeniatus*) and a non-native (*Knodus moenkhausii*) fish species in the Rio Doce basin. We confirm that both species have omnivorous diets, utilizing various resources available in the environment, and seem opportunistic due to the high variation in the predominant items between the sample sites. We verified a high dietary overlap between the two species in 70% of the sites. However, the hypothesis of a higher trophic niche overlap with increased degradation was not corroborated.

The species' diet includes plant materials, seeds, algae, and terrestrial insects such as Hymenoptera, Diptera, Coleoptera, and also some agricultural pests like those of the order Thysanoptera. Aquatic insects are also present, such as Chironomidae larvae, one of the items with the highest food importance index (IAi). They also consume other dipteran larvae and pupae, as well as some trichopterans. It is worth noting that, although they do not represent a

food resource, the species have ingested nylon threads, minerals and sediments (sand and small gravel). We believe these items were accidentally ingested by the fish, considering that they have a highly exploratory behavior, looking for drifting food items (Fogaça et al., 2003; Manna et al 2014; Ceneviva-Bastos & Casatti, 2007; Teresa & Casatti, 2013).

We observed a preference for plant material in *Deuterodon cf. taeniatus*, but it consumes all kinds of resources available in the environment, confirming that it's an opportunistic species with great trophic plasticity (Manna et al. 2012; Alonso et al., 2019). Adult individuals of *Deuterodon cf. taeniatus* consume more plant material than juveniles (Manna et al., 2012), so larger specimens may have preferred vegetal items. *Knodus moenkhausii* consumed mainly fragments of aquatic insects and filamentous algae, and exploited a variety of other items, including a large amount of inorganic detritus. The high variety of items consumed by this non-native species demonstrates opportunistic feeding in different environmental conditions (Ceneviva-Bastos & Casatti, 2007; Carvalho et al., 2019). In addition, we observed a larger gastrointestinal tract in native species, indicating that the relative increase in the intestine of larger specimens is associated with higher dietary plasticity and the use of items that are more difficult to digest, such as vegetables with rigid cell walls (Sabino & Castro 1990; Mazzoni et al., 2010).

The trophic niche overlap between the pair of species was high in most of the sites analyzed, sharing the resources available in these habitats. High values of trophic niche overlap can indicate competition for resources between species, which can lead to a change or decrease in the width of the trophic niche and affect the development and survival of native species (Britton et al., 2019). The feeding opportunism of *K. moenkhausii* is one of the reasons for its establishment and dispersal in new environments, and it is considered an introduced species in the Rio Doce, Jequitinhonha, Mucuri, Paraíba do Sul, and São Francisco basins (Bueno et al., 2021). It was first described based on specimens collected in the drainage of the Rio Paraguay basin with a presence in the Upper Paraná (Langeani et al., 2007; Carvalho et al., 2019). The dietary plasticity of *Deuterodon cf. taeniatus* seems to allow the species to maintain high abundance even with the presence of the non-native *Knodus moenkhausii* since generalist species have a wide trophic range and can restructure food chains in response to different impacts (Bartley et al., 2019; Costa and Angelini, 2020). On the other hand, native species that are more specialist may be more affected by the presence of the non-native species since competition can affect the local persistence of the natives, as they are less flexible in their use of resources, with less ability to exploit the environment (Clavel et al., 2011).

Our hypothesis about trophic niche overlap increasing with the level of environmental degradation was not corroborated. The trophic niche overlap was not affected by the Integrated Disturbance Index (IDI) or the set of environmental variables assessed here (i.e., mean depth, natural shelter, and vegetation cover). Regardless of the level of disturbance and habitat structure, the species show intermediate and high levels of trophic niche overlap among the sites studied. It is worth mentioning that the Rio Doce basin has suffered from human activities, land use and landscape changes over the centuries, which makes it challenging to define levels of degradation between sites. In parallel, environmental degradation does not seem to influence the increase in resource competition due to the plasticity and feeding opportunism of the two species, which can respond more quickly to habitat changes and reorganize their diet in a wide-ranging manner (Bartley et al., 2019), since they feed on a variety of items, both autochthonous and allochthonous. However, we observed that the trophic niche overlap value was intermediate at the site with the higher mean depth and the highest mean total cover. Here, we observed that the native species consumed a large fragment of terrestrial insects, and the non-native species prioritized autochthonous items. In river ecosystems, dense canopy cover generally induces a stronger linkage to terrestrial subsidies (Hill et al. 1995; Doi, 2009), leading to a more diverse and quality supply of resources for the aquatic system. Geomorphological and hydraulic processes, vegetation cover and aquatic biota are closely linked to the process of sediment retention (Gregory et al., 1991; Wang et al., 2006), functioning as a barrier in an area that is largely degraded due to human activities associated with changes in the landscape and land use. In our studied region, the site with the highest level of disturbance (IDI) has the high value of trophic overlap. It is located in the Rio Piranga hydrographic region and faces a number of human-induced pressures, such as disorderly urban expansion, deforestation, removal of riparian forest, domestic sewage disposal, pollution from agricultural activities and sand extraction (Gregório & Lima, 2007; PIRH, 2010). In this site, the species consumed microplastic (nylon thread) and a large amount of inorganic detritus.

Microplastics were frequently ingested by both species, most of which were nylon threads. Microplastics are plastic particles measuring between one and five millimeters (Oliveira et al., 2020). Plastics have been ingested by many river fish species around the world (Andrade et al., 2019; Urbanski et al., 2020; Azevedo-Santos et al., 2021), the ichthyofauna is the group that is most subject to accumulating microplastics for long periods, causing many physiological problems (blockage of the digestive tract, malnutrition, possibility of reaching the yolk sac and affecting the development of alevins) and even leading to the animals' death (Wright et al.,

2013; Atugoda et al., 2022; Smith et al., 2022). In addition, the chemical components in plastic particles can be transferred through the trophic chain and bioaccumulate (Farrel & Nelson, 2013; Smith et al., 2022). The study by Coelho et al. (2023) reported ingesting anthropogenic substances (microplastics, hooks) by fish in the Rio Doce basin. Most items were pieces of net and other fishing articles. The ingestion of microplastics by fish is more common than is currently reported, reinforcing the need for more research in freshwater environments and for more species (Azevedo-Santos et al., 2021).

