Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Ocean predators as sentinel species for detecting nano- and microplastic prevalence in pelagic food webs

Jay R Rooker

rookerj@tamug.edu

Texas A&M University

Karl Kaiser

Texas A&M University

RJ David Wells

Texas A&M University

Michelle Zapp Sluis

Texas A&M University

M Bryan Gahn

Texas A&M University

Alexandra Prouse

Texas A&M University

Alejandro Acosta

Florida Fish and Wildlife Conservation Commission

Piero Addis

University of Cagliari

Michael A Dance

Louisiana State University

Beatrice Padovani Ferreira

Federal University of Pernambuco

Manel Gazo

University of Barcelona

Bonnie J Holmes

University of the Sunshine Coast

Sebastian Jaquemet

UMR ENTROPIE

Chi-Ju Yu

National Taiwan Ocean University

Shoou-Jeng Joung

National Taiwan Ocean University
Firdes Saadet
Istanbul University
Daniel L Lippi
Federal University of Pernambuco
Julian Pepperell
Pepperell Research and Consulting Pty Ltd
Landes L Randall
Texas A&M University
Phillip J Sanchez
Smithsonian Tropical Research Institute
Brad L Smith
Brigham Young University - Hawaii
Owyn E Snodgrass
Southwest Fisheries Science Center
Ryan M Tharp
North Carolina State University
Anna Traina
National Research Council

Article

Keywords: microplastics, pelagic ecoystem, tuna, highly migratory species, biomagnification

Posted Date: July 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10045122/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Scientific Reports on October 6th, 2026. See the published version at https://doi.org/10.1038/s41598-026-72552-5.

Abstract

Quantifying nano- and microplastics (NMPs) in ocean predators is fundamental to understanding the prevalence of these contaminants and potential impacts on ecosystem health. Pyrolysis gas chromatography tandem mass spectrometry with lipid correction was used to determine NMP concentrations and polymer composition in the muscle tissue of two pelagic predators (dolphinfish [*Coryphaena hippurus*], yellowfin tuna [*Thunnus albacares*]) across the Atlantic, Pacific, and Indian Oceans. Species-specific differences in NMP concentrations were observed, with body burdens often markedly lower in yellowfin tuna relative to dolphinfish within regions or ocean basins. Differences in NMP concentrations were evident among ocean basins for both species while intra-ocean variation within the Atlantic Ocean or Pacific Ocean was more limited. Polyethylene was the dominant polymer present in the muscle tissue of both species followed by nylon-66, polypropylene, and polyvinyl chloride. Spatial variaton in polymer composition and NMP concentrations was reflective of regional plastic emissions and may serve as indicators of an individual's geographic origin and environmental history. No relationship between NMP body burden and trophic position was observed for either species. Trophic position of yellowfin tuna was consistently higher than dolphinfish in nearly all regions examined despite displaying lower NMP concentrations. Our findings establish that NMPs are pervasive in top predators in the ocean and represent a far-reaching threat to marine ecosystems.

Introduction

The production of synthetic plastics contributes significantly to environmental pollution in marine ecosystems (De Souza Machado et al. 2018, Enri-Cassola et al 2019). Pathways of plastics entering oceans are varied and originate from both terrestrial and marine sources including river runoff, atmospheric transport, shipping, fishing activities, and illegal dumping (GESAMP 2016, Schmidt et al. 2017, Lebreton et al. 2017, Pabortsava et al. 2020). Degradation and fragmentation of many larger (macro-) plastics by photolysis (sunlight/UV radiation), biodegradation (microorganisms), and mechanical processes (Dimassi et al. 2022) lead to the formation of nano- (< 1 um) and microplastics (1 um to 5 mm) (hereafter NMPs), which are increasingly implicated as contaminants of emerging concern (CECs) (Lambert and Wagner 2018, Stapleton and Hai 2023). A wide variety of NMP polymers are common in marine environments throughout major ocean basins (Coyle et al. 2020), and these synthetic compounds represent significant threats to marine ecosystems, often altering processes at the base of the food web. These ecological alterations include reductions in phytoplankton production and shifts in community structure of autotrophs (Mao et al. 2018, Hitchcock 2022) as well as decreases in grazing rates by secondary consumers (i.e., zooplankton) (Botterell et al. 2019). NMPs also have the capacity to adsorb and concentrate other environmental CECs (e.g., per- and polyfluoroalkyl substances, PFAS), releasing them into the tissues of consumers, which can result in negative additive or synergistic effects on predators and associated fauna (Soltanighias et al. 2024).

All tropic levels of marine food webs, ranging from autotrophs to apex predators, are exposed to varying levels of NMPs (Sethia et al. 2024). These contaminants regularly enter food webs via primary

consumers (i.e., herbivores) such as zooplankton or through small planktivorous fishes (Malinowski et al. 2023). Bioaccumulation and biomagnification of contaminants, including NMPs, has been linked to both predator size/age and their trophic position, with larger, older, and higher trophic-level consumers often displaying elevated contaminant body burdens (Akhbarizadeh et al. 2019, Parolini and Romano 2024). As a result, higher order consumers (i.e., top predators) with greater NMP exposure may be at an elevated risk of metabolic and neurodevelopmental disorders, depleted energy stores, reduced fertility, and lower growth rates (Coyle et al. 2020, Barceló et al. 2023). All of which can compromise the health and survival of top predators, potentially causing cascading effects through food webs that may alter the function and resiliency of marine ecosystems (Galloway et al. 2017). Apart from potential ecological consequences, many top predators found in open ocean ecosystems are large pelagic fishes that are important components of regional fisheries and readily consumed by humans (Justino et al. 2023), possibly resulting in adverse effects on human health (Huang et al. 2021, Li et al. 2023, Persiani et al. 2023).

A significant fraction of top predators found in tropical and temperate oceans are highly migratory, and thus these taxa serve as conduits for the wider dispersal (transport) of NMPs across ecosystems and ocean basins. Here, we characterize ocean-scale variability in NMP concentration and polymer composition of circumglobal pelagic fishes from multiple regions in the Atlantic, Pacific, and Indian Oceans. Two species with cosmopolitan distributions and common consistituents of pelagic food webs were selected for this investigation: dolphinfish (*Coryphaena hippurus*) and yellowfin tuna (*Thunnus albacares*). The central aim of this investigation was to characterize inter- and intra-ocean basin trends in NMP concentrations in the muscle tissue of these predators using a novel analytical approach that applies pyrolysis gas chromatography coupled with triple quadrupole mass spectrometry (Py-GC-qQq-MS) to quantify NMP concentrations and polymer types in muscle tissue (Gahn et al. 2026). The Py-GC-qQq-MS approach is a significant advancement over traditional microscopic and spectroscopic assessments since it provides a time-integrated measure of NMPs in biological tissue (muscle) rather than a snapshot from particle counts of NMPs present in the digestive tract of these predators. In addition to characterizing species- and region-specific trends in NMP concentration and polymer composition, we investigated the relationship between NMP body burden and trophic position of these predators by using compound-specific stable isotope analysis of amino acids (CSIA-AA) in $\delta^{15}N$ ($\delta^{15}N_{AA}$). The inclusion of both large pelagic species with varied life history and foraging traits across major ocean basins will help elucidate the pervasiveness of NMPs in open ocean food webs, while also serving as critical baselines for future investigations of NMP exposure of top predators.

Materials and Methods

Sample collections

Dolphinfish and yellowfin tuna were collected from five regions in both the Atlantic Ocean and Pacific Ocean, and a single region in the Indian Ocean. Samples were collected from 2021–2024 by recreational,

artisanal, and commercial anglers from the 11 regions. All muscle tissue was procured from port sampling harvested (dead) fish. In the Atlantic Ocean, regions included the Northwest Atlantic Ocean, Equatorial Atlantic Ocean, Caribbean Sea, and two marginal seas (Gulf of Mexico and Mediterranean Sea) (Table 1). Five regions were also sampled in the Pacific Ocean: Northwest Pacific Ocean, Northcentral Pacific Ocean, Northeast Pacific Ocean, Equatorial Pacific Ocean, and South Pacific Ocean. One region was sampled in the Southwest Indian Ocean. Regional samples (6 per region and species) were typically comprised of individuals from multiple sampling location, and larger specimens (adults) were targeted to minimize the influence of size on NMP concentrations for each species (Table 1). Apart from yellowfin tuna being absent from one region (Mediterranean Sea), our sampling design was balanced across regions and species. Muscle tissue was typically sampled from the anterior dorsal area of each specimen and kept on ice and stored at -20°C until samples were freeze-dried.

