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Development of electronic monitoring for the collection of biological data in the fisheries sector: a case study of skate species

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ABSTRACT

As sustainable fisheries management relies on comprehensive data, this thesis examines the implementation of electronic monitoring (EM) systems for collecting biological data in the fisheries sector and compares the effectiveness of EM to traditional manual sampling methods used in fish markets. This work focused on six commercially important skate species in continental Portugal (*Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui*, *Leucoraja naevus*, and *Raja undulata*). A detailed literature review covered morphometric relationships of these species, existing data was analyzed, and methodologies were selected for this study. Fieldwork involved sampling in a fish market and employing an EM system to collect morphometric data. The data collection process included measuring total length as it is the primary biological variable targeted in fisheries data collection, as well as five other alternative morphometric measures (disc width, disc length, pre-orbital distance, spiracle posterior edge distance, and interspiracle distance), both manually and via images.

This study found high correlations and predictive power between total length and all five alternative measurements using EM and *in situ* measurements. The findings endorse using EM and alternative measurements to estimate total length. These will enhance data collection, minimize the handling of skates, and enable EM to estimate total length in cases where sampling is not feasible. However, limitations exist, such as misidentification of species and difficulty in accurately measuring specimens due to the mixture of species in the boxes, overlapped individuals, or individuals covered by ice and/or mucus. These issues can affect the quality of the images and, consequently, the accuracy of the measurements. The present study provides a tested method for EM data collection that allows increased monitoring efforts contributing to better-informed decision-making and ultimately supporting sustainable fisheries management.

Keywords: Morphometric relationships, stock assessment, Portugal, Rajidae, Total length

RESUMO

O setor global das pescas é vital para a economia e segurança alimentar de muitas nações, proporcionando empregos para milhões de pessoas e fornecendo uma porção significativa das necessidades proteicas do mundo. No entanto, a sobre-exploração dos stocks pesqueiros a nível mundial tornou-se problemática, ameaçando os ecossistemas marinhos e a sua biodiversidade. A gestão sustentável e eficaz das pescas é fundamental para enfrentar este desafio, de maneira a garantir a sua perpetuidade.

Esta dissertação investiga a aplicação de sistemas de monitorização eletrónica (ME) para a recolha de dados biológicos no setor das pescas, com um foco específico em espécies de raias, comercialmente relevantes, em Portugal. O objetivo é avaliar o potencial destes sistemas em fornecer dados biológicos precisos, essenciais para as avaliações de stocks e os esforços de gestão sustentável e conservação, de uma forma eficiente tendo em vista superar ou complementar as limitações dos métodos tradicionais de amostragem. A amostragem tradicional nos mercados de pescado envolve a recolha manual de dados morfométricos, como o comprimento total.

No entanto, os métodos tradicionais de recolha de dados, como os observadores a bordo e em portos de pesca, têm limitações. Estas limitações incluem a quantidade de dias, viagens e indivíduos que conseguem amostrar por questões logísticas e orçamentais (incluindo recursos humanos), assim como na possibilidade de acesso a algumas componentes da captura e da frota, tendo por outro lado a vantagem do acesso direto e manuseamento dos indivíduos. Adicionalmente, os métodos manuais estão sujeitos a erros humanos na obtenção das medidas e no seu registo, quer em papel quer em base de dados. Os sistemas de ME oferecem uma solução promissora ao fornecer uma recolha contínua de dados, que são transmitidos para bases de dados remotas para análise futura, tendo como desvantagem por exemplo a impossibilidade de manuseamento dos indivíduos e a limitação de visualização apenas ao campo de visão definido *a priori*, sendo também necessário considerar os custos quer do sistema de monitorização eletrónica quer da amostragem que é necessária realizar das imagens recolhidas. A implementação destes sistemas requer uma consideração cuidadosa de vários fatores técnicos e operacionais, incluindo a colocação ideal das câmaras e o desenvolvimento de sistemas robustos de gestão de dados para lidar com os grandes volumes de dados gerados. Além disso, o sucesso destes sistemas é maximizado pela cooperação dos intervenientes envolvidos no processo de desembarque e venda do pescado.

Em Portugal as espécies de raias são de particular interesse devido à sua importância ecológica, e ao seu interesse comercial e desafios associados à sua gestão. Este estudo foca-se na implementação de sistemas de ME nos portos de pesca para a recolha de dados biológicos sobre as espécies de raias.

Este estudo foca-se nas seis principais espécies de raias desembarcadas em Portugal continental e os principais objetivos deste estudo são: i) avaliar e verificar a funcionalidade dos sistemas de ME na recolha de dados morfométricos comparativamente com medições obtidas por métodos manuais; ii) testar relações morfométricas de (cinco) medidas alternativas com o comprimento total de maneira a desenvolver modelos que consigam prever com precisão medidas de comprimento total com o intuito de facilitar a obtenção de medições através de ME.