It is also important to mention that most studies of the diet of the species *K. moenkhausii* and *D. cf. taeniatus* have been carried out in stream ecosystems, and our study brings the perspective of the consumption of food resources in river ecosystems. Rivers are more complex systems containing several interacting subsystems (Woodward & Hildrew, 2002; Doi, 2009). In addition, they are characterized by different degrees of erosion, transfer, and deposition of sediments along the longitudinal profile (Vannote et al., 1980; Allan & Castillo, 2007). The availability of autochthonous and allochthonous resources in river food webs is influenced by different light conditions, nutrient levels, and contributions from terrestrial sources, which can cause variation in the trophic base depending on the size of the river (Doi, 2009). Investigating and describing the diet of these species in rivers is an important step towards understanding the dynamics of food resources throughout the basin. Among the items ingested by the species, there is a large number of filamentous algae, and in larger rivers phytoplankton and algae are one of the main food sources for food webs (Delong & Thorp, 2006). The principal food source of *Deuterodon cf. taeniatus* in coastal streams of the Atlantic Forest is allochthonous plant material (Manna et al. 2019). *Deuterodon* sp. from the Rio Ubatiba, a coastal stream, ingests a wide variety of items, from organic matter, sediment (sand), algae, and seeds to crustaceans, oligochaetes, and terrestrial and aquatic insects (Mazzoni and Rezende, 2003). In the Rio das Velhas, they consume plants, algae, and insect remains (Alonso et al. 2019). According to our study, in the rivers of the Doce basin, the species preferentially ingests plant material, fragments of aquatic insects (Diptera larvae), terrestrial insects (Hymenoptera), and filamentous algae. In streams of the Upper Paraná River, *Knodus moenkhausii* frequently consumes autochthonous items such as algae, Ephemeroptera nymphs and Diptera larvae, and fragments of terrestrial insects (Hymenoptera and Araneae) are among the most dominant allochthonous items (Ceneviva-Bastos & Casatti, 2007). In other streams in the Rio Paranaíba sub-basin, they ingest aquatic insects (Diptera, Trichoptera, Ephemeroptera) and terrestrial insects (Coleoptera, Hymenoptera) and also consume detritus in streams influenced by pasture (Carvalho et al.

2019). In the Rio Doce basin, they prefer fragments of aquatic insects (Chironomidae, Ephemeroptera), filamentous algae, plant material, and a high frequency of inorganic detritus (sediment, sand).

We believe that our study is a good model for investigating the mechanisms underlying the process of species invasion through trophic niche overlap. It can be applied to other pairs of species and systems, making it possible to investigate other intra- and interspecific ecological interactions. Additionally, it allows for the exploration of diverse environmental effects, using other metrics and even different indices of degradation. We believe it is important to conduct more observational and experimental studies on species' behavior to understand their life habits and how they segregate in the environment. Through the analysis of stomach contents, we verified some of the processes underlying the use of resources by the species, both in the context of invasion and anthropogenic actions, because it is a tool that allows a more refined analysis of the items consumed by the species. We were also able to verify the variation in predominant items between the sites for both species, so it would be interesting to obtain data on the availability of resources to complement the study.

While this study only looked at one pair of species, it is a starting point in exploring the trophic dynamics of native and non-native species that share similar ecological requirements in the Rio Doce basin. The analysis of stomach contents represents the resources consumed by the fish minutes or hours before collection. For this reason, it would be interesting to incorporate stable isotope analysis into studies on diet and trophic niche overlap, as it makes it possible to verify the assimilation of material consumed over weeks or months (Andrade et al.; 2019) the availability of resources, and provides an overview of the species' dietary biology and energy flux in river systems.

5. Conclusion

We could describe and quantify the diet of the pair of native and non-native species in the Rio Doce basin, uncovering some mechanisms of the invasion process by analyzing stomach contents. We confirmed that both species have omnivorous feeding habits, with high trophic plasticity and food opportunism. *K. moenkhausii* and *D. cf. taeniatus* have high trophic niche overlap in most of the sites analyzed, indicating that the non-native species may compete for resources with the native species. However, the high trophic plasticity of *D. cf. taeniatus* may be helping to maintain this native species in the system even in the presence of a potential strong

invasive competitor. According to our study, trophic niche overlap is not affected by the level of degradation or by local environmental variables.