Nano/Microplastic (NMP) Quantification

An accelerated solvent extraction (ASE) system (Dionex ASE 350) was used to determine total lipid content in freeze-dried muscle tissue. An extraction filter (Dionex, ThermoFisher Scientific) was placed at the bottom of a clean stainless-steel ASE extraction cell (34 ml) and ground muscle tissue (~ 25 mg) was added to the cell with sand used to fill the void space. Next, a mixture of dichloromethane and hexane (1:1) at 100^{o}C and 1500 psi was used for the extraction. For each muscle tissue sample, extraction involved a 5-min preheating phase, 5-min heating phase, two 20-min static periods with 40% rinse, followed by a 5-min purge. Recovered solvent extracts were collected in amber glass vials and allowed to evaporate to dryness under a fume hood. Before and after weights of glass vials were used to calculate tissue lipid content (% of dry weight).

Freeze-dried muscle tissue for all individuals was digested using porcine pancreatic enzyme (Pez) combined with tris hydrochloride solution (Tris) (Gahn et al. 2026). The combined Pez/Tris solution served to dissolve the muscle tissue matrix, releasing NMPs for quantification. Digested samples were then subjected to vacuum filtration through a combusted glass fiber filter (0.7 µm), which was rinsed with milli-Q water and dried for approximately 24 hours at 38°C. Dried filters were then folded and placed in pyrolysis stainless steel cups pretreated with the internal standard poly(4-fluorostyrene) (PFS) and topped with 5 mg of $CaCO_3$ and quartz wool in preparation of pyrolysis gas chromatography. NMPs were quantified using a Frontier Auto-Shot AS-2020E sampler and EGA/PY 3030D multi-shot pyrolyzer coupled with an Agilent 8890 gas chromatograph and Agilent 7010B triple quadrupole mass spectrometer (Py-GC-qQq-MS). Pyrolyzates were chromatically separated on an ultra-alloy capillary column before being introduced to the MS detector. Injector split ratio, split flow, temperature, and purge flow followed the previously established protocol (Gahn et al. 2026).

The MS detector was regularly autotuned using Agilent ChemStation software (V. 10) and quantification of NMP polymers was based on dynamic multiple reaction monitoring (dMRM) using characteristic product ions. Calibration standards were a homogenous mixture of Frontier plastic polymers (Frontier

Labs, Lot # 21101501) and inert $CaCO_3$ and quartz wool fillers, which were used to improve combustion efficiency and reduce char build-up. The Py-GC-qQq-MS approach was used to quantify 11 commonly quantified polymers in the muscle tissue of the four pelagic fishes: acrylonitrile butadiene styrene (ABS), nylon-66 (N66), nylon-6 (PA), polycarbonate (PC), polyethylene (PE), polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), polypropylene (PP), polystyrene (PS), polyurethane (PUR), and polyvinyl chloride (PVC).

Accurate identification of NMPs relied on detailed quality assurance and quality control protocols. Lipid interference in NMP quantification with Py-GC-qQq-MS can occur (Monikh et al. 2025, Rauert et al. 2025) and, as a result, NMP concentrations were corrected by applying a mathematical lipid correction method based on total lipid content (Gahn et al. 2026). After correction, method accuracy established with co-spiked NMP standards ranged from 94–111% for N66, PE, PP, and PVC (N66 95 ± 17%, PE 111 ± 11%, PP 102 ± 5%, PVC 94 ± 7%), indicating applied lipid corrections were appropriate.

Trophic Position

Compound-specific stable isotope analysis of amino acids (CSIA-AA) in $\delta^{15}N$ ($\delta^{15}N_{AA}$) was used to estimate trophic position of each fish in relation to NMP concentration in their muscle tissue. CSIA-AA of $\delta^{15}N_{AA}$ was quantified using a Thermo Trace GC 1310 gas chromatograph coupled to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer via a GC IsoLink II combustion interface (GC-C-IRMS; Thermo Fisher Scientific, Waltham, MA) at the University of California Davis Stable Isotope Facility (UCD-SIF) (Yarnes and Herszage 2017). Nitrogen isotope ratios of amino acids were reported using delta notation (Eq. 1), where R_{Sample} represents the ratio of the heavy to light nitrogen isotope in the sample and $R_{Standard}$ represents the ratio of the heavy to light nitrogen isotope in the standard for each amino acid quantified.

$$\delta^{15}N_{AA}\ (‰) = [R_{Sample} / R_{Standard}] - 1 \times 1000 \quad (1)$$

Delta values were reported relative to internal standards: norleucine and amino acid reference mixtures developed by UCD-SIF. The mean standard deviation for reference materials was 0.66‰.

Trophic position was estimated using $\delta^{15}N_{AA}$ weighted means of select source (glycine, lysine, phenylalanine) and trophic (alanine, glutamic acid, leucine) amino acids (Nielsen et al. 2015). We utilized the CSIA-AA trophic position method previously described (Bradley et al. 2025), which applied updated trophic discrimination factor and reduced variation in trophic position estimates by including multiple source and trophic amino acids. Trophic position was estimated using Eq. 2, where λ represents the trophic level of primary producers, β represents the isotopic difference between $\delta^{15}N_{Trophic}$ and $\delta^{15}N_{Source}$ in primary producers, and Δ represents the difference in enrichment factors between $\delta^{15}N_{Trophic}$ and $\delta^{15}N_{Source}$ with each trophic level. λ, β, and Δ were set to 1, 3.6, and 5.7, respectively.

Trophic Position = $\lambda + (\delta^{15}N_{Trophic} - \delta^{15}N_{Source} - \beta) / \Delta$ (2)

Data Analysis

Analysis of variance (ANOVA) was used to test for regional differences in NMP concentrations of selected species, with reported ΣNMP representing the summed concentration (μg g^{-1} dry weight [DW]) of the five primary NMP polymers quantified for each individual fish. Significant findings were further evaluated using Tukey HSD to determine factor levels (i.e., regions) that were significantly different from one another. Since samples were purposely restricted to adults within a limited size range for each species, variation in fish size was limited and no adjustment was performed for size differences among regions. Pearson's correlation coefficients were also calculated based on concentrations of the five primary polymers found in the muscle tissue of dolphinfish and yellowfin tuna to determine relationships between NMP polymers. Canonical discriminant analysis (CDA) was used to display multivariate NMP means in a reduced space with CDA biplot vectors included to show the influence of specific polymers on ocean-basin association. Quadratic discriminant function analysis (QDFA) was then used to determine the classification accuracy of individuals to their respective ocean basin using their NMP signature. QDFA was applied to NMP data since it does not require the homogeneity of covariance matrices assumption among regions, and it is relatively robust to moderate deviations from normality. The relationship between ∑NMP and CSIA-AA based trophic position was evaluated for each species separately using standard least squares regression analysis with significance defined slopes significantly different from zero. Only individual fish with paired values of ∑NMP and CSIA-AA based trophic position were used to develop species-specific relationships, which reduced the sample size of dolphinfish included for this analysis. For all statistical testing, α was set at 0.05.

Results

Eleven NMPs were identified in the tissue of pelagic fishes using Py-GC-qQq-MS, with five polymers, polycarbonate (PC), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), nylon-66 (N66), accounting for over 99% of the total NMP concentration detected across all regions and between species (Table 1). Moreover, PC, PE, PP, PVC, and N-66 were commonly present in the muscle tissue of both species (> 50% frequency of occurrence), with PE and N66 detected in 89.8% and 98.4% of the individual fish assayed, respectively (Table S1). Concentrations of the remaining six NMP polymers were often negligible, and frequency of occurrence was relatively low and highly variable across regions and species: acrylonitrile butadiene styrene (ABS; 0.0%), nylon-6 (PA; 13.3%), polyethylene terephthalate (PET; 12.5%), polymethyl methacrylate (PMMA; 14.1%), polystyrene (PS; 35.2%), and polyurethane (PUR; 0.0%) (Table S1). Given that PC, PE, PP, PVC, N-66 were consistently detected in both species and comprised the bulk of NMP concentration, characterization and analysis of species- and region-specific variation in NMP body burdens focused on these five polymers.

Species- and region-specific differences in ∑NMP concentration (μg g^{-1} DW) based on the sum of the five polymers (PC, PE, PP, PVC, N66) were present both within and across ocean basins (Table 1). Muscle

tissue ∑NMP concentrations (± 1 SD) of dolphinfish varied significantly by region in the Atlantic Ocean (ANOVA, $p < 0.01$), with significantly lower body burdens observed for individuals from the Gulf of Mexico (6,227 ± 2,048 μg g^{-1} DW; Tukey HSD < 0.05) (Table 1). ∑NMP concentrations in dolphinfish for four other regions sampled in the Atlantic Ocean (Northwest Atlantic Ocean, Equatorial Atlantic Ocean, Caribbean Sea, Mediterranean Sea) were generally twofold higher than the Gulf of Mexico with mean concentrations between approximately 14,000 and 16,000 μg g^{-1} DW. Similarly, region-specific differences in ∑NMP concentrations were detected in the Pacific Ocean (ANOVA, $p < 0.01$), with dolphinfish from the Northcentral and Equatorial regions of the Pacific Ocean displaying significantly lower ∑NMP concentrations (6,272 ± 2,516 and 6,996 ± 2,343 μg g^{-1} DW, respectively) than other regions sampled in the Pacific Ocean (Tukey HSD, $p < 0.05$). The highest ∑NMP values were observed in the Northwest Pacific, with the mean concentration higher here (18,842 ± 9,887 μg g^{-1} DW) than 10 other regions sampled. ∑NMP concentrations for the one region sampled in the Southwest Indian Ocean (6,390 ± 1,525 μg g^{-1} DW) was comparable to the lowest body burdens observed in both the Atlantic and Pacific Oceans.