Inicialmente foi realizada uma revisão bibliográfica abrangente para reunir dados morfométricos existentes, relativos às espécies estudadas neste trabalho. Esta revisão serviu como base para a definição das morfometrias a amostrar neste estudo tanto nos portos de pesca como através da ME. A amostragem nos portos de pesca envolveu a recolha manual de dados morfométricos. Em contraste, a ME utilizou o sistema FishMetrics, empregando câmaras de alta resolução e software especializado para capturar imagens dos peixes e extrair medições morfométricas.

O estudo envolveu a determinação das relações entre o comprimento total e as outras morfometrias obtidas nas seis espécies de raias selecionadas. Estas relações foram obtidas tanto para os dados amostrados em portos de pesca, como para os dados amostrados através do sistema de ME. Estas relações foram também testadas.

Relativamente aos resultados da revisão de literatura relevantes para este trabalho, a maioria dos estudos apenas apresentou relações morfométricas, entre o comprimento total e a largura do disco, e poucos estudos apresentaram outra relação morfométrica (comprimento do disco e distância do focinho ao olho). No que diz respeito às espécies, houve alguma variância entre estudos, sendo o foco tanto monoespecífico como também multiespecífico. No entanto a maioria dos estudos reportou relações significativas com o comprimento total, para as medidas que testaram, podendo variar de estudo para estudo. Em relação aos resultados deste trabalho, a maioria das espécies tiveram relações morfométricas significativas com o comprimento total, em ambos os métodos de amostragem. No entanto, as espécies de raias de tamanho menor obtiveram relações morfométricas menos definidas, comparativamente com espécies que apresentam uma maior distribuição de comprimentos, especialmente para algumas das medidas alternativas pouco utilizadas (e.g. distância pré-orbital).

Contudo, o estudo identificou limitações do sistema FishMetrics. Um dos principais desafios foi a identificação das espécies e a medição dos peixes, ambas por vezes limitadas devido à mistura de espécies nas caixas, sobreposição de espécimes nas caixas e dificuldade de visualização dos mesmos por causa da presença de gelo e/ou muco. Estas questões podem afetar a qualidade das imagens e, consequentemente, a precisão das medições.

Por outro lado, o uso de medidas secundárias, como a largura do disco, o comprimento do disco e distância entre espiráculos, mostraram-se eficazes na previsão do comprimento total, proporcionando uma solução prática para casos em que as medições diretas desta variável não são possíveis.

Os resultados destacam o potencial dos sistemas de monitorização e amostragem eletrónica para melhorar a recolha de dados no setor das pescas. Estes sistemas eletrónicos remotos permitem aumentar o esforço de amostragem sem aumentar os recursos humanos necessários *in situ*, comparativamente com métodos tradicionais. O estudo também identificou áreas de melhoria, no que diz respeito aos intervenientes no processo de desembarque e venda de pescado, como reduzir as misturas de espécies e o número de indivíduos por caixa e possíveis ajustes nas práticas dos portos de pesca para facilitar uma melhor qualidade das imagens, como adicionar gelo apenas após a captação das imagens (no caso deste sistema de EM, após a venda). Além disso, a implementação bem-sucedida de sistemas de ME poderá levar a melhorias significativas na precisão e fiabilidade dos dados, apoiando estratégias de gestão mais eficazes.

Também existe a possibilidade de integrar o uso de tecnologias avançadas, como aprendizagem automática, de maneira a automatizar o processo de análise de dados, reduzindo o tempo e esforço necessários no processamento dos mesmos.

O presente estudo demonstra a viabilidade e os benefícios dos sistemas de ME para amostragem de espécies de raias em Portugal, demostrando o potencial destes sistemas na recolha de dados das pescas e destacando também as vantagens e desafios do uso dos mesmos para a recolha de dados morfométricos.

Concluindo, os sistemas de ME têm um elevado potencial para contribuir para a gestão sustentável das pescas, requerendo ainda refinamento e colaboração das partes envolvidas. O presente estudo serve como base para futura investigação e desenvolvimento, apelando a esforços para melhorar estas tecnologias e integrá-las em contexto de gestão. Aproveitando o potencial destes sistemas, podemos melhorar a monitorização, gestão e conservação dos stocks pesqueiros, assegurando a sua sustentabilidade para o futuro.