REFERENCES

- Agência Nacional de Águas e Saneamento Básico (ANA) – RIO DOCE. (2024). Ministério da Integração e do Desenvolvimento Regional – GOV.BR <https://www.gov.br/ana/pt-br/sala-de-situacao/rio-doce/rio-doce-saiba-mais>
- Allan, J. D., Castillo, M. M. (2007). Stream ecology: structure and function of running waters, 2nd edn. Springer, Dordrecht, The Netherlands. <https://link.springer.com/book/10.1007/978-1-4020-5583-6>
- Alonso, M. B., Carvalho, D. R., Alves, C. B. M., Moreira, M. Z., Pompeu, P. S. (2019) Changes in trophic characteristics of two fish species of *Astyanax* (Teleostei: Characidae) in response to aquatic pollution. *Zoologia* 36: 1-12. <https://doi.org/10.3897/zoologia.36.e30445>
- Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26, 32–46. <https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x>
- Andrade, M. C., Fitzgerald, D. B., Winemiller, K. O., Barbosa, P. S., Giarrizo, T. (2019). Trophic niche segregation among herbivorous serrasalmids from rapids of the lower Xingu River, Brazilian Amazon. *Hydrobiologia* 829, 265–280. <https://doi.org/10.1007/s10750-018-3838-y>
- Andrade, M. C., Winemiller, K. O., Barbosa, P. S., Fortunati, A., Chelazzi, D., Cincinelli, A., & Giarrizzo, T. (2019). First account of plastic pollution impacting freshwater fishes in the Amazon: Ingestion of plastic debris by piranhas and other serrasalmids with diverse feeding habits. *Environmental pollution (Barking, Essex:1987)*, 244, 766–773. <https://doi.org/10.1016/j.envpol.2018.10.088>
- Atugoda, T., Piyumali, H., Liyanage, S., Mahatantila, K., Vithanage, M. (2022). Fate and Behavior of Microplastics in Freshwater Systems. In: Rocha-Santos, T., Costa, M.F., Mouneyrac, C. (eds) *Handbook of Microplastics in the Environment*. Springer, Cham. https://doi.org/10.1007/978-3-030-39041-9_42
- Azevedo-Santos, V.M., Brito, M.F.G., Manoel, P.S. et al. (2021). Plastic pollution: A focus on freshwater biodiversity. *Ambio* 50, 1313–1324. <https://doi.org/10.1007/s13280-020-01496-5>
- Bartley, T. J., McCann, K. S., Bieg, C., Cazelles, K., Granados, M., Guzzo, M. M., MacDougall, A. S., Tunney, T. D., & McMeans, B. C. (2019). Food web rewiring in a changing world. *Nature ecology & evolution*, 3(3), 345–354. <https://doi.org/10.1038/s41559-018-0772-3>
- Bernery, C., Bellard, C., Courchamp, F., Brosse, S., Gozlan, R. E., Jaric, I., Teletchea, F., and Leroy, B. (2022). Freshwater Fish Invasions: A Comprehensive Review. *Annu. Ver. Ecol. Evol. Syst.* 53:427–56. <https://doi.org/10.1146/annurev-ecolsys-032522-015551>
- Britton, J. R., Roberts, C. G., Trigo, F. A., Nolan, E. T., De Santis, V. (2019). Predicting the ecological impacts of an alien invader: Experimental approaches reveal the trophic consequences of competition. *J Anim Ecol.* 88:1066–1078. <https://doi.org/10.1111/1365-2656.12996>

- Bueno, M. L., Magalhães, A. L. B., Andrade Neto, F. R., Alves, C. B. M., Rosa, D. de M., Junqueira, N. T., Pessali, T. C., Pompeu, P. S., Zenni, R. D. (2021). Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. *Biol Invasions* 23:3021–3034. <https://doi.org/10.1007/s10530-021-02564-x>
- Carvalho, D. R., Castro, D. M. P., Callisto, M., Chaves, A. J. M., Moreira, M. Z., Pompeu, P.S. (2019a) Stable isotopes and stomach content analyses indicate omnivorous habits and opportunistic feeding behavior of an invasive fish. *Aquat Ecol* 53(3):365–381. <https://doi.org/10.1007/s10452-019-09695-3>
- Carvalho, D. R., Flecker, A. S., Alves, C. B. M., Sparks, J., Pompeu, P. S. (2019b) Trophic responses to aquatic pollution of native and exotic livebearer fishes. *Sci Total Environ*. 681:503-515. <https://doi.org/10.1016/j.scitotenv.2019.05.092>
- Carvalho, D. R., Leal, C. G., Junqueira, N. T., Castro, M. A., Fagundes, D. C., Alves, C. B. M., Hughes, R., Pompeu, P. S. (2017) A fishbased multimetric index for Brazilian savanna streams. *Ecol Indic* 77:386–396. <https://doi.org/10.1016/j.ecolind.2017.02.032>
- Ceneviva-Bastos M., Casatti, L. (2007). Oportunismo alimentar de *Knodus moenkhausii* (Teleostei, Characidae): uma espécie abundante em riachos do noroeste do Estado de São Paulo, Brasil. *Iheringia Ser Zool* 97:7–15. <https://doi.org/10.1590/S0073-47212007000100002>
- Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405(6783), 234-242. DOI: 10.1038/35012241
- Clavel, J., Julliard, R. and Devictor, V. (2011). Worldwide decline of specialist species: toward a global functional homogenization? *Frontiers in Ecology and the Environment*, 9: 222-228. <https://doi.org/10.1890/080216>
- Coelho, P. N., Guimarães, T., Ferreira, W., Marcon, L., Travenzoli, N., Barros, L., Souza, K., Edesio, B., Assis, C. E. de, Arruda, V., Azevedo-Santos, V., Dergam, J. (2023). Besides mining, dams, non-native species... The ingestion of anthropogenic debris by fishes in the Doce River basin, southeastern Brazil. *Oecologia Australis*. 27. <https://doi.org/10.4257/oeco.2023.2704.07>
- Costa, I. D., Angelini, R. (2020). Gut content analysis confirms the feeding plasticity of a generalist fish species in a tropical river. *Acta Limnologica Brasiliensia*, 32, e21. <https://doi.org/10.1590/S2179-975X7819>
- Delong, M. D., Thorp, J. H. (2006). Significance of instream autotrophs in trophic dynamics of the Upper Mississippi River. *Oecologia* 147:76–85. <https://doi.org/10.1007/s00442-005-0241-y>
- Doi, H. (2009). Spatial patterns of autochthonous and allochthonous resources in aquatic food webs. *Popul Ecol*, 51: 57-64. <https://doi.org/10.1007/s10144-008-0127-z>
- Drager, D. H. C. (2022). A ictiofauna de riachos responde às alterações da paisagem no Cerrado? – Investigando os sinais sutis da assimetria flutuante. Dissertação De Mestrado, Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre do Instituto de Genética, Ecologia e Evolução da Universidade Federal de Minas Gerais.