Distinct regional differences in muscle tissue ∑NMP concentrations of yellowfin tuna were also present for individuals collected in the Atlantic and Pacific Oceans (ANOVA $p < 0.01$, Table 1), with trends consistent with regional patterns observed for dolphinfish. Mean ∑NMP concentrations (± 1 SD) of individuals sampled from the Gulf of Mexico (2,343 ± 3,111 μg g^{-1} DW) and Northcentral Pacific (917 ± 519 μg g^{-1} DW) regions again displayed significantly lower mean ∑NMP body burdens relative to other regions sampled within each respective ocean (Tukey HSD $p < 0.05$). Yellowfin tuna from two of the four other regions sampled in the Atlantic Ocean (Northwest, Northcentral) were found to have markedly higher ∑NMP concentrations, with means values of yellowfin tuna in each region over 5,000 μg g^{-1} DW. In the Pacific Ocean, yellowfin tuna from the Northeast region had the highest and most variable ∑NMP mean concentration (12,241 ± 11,801 μg g^{-1} DW). Interestingly, yellowfin tuna from the Northwest region, which was found to have the highest ∑NMP concentration for dolphinfish, displayed relatively low body burdens of ∑NMPs for yellowfin tuna (1,785 ± 1,476 μg g^{-1} DW). In the Indian Ocean, yellowfin tuna from the one region sampled had higher ∑NMP body burdens (8,274 ± 11,620 μg g^{-1} DW) than mean values observed for both the Atlantic and Pacific Oceans (Table 1).

Regional variation in percent composition of the five primary NMP polymers (PC, PE, PP, PVC, N-66) highlighted the dominance of PE and N66 in the body burdens of both species. For dolphinfish, PE was the dominant polymer detected, accounting for the largest fraction of the mean NMP concentration (pooled regions) in the Atlantic (65%), Pacific (60%), and Indian (43%) Oceans (Fig. 1). N66 was the second most abundant polymer in the muscle tissue of dolphinfish from the Atlantic (16%) and Pacific (21%) Oceans, ranging from 15% in the Northwest Atlantic to 35% in the Northcentral Pacific. N66 accounted for the highest fraction of NMP polymers for dolphinfish in the Indian Ocean (45%), with percent composition of this polymer similar to PE. For yellowfin tuna, PE again accounted for the largest fraction of quantified polymers in the Atlantic (44%), Indian (61%), and Pacific (53%) Oceans; however, PE contribution to overall polymer composition was more variable among regions sampled in both the

Atlantic and Pacific Oceans. Overall mean percent composition of N66 in yellowfin tuna was relatively consistent among the three oceans (range: 30 to 32%), but variable among the regions sampled within the Atlantic and Pacific Oceans; lowest and highest contributions of this polymer were observed for individuals from the Northcentral Pacific (8%) and Northwest Pacific (50%), respectively. For both dolphinfish and yellowfin tuna, percent composition of PP and PVC was minor to modest, with PP typically accounting for a larger percentage of the NMP body burden than PVC. PC was consistently present in the muscle tissue of both species but at low concentrations and often only accounted for 1–2% of total NMP body burden.

Relationships among the five primary NMP polymers in the muscle tissue of both dolphinfish and yellowfin tuna was investigated, and significant correlations between polymer types were observed (Pearson's $p < 0.05$; Fig. 2). For dolphinfish, paired comparisons between NMP polymers resulted in several significant correlations and all were positive. The strength of associations between NMP polymers was highest between PE and PP (0.79), with moderately strong correlations present for PE – PVC, N66 – PE, N66 – PP (0.4–0.6). PVC was significantly correlated with three of four polymers, albeit the strength of the relationships was less than 0.4 for both N66 and PP. Significant correlations between NMP polymers were also detected for yellowfin tuna, with most paired comparisons resulting in significant, positive correlations. The strongest associations across the five polymers for yellowfin tuna were observed between N66 – PE (0.81), N66 – PP (0.71), and PE – PP (0.64). PVC was significantly correlated with the same three polymers observed as significant for dolphinfish, but again the strength of the relationships for yellowfin tuna was less than 0.4 for both N66 and PC.

Quadratic discriminant function analysis (QDFA) parameterized with NMP concentrations of PC, PE, PP, PVC, and N66 as covariates from all regions in the Atlantic, Pacific, and Indian Oceans were run to determine whether NMP signatures of individual dolphinfish and yellowfin tuna sampled from the three ocean basins were distinct. Cross-validated classification success to the three ocean basins based on NMP concentrations (i.e., polymer signatures) was modest at 68% for dolphinfish and 58% for yellowfin tuna. Nevertheless, multivariate NMP means and 95% confidence intervals from CDA were distinct among individuals from the three ocean basins for both dolphinfish and yellowfin tuna (Fig. 3). For dolphinfish, discrimination of Indian Ocean samples was strongly influenced by N66, while discrimination of individuals sampled from the Atlantic and Pacific Oceans was influenced primarily by PE, PVC, and N66. For yellowfin tuna, discrimination of individuals from the Indian Ocean was again influenced strongly by N66. Biplot vectors from CDA showed that separation between individual yellowfin tuna from the Atlantic and Pacific Oceans was primarily influenced by PVC and PE (Fig. 3). Due to the presence of intra-basin variation in NMP signatures, we also ran QDFA models with all regions as the grouping factor, and classification success of dolphinfish to each of the 11 regions increased to 89%; however, regional classification dropped to 55% for yellowfin tuna (based on 10 regions).

Trophic position estimates derived from $\delta^{15}N_{AA}$ weighted means of select source (glycine, lysine, phenylalanine) and trophic (alanine, glutamic acid, leucine) amino acids indicated relatively consistent trophic position estimates within each species regardless of ocean basin (Fig. 4; Table S2). Mean trophic

position for both species in the three oceans was relatively similar: dolphinfish (range: 4.08–4.22) and yellowfin tuna (4.40–4.67), and the extent of observed trophic position estimates of individuals was markedly higher for yellowfin tuna (Fig. 4). ∑NMP concentrations increased in yellowfin with increasing trophic position, with the oppostive trend observed for dolphinfish. Nevertheless, in both species the relationship between muscle tissue ∑NMP concentration and trophic position was not signficant (F-test $p > 0.05$). Interestingly, the trophic position of yellowfin tuna was higher than dolphinfish in nearly all regions examined even though yellowfin tuna displayed lower ∑NMP concentrations.

Discussion

Quantification of NMPs in marine animals using Py-GC-qQq-MS approach represents a significant advancement over traditional particle-count microscopy coupled with advanced spectroscopic methods (Mariano et al. 2021). The approach provides a time-integrated measure of NMP concentration in biological tissue that more accurately reflects long-term exposure of predators to NMPs in the ocean. As a result, this study serves as the first comprehensive investigation of NMP body burdens of higher order consumers in pelagic ecosystems across multiple regions and oceans. The two species investigated are all highly migratory with ranges that encompass large expanses of oceans (Block et al. 2011, Merten et al. 2016, Rooker et al. 2019), and body burdens in the tissue of these predators serve as a robust representation of NMP ambient conditions in regions investigated. Consequently, selected taxa represent valuable indicator species for assessing the occurrence, prevalence, and potential risks of NMPs in pelagic ecosystems.

Species-specific variation in ∑NMP concentration was pronounced across regions sampled for the four pelagic fishes, with NMP body burdens elevated relative to other studies of marine fishes. Although studies applying Py-GC-qQq-MS analysis to quantify NMP concentrations in muscle tissue of marine fauna are limited, the approach was applied recently to predatory fishes that inhabit estuarine habitats in the Gulf of Mexico. Average ∑NMP body burdens for red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*) were below 1,000 μg g^{-1} DW while ∑NMP concentration in gafftopsail catfish (*Bagre marinus*) was reported at 1,600 μg g^{-1} DW (Mortuza et al. 2025). By contrast, observed NMP body burdens of dolphinfish and yellowfin tuna were markedly higher, and sometimes an order of magnitude above reported values for estuarine taxa. Of the two pelagic species examined, the lowest ∑NMP concentrations were observed for yellowfin tuna in the Atlantic and Pacific Oceans with average values across all regions sampled in both oceans at approximately 5,000 μg g^{-1} DW. ∑NMP body burdens of dolphinfish were often twofold higher than yellowfin tuna in most regions sampled.

