（ 続紙 1 ）

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論文題目	Trophic ecology of Japanese eels (*Anguilla japonica*) in river habitats with implications for the conservation of an endangered species （河川に生息するニホンウナギ（*Anguilla japonica*）の食物網解析による保全生態学的研究）		

（論文内容の要旨）

Declining wild Japanese eel (*Anguilla japonica*) populations led to the introduction of the species to the IUCN Red list as an endangered species. Conservation efforts need to address the current threats to the species (e.g. habitat fragmentation, water pollution, and overexploitation) and rely on a profound understanding of eel ecology, as well as suitable monitoring tools. The growth phase (yellow phase) of eels in continental waters represents the longest period in the eel life cycle and is crucial for the accumulation of energy reserves for the long oceanic spawning migration. Rivers provide key habitats during this time, in which eels distribute from brackish water to upstream freshwater areas. Due to their position as top predators in the riverine food web, as well as their long residency and broad habitat use in rivers, eels are considered a surrogate species for the conservation of riverine biota and restoration of riverine habitats. This thesis aimed to assess the trophic ecology of Japanese yellow-phase eels in rivers, adding to the understanding of the species ecology, and to introduce recent analysis methods of stable isotopes as monitoring tools for species and habitat management. The objectives of this thesis were the following; (1) The analysis of foraging behavior of yellow-phase Japanese eels in connected fresh- and brackish water habitats in rivers and the connection of foraging behavior, and habitat use through the analysis of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes of eels and their potential food sources. (2) The assessment of the dietary diversity and trophic niche width of different size classes of Japanese eels (≤250 mm total length and >250mm total length) in small rivers of urban and agricultural areas through the analysis of $\delta^{13}C$ and $\delta^{15}N$ of eels and their potential food sources, and therefore the evaluating the quality of riverine environments as eel habitats. (3) Furthermore, this thesis aimed to improve and ease the methodology of stable isotope analysis on eels by assessing the effects of chemical lipid-extraction on the stable isotope values of different tissues from Japanese eels and normalizing the ^{13}C depletion in lipid-rich tissue through mathematical solution and proposing non-lethal sampling methods for stable isotope studies on eels, through the estimation of isotopic turnover rates and trophic discrimination factors of epidermal mucus of eels.

The second chapter of this thesis assessed the foraging and food sources of yellow-phase eels between connected fresh- and brackish water habitats of three rivers through the analyses of stomach contents and stable isotopes. The predictable depletion in ^{13}C (relative to ^{12}C) from marine to freshwater habitats in rivers was used to infer the foraging behavior of eels and showed plasticity, as eels utilized fresh- and/or brackish water sites, or frequently moved between both habitats. The study implied the importance of riverine habitat connectivity during the growth phase of eels and provided a tool that allows the connection of habitat use and trophic ecology.

In the third chapter, the trophic niche width and trophic niche overlap of different size classes of eels (≤250 mm and >250 mm in total length) were assessed, utilizing stomach content and stable isotope analysis. The study was performed in two small rivers (< 15 km length) running through paddy or urban areas; as such rivers have great potential for habitat restoration

and species management. Trophic niche width and niche overlap of eels were shown to differ according to abiotic and biotic habitat conditions, indicting varying habitat suitability for different size classes of eels. As the trophic niche width reflects the diversity of energy sources assimilated by a consumer, it would pose a powerful indicator of habitat connectivity and species resilience to changing environmental conditions.

The fourth chapter studied the improvement of methodology for stable isotope analysis. Stable isotope analysis commonly relies on the usage of white muscle tissue, representing a lethal-sampling method which is conflicting with long-term monitoring, and the work on endangered species. Therefore, epidermal mucus of eels was tested; in a laboratory feeding experiment with small eels (<120 mm in total length); as a possible surrogate tissue, allowing a non-lethal and repeated sampling. Isotopic turnover rates and trophic discrimination factors of eel mucus were estimated using growth- and time-based models, allowing its future application in stable isotope studies on eels. Furthermore, the effects of chemical lipid-extraction on different eel tissues were tested, and were proposed to be replaced by a time-saving arithmetically correction based on C:N ratios of samples.

In conclusion, the results of this study contributed to the understanding of the trophic ecology of yellow-phase Japanese eels in rivers, and introduced analyses of nitrogen and carbon stable isotopes as possible monitoring tools for the management and conservation of this endangered species. The use of epidermal mucus of eels for stable isotope studies was promoted through the first estimation of trophic discrimination factors and turnover rates of mucus and would allow the application of non-lethal sampling methods in the future, as well as repeated-measure studies. The establishment of monitoring tools is crucial for the success of management efforts such as habitat restorations and species conservation, such measures should be stepwise-adaptive and process-orientated. Furthermore, small rivers in urban and agricultural areas were discussed to hold great potential for future eel habitat restoration projects.

（ 続紙 ２ ）

（論文審査の結果の要旨）

ニホンウナギ（以下ウナギ）は西マリアナ海嶺南部海域で産卵し、葉型仔魚は黒潮により我が国沿岸まで輸送され、冬春季にシラスウナギとして多くが河川に遡上する。我が国の天然ウナギの漁獲量は、1960 年代の約 3,000 トンから近年は 100 トン未満まで減少し、2014 年に IUCN により絶滅危惧種（EN）に指定された。ウナギの多くは産卵回遊までの間河川で長期間生活することから、河川に生息するウナギの生態の解明と好適な環境の保全は、ウナギ資源の再生のために不可欠である。本研究は、福島県と和歌山県に注ぐ河川をフィールドとして、河口汽水域から河川中流域に生息するウナギの摂餌生態と食物網構造を炭素・窒素安定同位体比分析などにより詳細に解析し、本種資源の回復方策につながる重要な知見を提示した。本論文の評価すべき点は以下の通りである。

１．ウナギは汽水域と淡水域の間を広く索餌移動するが、横断構造物のある河川では構造物により索餌域が限定されており、本種の生息にとって、海から河川中流域まで生物の移動を阻害しない連続性の重要性が示された。
２．我が国の小河川には未だに多くのウナギが生息することを明らかにした。ウナギは富栄養環境に対する耐性が高く餌生物の範囲が広いゼネラリストであることから、河口からの移動、隠れ場、餌生物、溶存酸素濃度などの条件が満たされれば、本種は多様な河川に生息して成長できることがわかった。これらの結果から、都市を流れる河川や護岸された水田の用水路においても、好適な環境を再生することによってウナギ資源の回復に貢献できる可能性が示された。
３．ウナギの食性の解明と環境への適応度のモニタリング手法としての炭素・窒素安定同位体比分析の有効性を明らかにした。さらに、飼育実験により体表粘液の炭素・窒素安定同位体比が食性解析に有効であることをウナギで初めて示し、絶滅危惧種であるウナギを殺すことなく炭素・窒素安定同位体比分析を行う手法を開発した。

以上のように、本論文は日本の食文化において重要な位置を占めているにもかかわらず、資源が急激に減少しつつあることから社会的にも注目されているニホンウナギの摂餌生態を解明し、本種資源の保全と再生につながる環境と生態系の回復方策のための重要な知見を提示しており、水産学、水産資源生態学、森里海連環学、地球環境学の分野に寄与するところが大きい。

よって本論文は博士（地球環境学）の学位論文として価値あるものと認める。また、令和３年２月５日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。

なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公開可能日：　　年　　月　　日以降