Dumelle, M., Kincaid, T., Olsen, A. R., & Weber, M. (2023). spsurvey: Spatial Sampling Design and Analysis in R. *Journal of Statistical Software*, 105(3), 1–29.

<https://doi.org/10.18637/jss.v105.i03>

Farrell, P., & Nelson, K. (2013). Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). *Environmental pollution* (Barking, Essex:1987), 177, 1–3.

<https://doi.org/10.1016/j.envpol.2013.01.046>

Firth, B. L., Poesch, M. S., Koops, M. A., Drake, D. A. R., Power, M. (2021). Diet overlap of common and at-risk riverine benthic fishes before and after Round Goby (*Neogobius melanostomus*) invasion. *Biol Invasions*, 23:221–234. <https://doi.org/10.1007/s10530-020-02366-7>

Fogaça, F. N. O., Aranha, J. M. R., & Esper, M. De L. P. (2003). Ictiofauna do rio do quebra (Antonina, PR, Brasil): ocupação espacial e hábito alimentar. *Interciencia*, 28(3), 168-173.

http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0378-18442003000300009&lng=es&tlng=pt

Godinho, A. L. (1996). Peixes do Parque Estadual do Rio Doce. Belo Horizonte: Instituto Estadual de Florestas/Universidade Federal de Minas Gerais, 1, 48.

Gregório, E., Lima, I. P. G. de. (2007). Bacia Hidrográfica do Rio Doce: Informações sobre as bacias dos rios afluentes e seus CBH's (comitês de bacias hidrográficas).

<https://cenfopgeografia.wordpress.com/wp-content/uploads/2010/02/apostila-bacia-do-doce.pdf>

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An Ecosystem Perspective of Riparian Zones. *BioScience*, 41(8), 540–551. <https://doi.org/10.2307/1311607>

Grossman, G. D. (1986). Food resources partitioning in a rocky intertidal fish assemblage. *Journal of Zoology*, 1: 317-355. <https://doi.org/10.1111/j.1096-3642.1986.tb00642.x>

Hill, W. R., Mulholland, P. J., & Marzolf, E. R. (2001). Stream Ecosystem Responses to Forest Leaf Emergence in Spring. *Ecology*, 82(8), 2306–2319.

<https://doi.org/10.2307/2680233>

Hyslop, E. J. (1980). Stomach contents analysis—a review of methods and their application. *Journal of Fish Biology*, 17: 411-429. <https://doi.org/10.1111/j.1095-8649.1980.tb02775.x>

Kaufmann, P. R., Levine, P., Robison, E. G., Seeliger, C., Peck, D. V. (1999). Quantifying physical habitat in wadeable streams. EPA/620/R-99/003.

<https://archive.epa.gov/emap/archive-emap/web/pdf/phyhab.pdf>

Kawakami, E., & Vazzoler, G. (1980). Método gráfico e estimativa de índice alimentar aplicado no estudo de alimentação de peixes. *Boletim Do Instituto Oceanográfico*, 29(2), 205–207. <https://doi.org/10.1590/S0373-55241980000200043>

Kolar, C. S., Lodge, D. M. (2002) Ecological Predictions and Risk Assessment for Alien Fishes in North America. *Science* 298: 1233-1236. DOI: 10.1126/science.1075753

Langeani, F., Castro, R. M. C., Oyakawa, O.T., Shibatta, O. A., Pavanelli, C. S., Casatti, L. (2007). Ichthyofauna diversity of the upper rio Paraná: present composition and future perspectives. *Biota Neotrop* 7:181–197. <https://doi.org/10.1590/S1676-06032007000300020>

- Larentis, C., Kotz Kliemann, B.C., Neves, M.P., Delariva, R.L. (2022) Effects of human disturbance on habitat and fish diversity in neotropical streams. PLoS ONE 17(9): e0274191. <https://doi.org/10.1371/journal.pone.0274191>
- Leitão, R.P., Zuanon, J., Mouillot, D., Leal, C.G., Hughes, R.M., Kaufmann, P.R., Villéger, S., Pompeu, P.S., Kasper, D., de Paula, F.R., Ferraz, S.F.B. and Gardner, T.A. (2018). Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. *Ecography*, 41: 219-232. <https://doi.org/10.1111/ecog.02845>
- Ligeiro, R., Hughes, R.M., Kaufmann, P.R., Macedo, D.R., Firmiano, K.R., Ferreira, W. R. et al. (2013). Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. *Ecol Indic.* 2013; 25:45–57. <https://doi.org/10.1016/j.ecolind.2012.09.004>
- Losos, J. B. (1995). Community evolution in Greater Antillean Anolis lizards: phylogenetic patterns and experimental tests. *Phil. Trans. Royal Soc. Lond. B Biol. Scien.* 349(1327): 69-75. <https://doi.org/10.1098/rstb.1995.0092>
- Maia, C., Salvador, G. N., Begot, T. O., Freitas, P. V., Nonato, F. A. S., Torres, N. R., Juen, L. & Montag, L. F. A. (2022). Fish functional responses to local habitat variation in streams within multiple land uses areas in the Amazon. *Neotropical Ichthyology*, 20(4): e220091. <https://doi.org/10.1590/1982-0224-2022-0091>
- Manna, L., R., Rezende, C. F., Mazzoni, R. (2014). Habitat use by *Astyanax taeniatus* (Jenyns, 1842) (Characiformes: Characidae) in a coastal stream from Southeast Brazil. *Neotropical Ichthyology*, 12(1): 187-192. <https://doi.org/10.1590/S1679-62252014000100020>
- Manna, L. R., Villéger, S., Rezende, C. F., Mazzoni, R. (2019). High intraspecific variability in morphology and diet in tropical stream fish communities. *Ecol Freshw Fish.*, 28: 41–52. <https://doi.org/10.1111/eff.12425>
- Manna, L., Rezende C. F. (2021). Variação intraespecífica em peixes de riacho com ênfase na ecologia trófica. *Oecologia Australis*, 25(2):301–322. <https://doi.org/10.4257/oeco.2021.2502.06>
- Manna, L., Rezende, C., & Mazzoni, R. (2012). Plasticity in the diet of *Astyanax taeniatus* in a coastal stream from south-east Brazil. *Brazilian Journal of Biology*, 72(4), 919–928. doi:10.1590/s1519-69842012000500020
- Mazzoni, R., Nery, L. L. & Iglesias-Rios, R. (2010). Ecologia e ontogenia da alimentação de *Astyanax janaeirensis* (Osteichthyes, Characidae) de um riacho costeiro do Sudeste do Brasil. *Biota Neotropica*, vol. 10, no. 3, p. 53-60. <http://dx.doi.org/10.1590/S1676-06032010000300005>
- Mazzoni, R., Rezende, C. F. (2003). Seasonal diet shift in a Tetragonopterinae (osteichthyes, characidae) from the Ubatiba river, RJ, Brazil. *Braz. J. Biol.*, 63(1): 69-74. <https://doi.org/10.1590/S1519-69842003000100009>
- Mello, K. de, Taniwaki, R. H., Paula, F. R. de, Valente, R. A., Randhir, T. O., Macedo, D. R., ... Hughes, R. M. (2020). Multiscale land use impacts on water quality: Assessment, planning, and future perspectives in Brazil. *Journal of Environmental Management*, 270, 110879. <https://doi.org/10.1016/j.jenvman.2020.110879>