Given the potential value of large pelagic fishes as indicators of microplastic risks in marine ecosystems, several studies have addressed the prevalence of microplastic ingestion in ocean predators using more conventional methods (microscopic quantification of plastics in stomachs), often followed by chemical characterization with spectroscopic analysis (Torresi et al. 2024). Findings from microscopic and/or spectroscopic analysis are not directly comparable to our findings due in part to the fact that entry and integration of NMPs in the muscle tissue of pelagic fishes occurs through both the gastrointestinal tract

as well as absorption through the gills *(34)*, with stomach content analysis often biased toward larger microplastics that are likely excreted. Both pathways (prey versus gills) contribute to NMP body burden in the blood stream and eventually to their presence in muscle and other tissues. Nevertheless, observations from coupled microscopic and spectroscopic analysis provide some useful context for explaining trends observed in the present study. Although sample sizes were very limited, a recent study observed that several microplastic polymers were present in the gastrointestinal tract and gills of dolphinfish, yellowfin tuna, and other pelagic fishes (Pereira et al. 2023). Moreover, through the application of microscopic and spectroscopic methods, earlier studies have reported high occurrences of microplastics (~ 80–100% of individuals assayed) for dolphinfish (Li et al. 2022) and yellowfin tuna (Justino et al. 2023). Our observation of NMPs present in the muscle tissue of 100% of the individuals assessed with Py-GC-qQq-MS aligns well with these studies and suggest that despite being relatively far removed from terrestrial sources of microplastics, large pelagic fishes and associated communities remain vulnerable to NMP contamination in the open ocean.

Region-specific variation in muscle tissue ∑NMP concentrations centered on dolphinfish and yellowfin tuna since both species maintained broad geographic coverage across the regions investigated. Species- and inter-ocean differences in ∑NMP concentrations were evident while intra-basin variation for both species within the Atlantic Ocean or within the Pacific Ocean was more restricted. For example, average ∑NMP concentrations in dolphinfish were comparable in four of the five regions sampled in both the Atlantic Ocean (range: ~14,000–16,000 μg g^{-1} DW) and Pacific Ocean (range: ~6,000–10,000 μg g^{-1} DW), indicating that NMP loading or exposure to these CECs may be relatively similar across broad geographic areas within the same ocean, which aligns well with spatial predictions of plastic concentration at the ocean-basin scale (Kaandorp et al. 2023). Still, within each ocean, ∑NMP concentration in one region was markedly different for dolphinfish relative to the four other regions.

In the Atlantic Ocean, ∑NMP body burdens of dolphinfish from the Gulf of Mexico displayed concentrations more than 50% lower than other regions investigated, while in the Pacific Ocean dolphinfish collected in the Northwest Pacific displayed ∑NMP concentrations nearly twofold higher than any other region sampled in this ocean basin. Similar trends in both the Atlantic and Pacific Oceans were also observed for yellowfin tuna, with ∑NMP body burdens again lowest in the Gulf of Mexico for this species relative to regions in the Atlantic Ocean. Increased ∑NMP concentrations for dolphinfish collected in the Northwest Pacific off Taiwan in the East China Sea is not unexpected and ostensibly linked to higher levels of plastic emission in the western Pacific Ocean, as marine plastics in this region are present at extremely elevated levels (Kvale et al. 2020). This includes surface waters off Taiwan and China which are known to be highly enriched in NMPs (Jambeck et al. 2015), and likely responsible for high levels present in dolphinfish from this region. In contrast, lower ∑NMP body burdens observed for dolphinfish and yellowfin tuna from the Gulf of Mexico relative to other regions in the Atlantic Ocean was unexpected given that microplastics concentrations previously reported in the northern Gulf of Mexico are among the highest in the Atlantic Ocean (Di Mauro et al. 2017). Dolphinfish and yellowfin tuna in the Gulf of Mexico commonly reside in offshore waters associated with a major mesoscale oceanographic feature, the Loop Current. This mesoscale current is a major transport system that brings in warm,

oceanic waters from the Caribbean Sea into the Gulf of Mexico. The Loop Current and associated mesoscale features also serve to influence the spatial distribution and alter residency times of contaminants (NMPs) in the northern Gulf of Mexico, which are closely linked to circulation patterns (Zhou et al. 2025). It is possible that Loop Current dynamics and associated water mixing serve to alter (i.e., reduce) NMP concentrations in surface waters of the outer shelf and slope where dolphinfish and yellowfin tuna reside.

The occurrence of dominant NMP polymer types present in the muscle tissue of the pelagic fishes investigated align with reported abundance of NMP polymers in surface waters of the ocean (Erni-Cassola et al. 2019). For the two species investigated and across nearly all regions, PE was the most abundant polymer type, and overall comprised the bulk of all NMPs observed across all dolphinfish (62%) and yellowfin tuna (50%) assayed. Findings from a meta-analysis of NMP polymers present in surface waters of the Atlantic and Pacific Oceans indicated that PE was the most prevalent and abundant polymer, accounting for > 50% of total polymer concentration quantified in open ocean waters off the continental shelf (Erni-Cassola et al. 2019). This suggests that these two top predators accurately reflect environmental NMP conditions in their muscle tissue. Apart from PE, other primary NMP polymers in dolphinfish and yellowfin tuna, N66 and PP were consistently present in the muscle tissue of both species investigated and across all regions sampled. Again, our results of N66 and PP being moderately abundant in the muscle tissue of these two species are in accord with the relative abundance of these polymers present in surface waters of the Atlantic and Pacific Oceans (Pabortsava and Lampitt 2020,, Zhou et al. 2025). Finally, NMP polymers accounting for minor contributions to overall muscle tissue NMP body burdens of dolphinfish and yellowfin tuna, such as PS (< 1.0% of total NMP composition), are also commonly observed at reduced levels (< 5%) in surface waters of the ocean (Erni-Cassola et al. 2019). Overall, our findings suggest that NMP polymers detected in the pelagic species investigated reflect the relative composition of NMP polymer types in surface waters, confirming their value as sentinel species for characterizing the abundance and distribution of NMPs in the ocean.

Positive correlations were present between several of the NMP polymers quantified in the tissue of dolphinfish and yellowfin tuna. Significant correlations between PE, PP, and N66 are not surprising since these polymers, both separately and blended, are used in a variety of applications ranging from packaging to fishing applications (Graziano et al. 2018, Hossain et al. 2024). For example, PP and PE polymers are commonly blended to make ropes and nets for commercial fishing and shipping operations because blends of mixed fibers increase the strength and durability of certain gear (Juan et al. 2021). At the same time, lost gears (e.g., ghost netting) manufactured from PP-PE-N66 blends are a meaningful source of NMP pollution in the ocean (Wataniyakun et al. 2025). While correlations were observed among polymer types, regional variation in NMP polymer composition for both dolphinfish and yellowfin tuna was present within and among ocean basins, potentially indicating that NMP signatures in the muscle tissue of these predators may be useful for discriminating individuals from different geographic regions. Chemical tracers in muscle tissue or hard parts (e.g., otoliths) are commonly used to assess the origin, migration ecology, and stock structure of marine fishes (Rooker et al. 2008, Madigan et al. 2014, Graves et al. 2015, Rooker et al. 2023), and therefore NMP signatures may also serve as anthropogenic

markers for addressing ecological questions related to the origin and movements of pelagic fishes and other marine taxa.

Contaminants have the potential to accumulate and magnify across trophic levels in marine food webs (Cai et al. 2007, Kljakovic-Gaspic and Ticina 2021, Cheng et al. 2022). For microplastics, links to biomagnification in higher trophic level predators are often less evident or inconclusive (Miller et al. 2020, Covernton et al. 2022, Gao et al. 2024). Similarly, our findings did not establish a clear link between trophic position and NMP body burden. While a positive association was observed between trophic position and ∑NMP concentration for yellowfin tuna, the relationship was not significant and possibly compromised by pooling data across all geographic regions sampled. Moreover, of the two species investigated, trophic position was consistently higher for yellowfin tuna while displaying lower ∑NMP body burdens relative to dolphinfish. The apparent mismatch between trophic position and ∑NMP body burden between the two species may be related to differences in foraging behaviors, which results in each species exploiting different prey fields. Dolphinfish feed almost exclusively on fishes and invertebrates in near surface waters, and often display nondiscriminatory foraging behaviors with Sargassum and plastic debris often present in their stomachs (Rudershausen et al. 2010, Brewton et al. 2016). Yellowfin tuna feed in surface waters but also dive hundreds of meters to actively feed on a variety of deepwater prey in the mesopelagic zone (Hoolihan et al. 2014, Duffy et al. 2017, Willis et al. 2025). Since concentrations of microplastics often peak in surface waters and gradually decrease with depth (Zhao et al. 2025), it is plausible to assume that dolphinfish experience significantly higher exposure to NMPs by foraging on prey that inhabit surface waters, while yellowfin tuna exposure to NMPs is moderated to some degree by feeding on deepwater prey in the mesopelagic zone with potentially lower associated NMP body burdens.

Inter-ocean variation in mean trophic position based on CSIA-AA was generally negligible for both species investigated. Differences were often only about 0.2 trophic steps among species-specific means for each of the three oceans for both dolphinfish and yellowfin tuna, suggesting these species play similar functional roles in pelagic food webs regardless of location. Similarly, intra-ocean variation in trophic position was relatively minor for dolphinfish and yellowfin tuna sampled from five regions in both the Atlantic and Pacific Ocean. For example, despite sampling dolphinfish from different regions in the Atlantic Ocean that vary greatly in biological and physicochemical conditions, estimated trophic position was highly similar among the five regions (~ 4.0, 4.1, 4.1, 4.1, 4.2), supporting the premise of this species fulfills similar trophic roles throughout the Atlantic Ocean. Our trophic position estimates are in accord with previous studies applying CSIA-AA based approach to estimate trophic position of pelagic species such as dolphinfish and tunas (Bradley et al. 2015). Moreover, a recent study reported similar trophic position estimates for dolphinfish collected in different ocean basins using a similar CSIA-AA approach (Prouse 2025), while trophic position estimates derived for yellowfin tuna using other dietary tracers have also reported comparable values across different geographic regions (Popp et al. 2007). As a result, geographic differences in NMP concentrations observed for the species investigated are presumably a function of ambient NMP conditions rather than region-specific shifts in foraging strategies by these taxa.

Declarations

Acknowledgments

A special thanks Jeffrey Buckel, Shane Cantrell, Brett Falterman, Caroline Vieira Feitosa, Elliot Hazen, and members of the *Fisheries Ecology Lab* and *Shark and Fisheries Science Lab* for assistance with sample collections and/or comments on earlier drafts of the manuscript. We also want to thank those who participated with global sampling efforts from various labs and locations in the Atlantic, Pacific, and Indian Oceans.

Funding: Analysis and development of the manuscript was supported by the Gulf Research Institute for Highly Migratory Species (J.R.R.), the McDaniel Charitable Foundation (J.R.R.), and Texas A&M University Edges Fellowship (R.J.D.W.). Tissue collections used for microplastic analysis were obtained from a variety of projects and sources with financial assistance from several entities.

Author contribution: Conceptualization: J.R.R., K.K., and R.J.D.W. Methodology: J.R.R., K.K., R.J.D.W., M.S.Z., and M.B.G. Sample Acquisition: J.R.R., R.J.D.W., A.P., A.A., P.A., J.A.B., M.A.D., B.P.F., M.G., B.H., S.J., S.J.J., F.S.K., D.L.L., J.G.P., P.J.S., B.L.S., O.E.S., R.M.T., A.T., and C.J.Y. Investigation: J.R.R., K.K., R.J.D.W., M.Z.S., and M.B.G. Data Analysis and Visualization: J.R.R. Supervision: J.R.R., K.K., and R.J.D.W. Writing—original draft: J.R.R. Writing-reviewing and editing: J.R.R., K.K., R.J.D. W., M.S.Z., M.B.G, A.P., A.A., P.A., J.A.B., M.A.D., B.P.F., M.G., B.H., S.J., S.J.J., F.S.K., D.L.L., J.G.P., L.L.R., P.J.S., B.L.S., O.E.S., R.M.T., A.T., and C.J.Y. Funding Acquisition: J.R.R., K.K., and R.J.D.W.

Competing interests: Authors declare that they have no competing interests.

Data and materials availability: All data needed to evaluate conclusions of the paper are present in the paper and/or Supplementary Materials. Raw data (% lipid and concentration of all polymer types per individual fish) available upon request.

References

1. Akhbarizadeh R, Moore F, Keshavarzi B. 2019 Investigating microplastics bioaccumulation and biomagnification in seafood from the Persian Gulf: a threat to human health? *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess*. **36**, 1696-1708
2. Alberghini L, Truant A, Santonicola S, Colavita G, Giaccone V. 2023 Microplastics in Fish and Fishery Products and Risks for Human Health: A Review. *Internat. J. Environ. Res. Public Health **20***, 789.
3. Barceló D, Picó Y, Alfarhan AH. 2023 Microplastics: Detection in human samples, cell line studies, and health impacts. *Environ. Toxicol. Pharm*. **101**, 104204.
4. Block BA et al. 2011 Tracking apex marine predator movements in a dynamic ocean. *Nature* **475**, 86-90.

5. Botterell ZLR, Beaumont N, Dorrington T, Steinke M, Thompson RC, Lindeque PK. 2019 Bioavailability and effects of microplastics on marine zooplankton: A review, *Environ. Pollut.* **245**, 98-110.
6. Bradley CJ, Wallsgrove NJ, Choy CA, Drazen JC, Hetherington ED, Hoen DK, Popp BN. 2015 Trophic position estimates of marine teleosts using amino acid compound specific isotopic analysis. *Limnol. Oceanogr.:Methods* **13**, 476-493.
7. Brewton RA, Ajemian MJ, Young PC, & Stunz GW (2016) Feeding ecology of Dolphinfish in the Western Gulf of Mexico. Transactions of the American Fisheries Society, **145(4),** 839–853.
8. Cai Y, Rooker JR, Gill G, Turner JP. 2007 Bioaccumulation of mercury in pelagic fishes from the Gulf of Mexico: evaluating links to dietary history and trophic position using stable isotopes and fatty acids. *Can. J. Fish. Aquat. Sci.* **64**, 458-469.
9. Cheng H, Lv C, Li J, Wu D, Zhan X, Song Y, Zhao N, Jin H. 2022 Bioaccumulation and biomagnification of emerging poly-and perfluoroalkyl substances in marine organisms. *Sci. Total Environ.* **851**, 158117.
10. Covernton GA, Metherel AH, McMeans BC, Bucci K, Langenfeld D, McNamee R, Veneruzzo C, Hoffman MJ, Orihel DM, Paterson MJ, Provencher JF. 2024 Increasing microplastic exposure had minimal effects on fatty acid composition in zooplankton and yellow perch in a large, in-lake mesocosm experiment. *Can. J. Fish. Aquat. Sci.* **81**, 1717-27.
11. Coyle R, Hardiman G, O'Driscoll K. 2020 Microplastics in the marine environment: A review of their sources, distribution processes, uptake and exchange in ecosystems. *Case Stud. Chem. Environ. Eng.* **2**, 100010.
12. De Souza Machado AA, Kloas W, Zarfl C, Hempel S, Rillig MC. 2018 Microplastics as an emerging threat to terrestrial ecosystems. *Glob. Chang. Biol.* **24**, 1405-1416.
13. Dimassi SN, Hahladakis JN, Yahia MND, Ahmad MI, Sayadi S, Al-Ghouti MA. 2022 Degradation-fragmentation of marine plastic waste and their environmental implications: A critical review. *Arab. J. Chem.* **15**, 104262.
14. Di Mauro R, Matthew JK, Benfield MC. 2017. Abundant plankton-sized microplastic particles in shelf waters of the northern Gulf of Mexico. *Environ. Pollut*. **230**, 798-809.
15. Duffy LM, Kuhnert PM, Pethybridget HR, Young JW, Olson RJ, Logan JM, Goni N, Romanov E, Allain V, Studinger MD, Abecassis M et al. 2017 Global trophic ecology of yellowfin, bigeye, and albacore tunas: Understanding predation on micronekton communities at ocean-basin scales. *Deep Sea Res. Part II: Topical Stud. Oceanogr.***140**, 55-73
16. Erni-Cassola G, Zadjelovic V, Gibson MI, Christie-Oleza JA. 2019 Distribution of plastic polymer types in the marine environment; A meta-analysis. *J. Hazard Mater*. **369**, 691-698.
17. Gahn MB, Wharton M, Mortuza A, Hala D, Marshall CD, Kaiser K. 2026 Rapid and sensitive quantification of nano- and microplastics in water, sediment, and biological tissue by pyrolysis-gas chromatography tandem mass spectrometry with dynamic reaction monitoring. *Analyt. Chem*. **98**, 633-641.