- Meyerson, L. A., D. Simberloff, L. Boardman, J. L. Lockwood. (2019). Toward “Rules” for Studying Biological Invasions. *Bull Ecol Soc Am* 100(4): e01607. <https://doi.org/10.1002/bes2.1607>
- Neves, M.P., Delariva, R.L., Perkins, D.M., Fialho, C.B. and Kratina, P. (2023). Trophic plasticity of omnivorous fishes in natural and human-dominated landscapes. *Limnol Oceanogr*, 69: 189-202. <https://doi.org/10.1002/lno.12467>
- Oliveira, C. W. de S., Corrêa, C. dos S., Smith, W. S. (2020). Food ecology and presence of microplastic in the stomach content of neotropical fish in an urban river of the upper Paraná River Basin. *Rev. Ambient. Água* 15 (4): e255. <https://doi.org/10.4136/ambi-agua.2551>
- Peck, D., Herlihy, A., Hill, B., Hughes, R., Kaufmann, P., Klemm, D., Lazorchak, J., McCormick, F., Peterson, S., Ringold, P., Magee, T., & Cappaert, M. (2006). Monitoring and Assessment Program — Surface Waters Western Pilot Study: field operations manual for wadeable streams. EPA/620/R-06/003. Washington, DC: U.S.Environmental Protection Agency.
- Pianka, E. R. (1973). The Structure of Lizard Communities. *Annual Review of Ecology and Systematics*, 4, 53–74. <http://www.jstor.org/stable/2096804>
- Plano Integrado de Recursos Hídricos da Bacia Hidrográfica do Rio Doce e Planos de Ações para as Unidades de Planejamento e Gestão de Recursos Hídricos no Âmbito da Bacia do Rio Doce - PIRHDOCE. (2010). Volume 1 – Relatório Final. https://www.cbhdoce.org.br/wp-content/uploads/2014/10/PIRH_Doce_Volume_I.pdf
- Rawer-Jost, C., Zenker, A., & Bohmer, J. (2004). Reference conditions of German stream types analysed and revised with macro invertebrate. *Limnologica*, 34(4), 390-397. [https://doi.org/10.1016/s0075-9511\(04\)80008-2](https://doi.org/10.1016/s0075-9511(04)80008-2)
- Sabino, J. & Castro, R.C. (1990). Alimentação, período de atividade e distribuição espacial dos peixes de um riacho de floresta atlântica (sudeste do Brasil). *Rev. Brasil. Zool.* 50(1):23-36.
- Salvador, G. N., Hughes, R. M., Vieira, F., Ligeiro, R., Montag, L. F. A. (2023). Mine tailings storage dams modify upstream headwater fish assemblages. *Freshwater Biology*, 67:1708–1724. <https://doi.org/10.1016/j.watbs.2023.100136>
- Salvador, G. N., Montag, L. F. A., Hughes, R. M., Almeida, S. M., Prudente, B. S., Pessali, T. C., Barroso, T. A., Cianciaruso, M. V., Ligeiro, R., Juen, L., & Carlucci, M. B. (2022). Influences of multiple anthropogenic disturbances coupled with a tailings dam rupture on spatiotemporal variation in fish assemblages of a tropical river. *Freshwater Biology*, 67, 1708–1724. <https://doi.org/10.1111/fwb.13967>
- Schoener, T. W. (1983). Field Experiments on Interspecific Competition. *The American Naturalist*, 122(2), 240–285. <https://doi.org/10.1086/284133>
- Silva, K. R. A. da. (2012). Sobreposição de nicho de duas espécies simpátricas de *Arthrosaura* (Squamata: Gymnophthalmidae), na Floresta Nacional de Caxiuanã, Pará. 40 f. Dissertação (Mestrado) - Curso de Zoologia, Universidade Federal do Pará, Belém - PA.
- Simberloff, D., & Rejmánek, M. (2011). *Encyclopedia of biological invasions*. California: University of California Press. First Edition, 792.
- Smith, W. S., Lima, R. de F., Castelo, N. S. B., Cavallari, D. E., Pinheiro, L. A. S., Soinski, T. A., Stefani, M. S., Oliveira, J. da S., Silva, F. L. da (2022). Peixe e plástico em ecossistemas

de água doce: contribuição da ciência brasileira e pesquisas futuras. In: Pompêo, M., Rani-Borges, B., & Paiva, T. C. B. de. (2022). Microplásticos nos ecossistemas: impactos e soluções. São Paulo: Instituto de Biociências da USP.