18. Galloway T, Cole M, Lewis C. 2017 Interactions of microplastic debris throughout the marine ecosystem. *Nat. Ecol. Evol*. **1**, 0116.
19. Gao S, Zhang S, Feng Z, Lu J, Fu G, Yu W. 2024 The bio-accumulation and -magnification of microplastics under predator–prey isotopic relationships. *J. Hazard. Materials* **480**, 135896.
20. GESAMP. 2016 Sources, fate and effects of microplastics in the marine environment: part two of a global assessment (eds Kershaw, P. J. & Rochman, C. M.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). *Rep. Stud. GESAMP* **93**, 220.
21. Graves JE, Wozniak AS, Dickhut RM, Cochran MA, MacDonald EH, Bush E, Arrizabalaga H, Goñi N. 2015 Transatlantic movements of juvenile Atlantic bluefin tuna inferred from analyses of organochlorine tracers *Can. J. Fish. Aquat. Sci.* **72**, 625-633.
22. Graziano A, Jaffer A, Sain M. 2018 Review on modification strategies of polyethylene/polypropylene immiscible thermoplastic polymer blends for enhancing their mechanical behavior. *J. Elastom. Plastics* **51**, 009524431878380.
23. Hitchcock JN. 2022 Microplastics can alter phytoplankton community composition. *Sci. Total Environ.* **1**, 819:153074.
24. Hoolihan JP, Wells RJD Luo J, Falterman, B, Prince ED, Rooker JR (2014) Vertical and horizontal movements of yellowfin tuna (*Thunnus albacares*) in the Gulf of Mexico. Marine and Coastal Fisheries 6: 211-222
25. Hossain MT, Shahid MA, Mahmud N, Habib A, Rana MM, Khan SA, Hossain MD. 2024 Research and application of polypropylene: a review. *Discover. Nano.* **19**, 2.
26. Huang W, Song B, Liang J, Niu Q, Zeng G, Shen M, Deng J, Luo Y, Wen X, Zhang Y. 2021
27. Microplastics and associated contaminants in the aquatic environment: A review on their ecotoxicological effects, trophic transfer, and potential impacts to human health
28. *J. Hazard. Mater.* **405**, 124187.
29. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Lavender Law K. 2015 Plastic waste inputs from land into the ocean. *Science* **347**, 768-771.
30. Juan R, Paredes B, Garcia-Munoz DC. 2021 Quantification of PP contamination in recycled PE by TREF analysis for improved the quality and circularity of plastics. *Polymer Testing* **100**, 107273.
31. Justino AKS, Ferreira GVB, Fauvelle V, Schmidt N, Lenoble V, Pelage L, Martins K, Travassos P, Lucena-Frédou F. 2023 From prey to predators: Evidence of microplastic trophic transfer in tuna and large pelagic species in the southwestern Tropical Atlantic. *Environ. Pollut.* **327**,121532.
32. Kaandorp MLA, Lobelle D, Kehl C, Dijkstra HA, van Sebille E. 2023 Global mass of buoyant marine plastics dominated by large long-lived debris. *Nat. Geosci.* **16**, 689-694.
33. Kljakovic-Gaspic Z, Ticina V. 2021 Mercury and selenium levels in archive samples of wild Atlantic bluefin tuna from the Mediterranean Sea. *Chemosphere* **284**, 131402.

34. Kvale K, Prowe AEF, Chien CT, Landolfi A, Oschlies A. 2020 The global biological microplastic particle sink. *Sci Rep*. **10**, 16670.
35. Lambert S, Wagner M. 2018 Microplastics Are Contaminants of Emerging Concern in Freshwater Environments: An Overview. In: Wagner, M., Lambert, S. (eds) Freshwater Microplastics. The Handbook of Environmental Chemistry, vol. 58. Springer, Cham.
36. Lebreton L, van der Zwet J, Damsteeg JW, Slat B, Andrady A, Reisser J. 2017, River plastic emissions to the world's oceans. *Nat. Commun.* **8**, 15611.
37. Li W, Pan Z, Xu J, Liu Q, Zou Q, Lin H, Wu L, Huang H. 2022 Microplastics in a pelagic dolphinfish (*Coryphaena hippurus*) from the Eastern Pacific Ocean and the implications for fish health. *Sci. Total Environ.* **809**, 151126.
38. Li Y, Tao L, Wang Q, Wang F, Li G, Song M. 2023 Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects. *Environ. Health* **2023** ***1***, 249-257.
39. Madigan DL, Baumann Z, Carlisle AB, Hoen DK, Popp BN, Dewar H, Snodgrass OE, Block BA, Fisher NS. 2014 Reconstructing transoceanic migration behaviors of Pacific bluefin tuna using a chemical tracer toolbox. *Ecology* **95**,1674-1683.
40. Malinowski CR, Searle CL, Schaber J, Höök TO. 2023 Microplastics impact simple aquatic food web dynamics through reduced zooplankton feeding and potentially releasing algae from consumer control. *Sci. Total Environ*. **904**, 166691.
41. Mao Y, Ai H, Chen Y, Zhang Z, Zeng P, Kang L, Li W, Gu W, He Q, Li H. 2018 Phytoplankton response to polystyrene microplastics: Perspective from an entire growth period. *Chemosphere* **208**, 59-68.
42. Mariano S, Tacconi S, Fidaleo M, Rossi M, Dini L. 2021 Micro and nanoplastics identification: classic methods and innovative detection techniques. *Front. Toxicol*. **3**, 636640.
43. Merten W, Appeldoorn R, Hammond D. 2016 Movement dynamics of dolphinfish (*Coryphaena hippurus*) in the northeastern Caribbean Sea: Evidence of seasonal re-entry into domestic and international fisheries throughout the western central Atlantic. *Fish. Res*. **175**, 24-34.
44. Miller K. 2024 Nano and microplastics in the muscle tissue of top predators in the Ocean. M.S. Thesis, Texas A&M University.
45. Miller ME, Hamann M, Kroon FJ. 2020 Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. *PLoS One* **15**, e0240792.
46. Monikh FA, Materić D, Valsami-Jones E, Grossart HP, Altmann K, Holzinger R, Lynch I, Stubenrauch J, Peijnenburg W. 2025 Challenges in studying microplastics in human brain. *Nature Med.* **31**, 4034-4035.
47. Mortuza A, Meese EN, Wharton M, Gahn MB, Petersen LH, Quigg A, Wells RJD, Kaiser K, Hala D. 2025Comparing persistent (polycyclic aromatic hydrocarbons and polychlorinated biphenyls) and emerging nano(micro)plastics (NMPs) pollutant body-burdens in oysters and fish from Matagorda Bay (Texas, USA). *Mar. Pollut. Bull.* **221**, 118495.
48. Nelms SE, Galloway TS, Godley BJ, Jarvis DS, Lindeque PK. 2023 Investigating microplastic trophic transfer in marine top predators. *Environ. Pollut.* **238**, 999-1007.

49. Nielsen JM, Popp BN, Winder M. 2015 Meta-analysis of amino acid stable nitrogen isotope ratios for estimating trophic position in marine organisms. *Oecologia* **178**, 631-642.
50. Pabortsava K, Lampitt RS. 2020 High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. *Nat. Commun.* **11**, 4073.
51. Parolini M, Romano A. 2024 Geographical and ecological factors affect microplastic body burden in marine fish at global scale. *Environ Pollut.* **352**, 124121.
52. Pereira R, Rodrigues SM, Silva D, Freitas V, Almeida CMR, Ramos S. 2023 Microplastic contamination in large migratory fishes collected in the open Atlantic Ocean. *Mar. Pollut. Bull*. **186**,114454.
53. Persiani E, Cecchettini A, Ceccherini E, Gisone I, Morales MA, Vozzi F. 2023 Microplastics: a matter of the heart (and vascular system). *Biomedicines* **11**, 264 (2023).
54. Popp BN, Graham BS, Olson RJ, Hannides CCS, Lott MJ, López-Ibarra GA, Galván-Magaña G, Fry B. 2007 Insight into the trophic ecology of yellowfin tuna, *Thunnus albacares*, from compound-specific nitrogen isotope analysis of proteinaceous amino acids. Terr. Ecol. **1**, 173-190.
55. Prouse A. 2025 Trophic ecology and contamination body burden of marine predators across ocean basins. Ph.D. Dissertation, Texas A&M University.
56. Rauert C, Charlton N, Bagley A, Dunlop SA, Symeonides C, Thomas KV. 2025 Assessing the efficacy of pyrolysis-gas chromatography-mass spectrometry for nanoplastic and microplastic analysis in human blood. *Environ. Sci. Technol*. **59**, 1984-1994.
57. Rooker JR, Secor DH, DeMetrio G, Scholesser R, Block BA, Neilson JD. 2008 Natal homing and connectivity in Atlantic bluefin tuna populations. *Science* **322**, 742-744.
58. Rooker JR, Dance MA, Wells RJD, Ajemian MJ, Block BA, Castleton MR, Drymon JM, Falterman BJ, Franks JS, Hammerschlag N, Hendon JM, Hoffmayer ER, Kraus RT, McKinney JA, Secor DH, Stunz GW, Walter JF. 2019 Population connectivity of pelagic megafauna in the Cuba-Mexico-United States triangle. *Sci. Rep*. **9**, 1663.
59. Rooker JR, Zapp Sluis M, Kitchens LL, Dance MA, Falterman B, Lee JM, Liu H, Miller N, Murua H, Rooker AM, Saillant E, Walter JF, Wells RJD. 2023 Nursery origin of yellowfin tuna in the western Atlantic Ocean: significance of Caribbean Sea and trans-Atlantic migrants. *Sci. Rep.* **13**, 16277.
60. Rudershausen PJ, Buckel JA, Edwards J, Gannon DP, Butler CM, Averett TW. 2010 Feeding ecology of blue marlins, dolphinfish, yellowfin tuna, and wahoos from the North Atlantic Ocean and comparisons with other ocean. *Tran. Amer. Fish. Soc.* **139**, 1335-1359.
61. Schmidt C, Krauth T, Wagner S. 2017 Export of plastic debris by rivers into the sea. *Environ. Sci. Tech.* ***51***, 12246-12253.
62. Sethia P, Nandhini D, Amutha S. 2024 Effects of marine microplastic on marine life and the food webs – A detailed review. *Mar. Ecol*. **45**, e12819.
63. Soltanighias T, Umar A, Abdullahi M, Abdallah MA, Orsini L. 2024 Combined toxicity of perfluoroalkyl substances and microplastics on the sentinel species *Daphnia magna*: Implications for freshwater ecosystems. *Environ. Pollut.* **363**, 125133.

64. Stapleton MJ, Hai FI. 2023. Microplastics as an emerging contaminant of concern to our environment: a brief overview of the sources and implications. *Bioengineered* **14**, 2244754.
65. Torresi M, Giménez J, Navarro J, Coll M, García-Barcelona A, Macías D, Borrell A, Garcia-Garin O. 2024 Microplastic characterization in the stomachs of swordfish (*Xiphias gladius*) from the western Mediterranean Sea. *Mar. Pollut. Bull.* **206**, 116767.
66. Wataniyakun W, Gall ML, Rakwe ME, Karl CW, Larsen RB. 2025 Biodegradable fishing gears: A potential solution to ghost fishing and marine plastic pollution. *Mar. Pollut. Bull.* **212**, 117607.
67. Willis C, Gardner KG, Arostegui MC, Braun CD, Golet W, Houghton L, Llopiz JK, Govindarajan AF, Thorrold SR 2025 Evaluating the importance of mesopelagic prey to three top teleost predators in the northwest Atlantic Ocean, *ICES Journal of Marine Science* **82(3)**, fsaf028
68. Yarnes CT, Herszage J. 2017 The relative influence of derivatization and normalization procedures on the compound-specific stable isotope analysis of nitrogen in amino acids. *Rapid Commun. Mass Spectrom.* **31**, 693-704.
69. Zhou X, Xiao S, Ramirez M, Bracco A. 2025 Modeling river and urban related microplastic pollution off the southern United States. *Emerg. Contam*. **1**, 9.

Table

Table 1. Species- and region-specific variation in mean ∑NMP concentrations (μg g^{-1} DW) in the muscle tissue of dolphinfish and yellowfin tuna. ∑NMP concentrations were based on the sum of the five primary polymers detected (PC, PE, PP, PVC, N66) for each individual and average by species for each region. Primary sampling location within each region also denoted. Standard deviation (1 SD) around means also shown.

Ocean/Region	Primary Sampling Area	Dolphinfish				Yellowfin Tuna			
Atlantic Ocean		N	Mean FL (cm)	∑ NMPs	1 SD	N	Mean FL (cm)	∑ NMPs	1 SD
Northwest	South Atlantic Bight	6	109	14,362	9,461	6	104	7,845	3,852
Gulf of Mexico	Northern Gulf of Mexico	6	117	6,277	2,048	6	125	2,346	3,111
Mediterranean	Balearic, Tyrrhenian, Aegean Seas	6	61	15,087	7,794				
Northcentral	Caribbean Sea	6	86	16,026	10,522	6	98	5,013	2,120
Equatorial	Brazil	6	122	15,910	5,865	6	122	3,261	3,258
All Atlantic		30		13,532		24		4,616	
Pacific Ocean									
Northwest	Taiwan	6	93	18,842	9,887	6	134	1,785	1,476
Northcentral	Hawaiian Islands	6	102	6,272	2,516	6	117	917	519
Northeast	California/Mexico	6	91	9,932	2,879	6	NA	12,241	11,801
Equatorial	Panama	6	95	6,966	2,343	6	116	7,087	5,427
Southwest	E. Australia	6	122	8,357	2,638	6	138	2,767	2,318
All Pacific		30		10,074		30		4,959	
Indian Ocean									
Southwest	Reunion Island	6	104	6,390	1,525	6	117	8,274	11,620

Figures

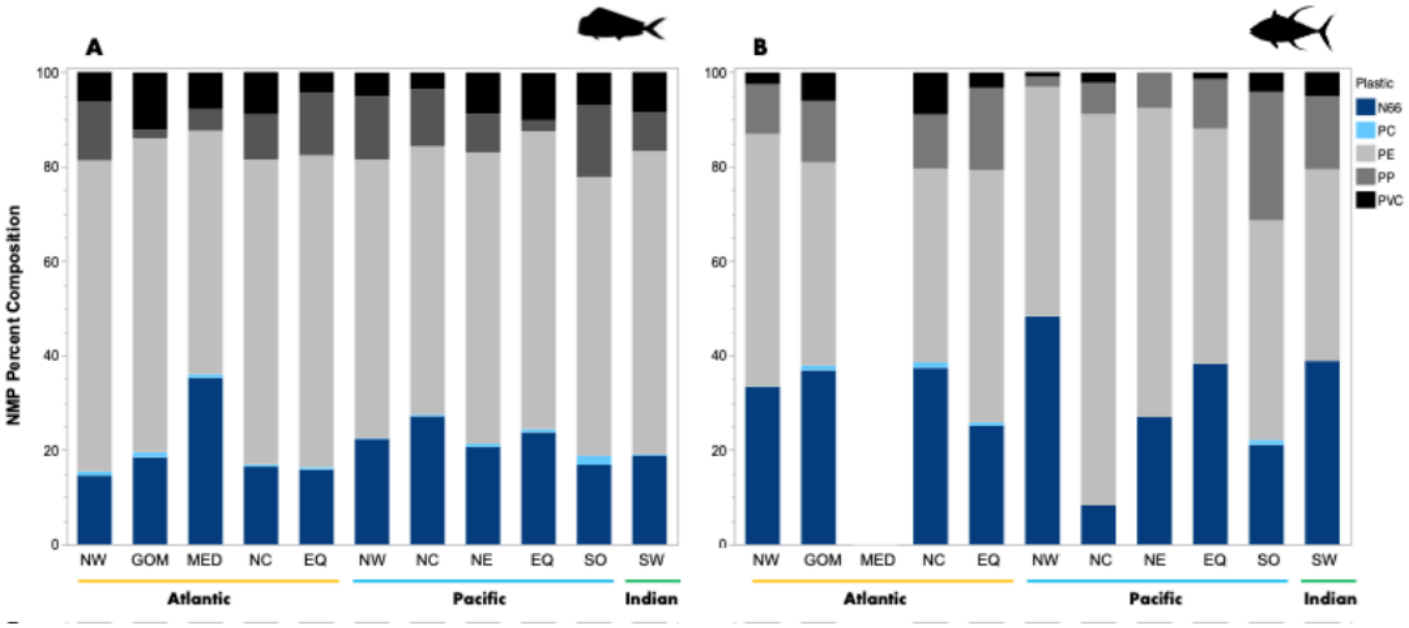


Figure 1

Percent composition of the five primary NMP polymers (PC, PE, PP, PVC, N66) quantified in the muscle tissue of dolphinfish (A) and yellowfin tuna (B) for all regions sampled from the Atlantic, Pacific, and Indian Oceans. Composition based on all individuals collected within each region. Region codes: Atlantic (NW = Northwest, GOM = Gulf of Mexico, MED = Mediterranean Sea, NC = Northcentral, EQ = Equatorial); Pacific (NW = Northwest, NC = Northcentral, NE = Northeast, EQ = Equatorial, SO = Southwest); Indian (SW = Southwest).