Souza, C. P de. (2022). Alterações Da Paisagem São Indicadoras Da Ocorrência De Peixes Não Nativos Na Bacia Do Rio Doce? Dissertação De Mestrado, Programa de Pós-Graduação em Ecologia, Conservação e Manejo da Vida Silvestre do Instituto de Genética, Ecologia e Evolução da Universidade Federal de Minas Gerais.

Souza, C. P. de., Rodrigues-Filho, C. A. de S., Barbosa, F. A. R., & Leitão, R. P. (2021). Drastic reduction of the functional diversity of native ichthyofauna in a Neotropical Lake following invasion by piscivorous fishes. *Neotropical Ichthyology*, 19(3), e210033.

<https://doi.org/10.1590/1982-0224-2021-0033>

Spínola, L. A., & Ferreira Júlio Junior, H. (2007). Espécies invasoras: conceitos, modelos e atributos. *Interciencia*, 32(9), 580-585.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology, *Eos Trans. AGU*, 38(6), 913–920. doi:10.1029/TR038i006p00913.

Teresa, F.B., Casatti, L. (2013). Development of habitat suitability criteria for neotropical stream fishes and an assessment of their transferability to streams with different conservation status. *Neotrop. Ichthyol.* 11:395–402 <https://doi.org/10.1590/S1679-62252013005000009>

Toft, C. A. (1985). Resource Partitioning in Amphibians and Reptiles. *Copeia*, 1985(1), 1. <https://doi.org/10.2307/1444785>

Tuomisto, H. e Ruokolainen, K. (1997). The role of ecological knowledge in explaining biogeography and biodiversity in Amazonia. *Biodiversity and Conservation* 6, 347-357. <https://doi.org/10.1023/A:1018308623229>

Urbanski, B.Q., Denadai, A.C., Azevedo-Santos V.M., and Nogueira, M.G. (2020). First record of plastic ingestion by an important commercial native fish (*Prochilodus lineatus*) in the middle Tiete River basin, Southeast Brazil. *Biota Neotropica* 20: e20201005. <https://doi.org/10.1590/1676-0611-BN-2020-1005>

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. (1980). The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences*. 37(1): 130-137. <https://doi.org/10.1139/f80-017>

Vitule, J. R. S., Freire, C. A., & Simberloff, D. (2009). Introduction of non-native freshwater fish can certainly be bad. *Fish and fisheries*, 10(1), 98-108. <https://doi.org/10.1111/j.1467-2979.2008.00312.x>

Vitule, J. R. S., Prodócimo, V. (2012). Non-native species introduction and biological invasions. *Estud. Biol., Ambiente Divers*, 34(83), 225-237. <https://doi.org/10.7213/estud.biol.7335>

Wang, J., Jiang, R-J., Xiao, Y., Yin, R., Chen, F., Zhou, Y-d., Xu, H-X. (2022). Trophic Niche Partitioning of Five Sciaenidae Species Sampled in Zhoushan Archipelago Waters via Stable Isotope Analysis. *Front. Mar. Sci.* 9:880123.

Wang, L., Seelbach, P., Hughes, R. (2006). Landscape Influences on Stream Habitats and Biological Assemblages. *American Fisheries Society Symposium*, 48 :1–23.

- Wang, Y., Tan, W., Li, B., Wen, L., & Lei, G. (2021). Habitat alteration facilitates the dominance of invasive species through disrupting niche partitioning in floodplain wetlands. *Diversity and Distributions*, 27, 1861–1871. <https://doi.org/10.1111/ddi.13376>
- Woodward, G., Hildrew, A. G. (2002). Food web structures in riverine landscapes. *Freshw. Biol.* 47:777–798. <https://doi.org/10.1046/j.1365-2427.2002.00908.x>
- Wootton, R. J. (1998) *Ecology of Teleost Fishes*. Kluwer. Dordrecht, Holandia. 386 pp.
- Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environmental pollution* (Barking, Essex: 1987), 178, 483–492. <https://doi.org/10.1016/j.envpol.2013.02.031>
- Zhang, J. (2016). *Species Association Analysis: Miscellaneous functions for analysing species association and niche overlap*. DOI:10.32614/CRAN.package.spaa

SUPPLEMENTARY MATERIAL

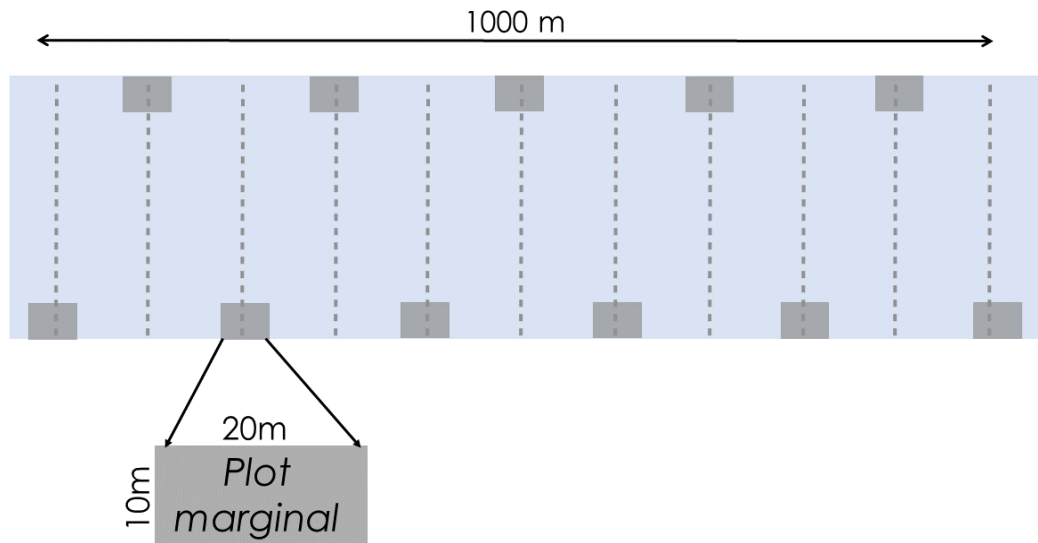


Figure A1. Demonstration of the 11 marginal plots where information on environmental variables and fish collection was obtained in river sites in the Rio Doce basin.