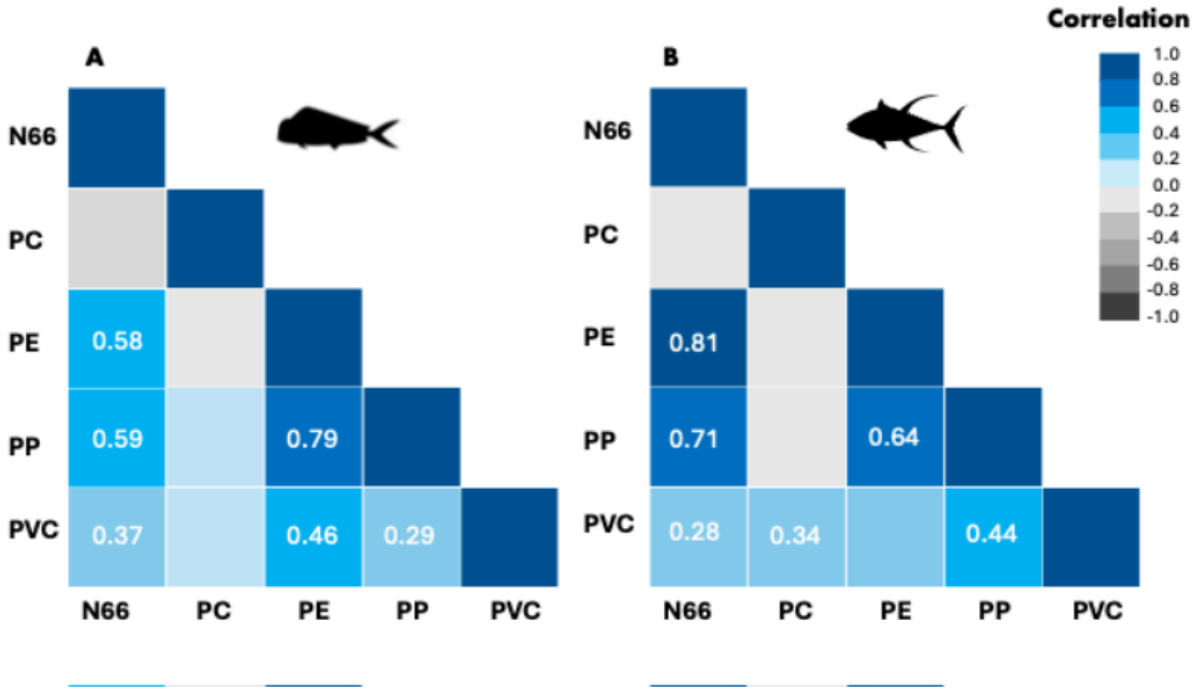


Figure 2

Correlation matrix for the five primary NMP polymers (PC, PE, PP, PVC, N66) quantified in the muscle tissue of dolphinfish (A) and yellowfin tuna (B). The strength and direction of linear correlation is shown by colors. Darker blue shading associated with stronger, positive correlations. Significant correlations between polymer types are denoted by including values (correlation coefficients) in matrix squares.

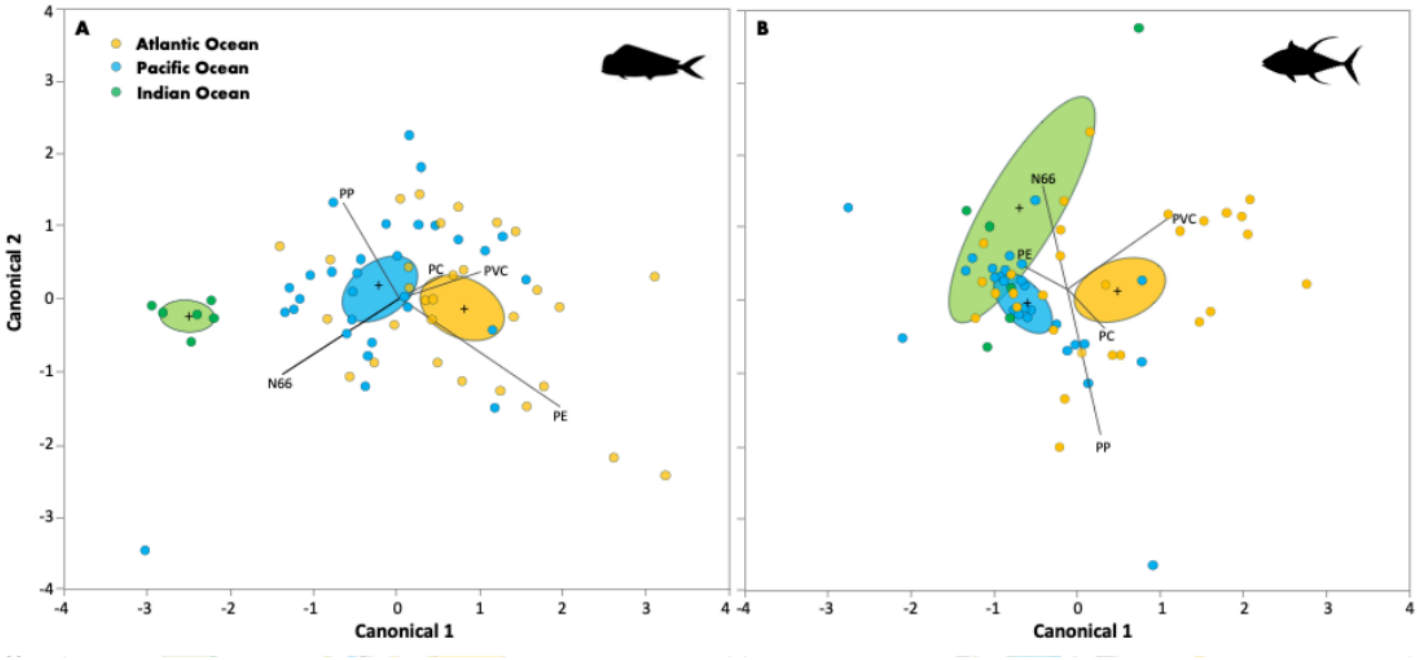


Figure 3

Canonical discriminant analysis (CDA) plots based on the five primary NMP polymers quantified (PC, PE, PP, PVC, N66) in the muscle tissue of dolphinfish (A), and yellowfin tuna (B) from the Atlantic, Pacific, and Indian Oceans. Ellipses represent 95% confidence limit around each multivariate mean (+) and biplot vectors show the influence of each polymer on ocean-basin discrimination.

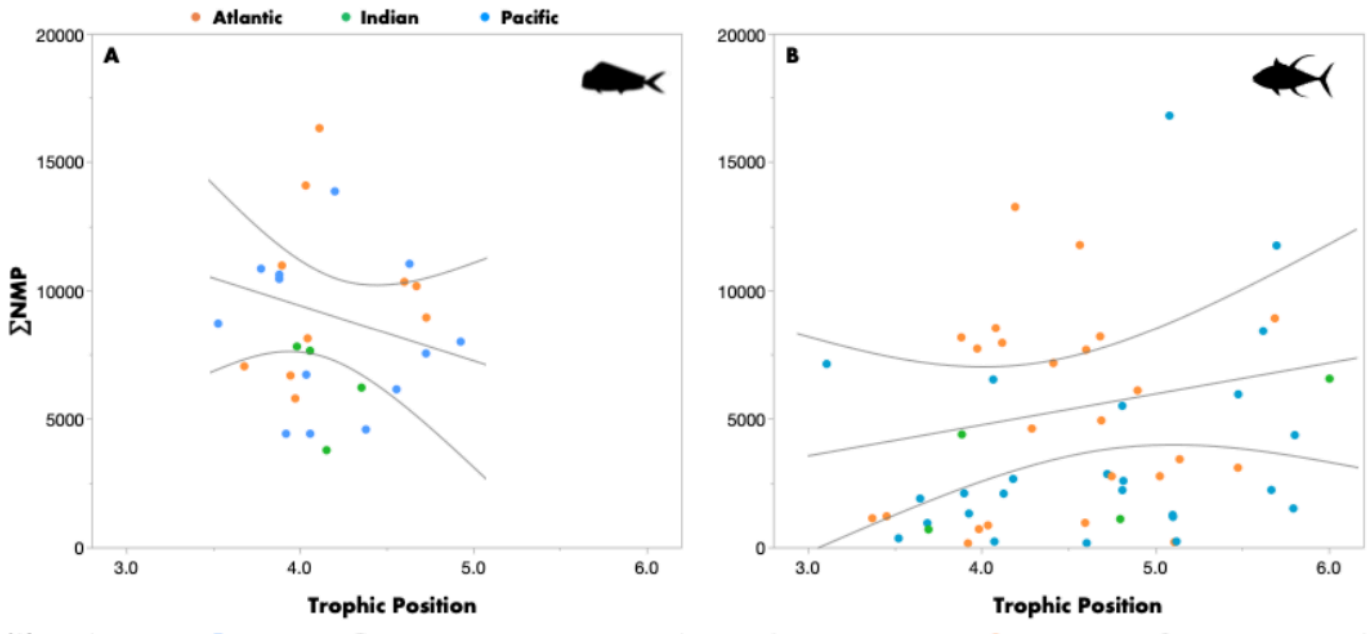


Figure 4

Relationship between ∑NMP concentrations (μg g^{-1} DW) and trophic position (TP) by ocean basin for dolphinfish (A) and yellowfin tuna (B). Linear regression and 95% confidence intervals shown. Trophic position based on $\delta^{15}N_{AA}$ weighted means of select source and trophic amino acids.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementalMaterialSciRep.docx