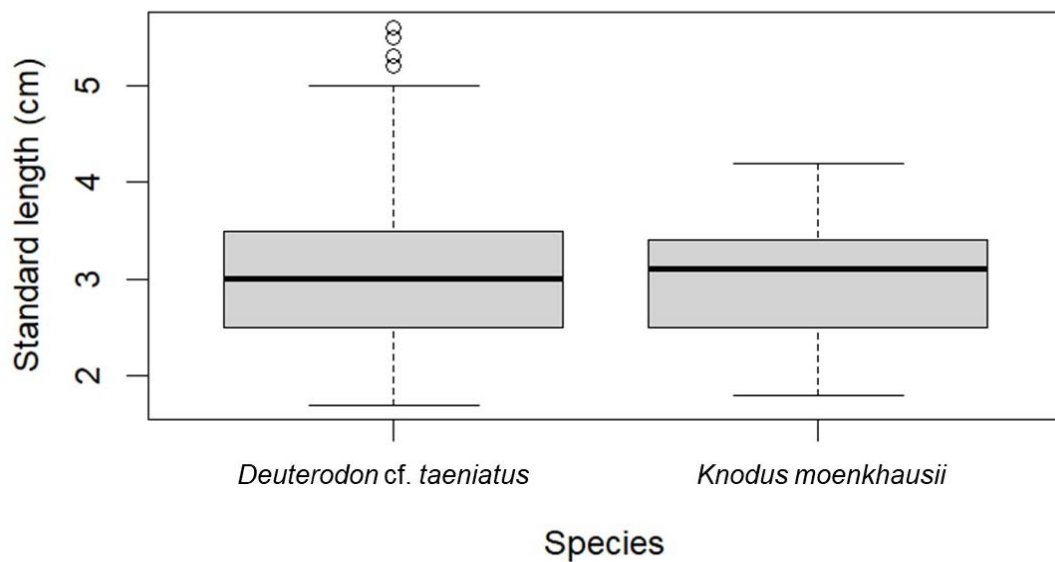


Figure A2. Standard length (cm) of the native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* from the Rio Doce Basin, Brazil. There was no difference in size between the specimens analyzed ($F(1,323) = 3.389, p = 0.06$).

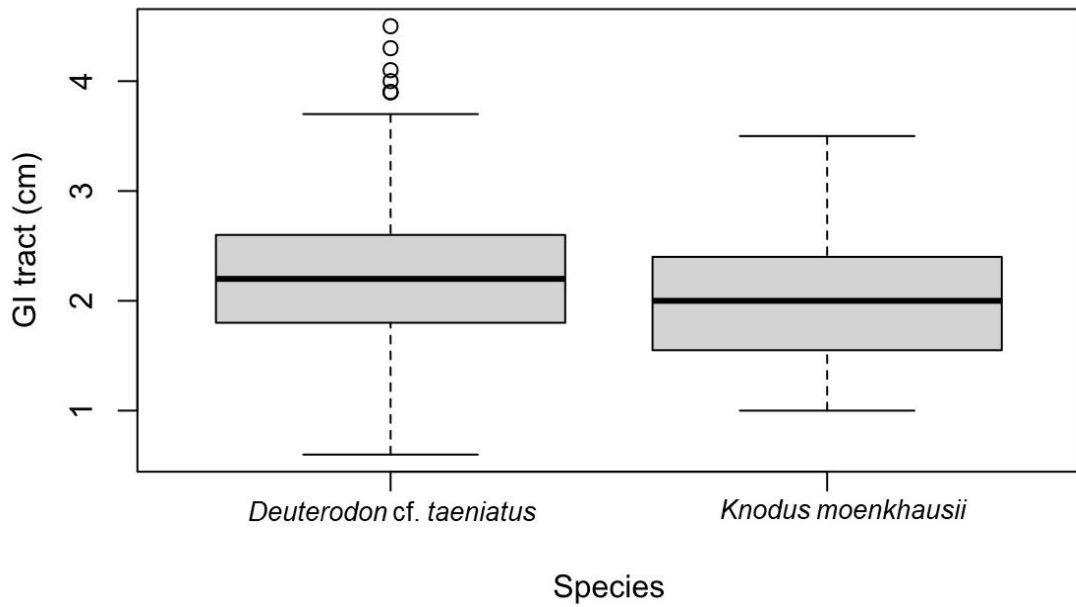


Figure A3. Gastrointestinal tract (cm) of the native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* from the Rio Doce Basin, Brazil. There was a difference in the size of the tract between the specimens analyzed ($F(1,323) = 10.935, p = 0.001^*$).

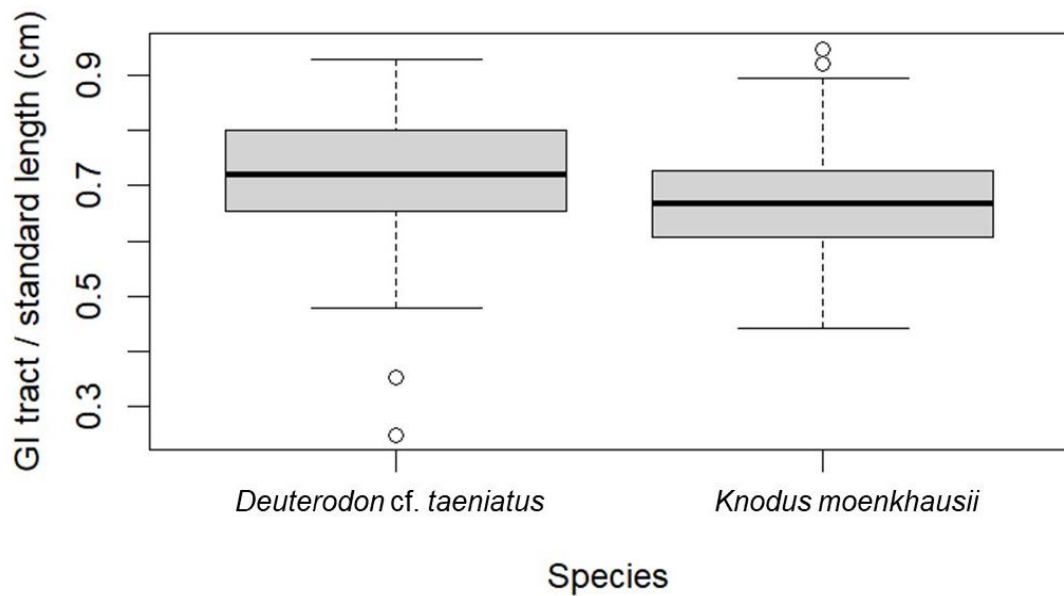


Figure A4. The ratio between gastrointestinal tract size and standard length (cm) of the native fish *Deuterodon cf. taeniatus* and the non-native fish *Knodus moenkhausii* from the Rio Doce Basin, Brazil. There was a difference in the size of the tract in relation to the size of the body between the specimens analyzed ($F(1,323) = 15.992, p < 0.001^*$).

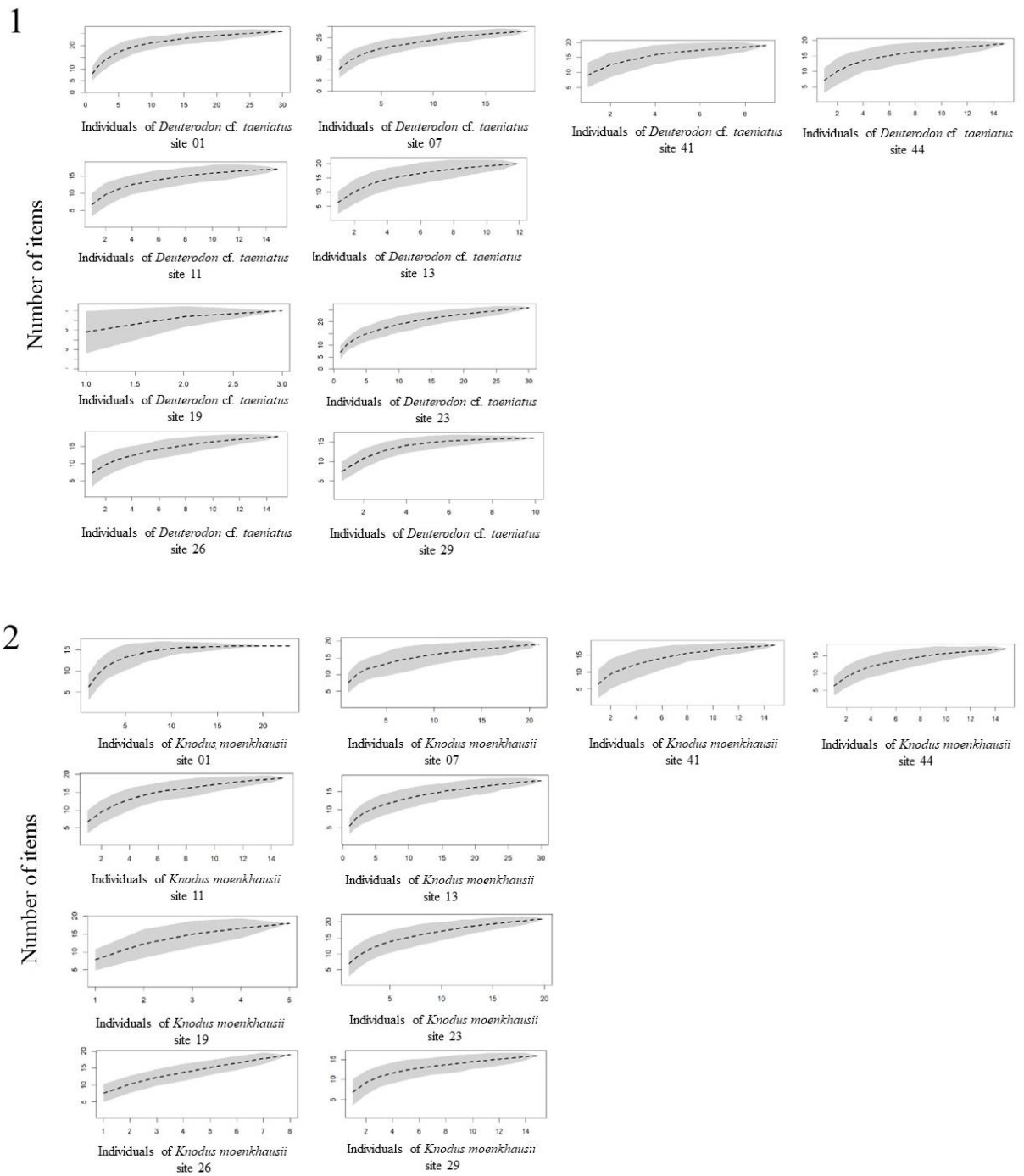


Figure A5. Accumulation curves of food items consumed in each studied site in the Rio Doce basin, by the two characid fish species: (1) *Deuterodon cf. taeniatus* and (2) *Knodus moenkhausii*.