Palavras-chave: Relações morfométricas, Avaliação de stock, Portugal, Rajidae, Tamanho total

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LIST OF ABREVIATIONS

a	Regression intercept
AI	Artificial Intelligence
AIS	Automatic identification system
b	Regression slope
CFP	Common Fisheries Policy
CL	Tail length
cm	Centimeters
DL	Disc length
DW	Disc width
EEZ	Exclusive economic zone
EM	Electronic monitoring
EU	European Union
F	Female
FAO	Food and Agriculture Organization
g	Grams
GPS	Global positioning system
ICES	International Council for the Exploration of the Sea
ID	Identification
IPMA	Instituto Português do Mar e da Atmosfera
ISD	Interspiracle distance
IUCN	International Union for Conservation of Nature
IUU	Illegal, unreported and unregulated fishing
M	Male
mm	Millimeters
MSY	Maximum sustainable yield
MW	Mouth width
n or N	Number of samples
N_S	Number of samples per sex
N_T	Number of samples per size category
P	Probability
Q_1	First quartile
Q_2	Median
Q_3	Third quartile
r^2	Coefficient of determination
REM	Remote electronic monitoring
RJC	*Raja clavata*
RJE	*Raja microocellata*
RJH	*Raja brachyura*
RJM	*Raja montagui*
RJN	*Leucoraja naevus*
RJU	*Raja undulata*
SD1	Pre-dorsal length
SE/POD	Pre-orbital length

SPED	Spiracle posterior edge distance
T	Size Category
TAC	Total allowable catch
TL	Total length
VMS	Vessel monitoring system

1 INTRODUCTION

1.1 Fisheries management

Fisheries are an important activity that plays a crucial role in the economy of many countries around the world, and one of its main contributions is as a vital source of protein for millions of people, especially in many developing countries. In 2020, global fisheries and aquaculture production reached 214 million tons, of which 90.3 million tons came from capture fisheries and 78.8 million tons from marine waters (FAO, 2022). However, fish and other species of commercial interest are not an infinite resource; 80% of fish stocks were fully exploited, overexploited, or depleted, as reported in 2009 (Flothmann *et al.*, 2010), and the number of fish stocks under exploitation within biologically sustainable levels has been decreasing, in 2019 this value was 64.6%, in contrast, the number of fish stocks fished at a biologically unsustainable level has been increasing to 35.4% in 2019 (FAO, 2022). Effective fisheries management is crucial to ensure that fishing activities are conducted in a way that minimizes detrimental impacts on fish stocks and ecosystems. (Grafton *et al.*, 2006; Prager and Rosenberg, 2008; Medeiros *et al.*, 2018). This involves implementing sustainable measures and policies to maintain healthy fish populations and safeguard the marine ecosystem while achieving the socio-economic goals governments and stakeholders aim to obtain in fisheries. Fisheries management regimes typically consist of a variety of tools designed to limit either the methods used to catch fish as well as quantity and types of catch (such as fishing gear regulations, fishing seasons and/or area closures, quotas, minimum landing size) (Selig *et al.*, 2017; Fernández *et al.*, 2020). In Europe, the Common Fisheries Policy (CFP) of the European Union (EU) sets the guidelines for fisheries management, which aims to ensure environmentally sustainable exploitation of marine biological resources and the long-term viability of the sector (Frost and Andersen, 2006). To achieve this objective, the EU has adopted legislation on access to EU waters, the allocation and use of resources, total allowable catches (TACs), fishing effort limitation, and technical measures (Hentrich and Salomon, 2006; Penteriani *et al.*, 2010).

1.2 Stock assessment

One crucial part of fisheries management is stock assessment as it provides vital data on the health and abundance of fish populations. This enables sustainable use, ecosystem protection, economic viability, regulatory compliance, adaptation to environmental change, and stakeholder engagement. Stock assessment is the scientific process of gathering and analyzing information on the status of populations and estimating its sustainable yields (Methot *et al.*, 2014). Assessments are fundamental to the management of fisheries since their aim is to attain exploitation within biological sustainability (Gebremedhin *et al.*, 2021). The evaluation involves acquiring and analyzing data to determine fish population size and fishing mortality and to make informed decisions about managing these resources responsibly and within sustainable levels (Walters and Martell, 2002). Additionally, it encompasses quantitative methods for assessing populations within ecosystems using various sampling techniques to comprehend aspects like abundance, growth, reproduction, and feeding trends while also considering evolutionary impacts due to fishing activities on traits and behavior affecting ecosystem health and economic value (Jennings *et al.*, 1998; Conover and Munch, 2002; Swain *et al.*, 2007; Kuczynski *et al.*, 2018). Furthermore, ecological and socio-economic parameters can also be considered when evaluating sustainability (Colloca *et al.*, 2013; Melnychuk *et al.*, 2017).

1.3 Data used in stock assessment

In the context of stock assessment, two main types of data are used: fishery-independent and fishery-dependent data. These data are crucial in stock assessment to evaluate the status and trends in populations of exploited species (Pennino *et al.*, 2016). By incorporating diverse data sources and using various methodologies, stock assessment allows for a comprehensive understanding of the status and evolution of fish stocks (Kindong *et al.*, 2020). Both fishery-independent and fishery-dependent data can include biological data on species such as the number and weight of individuals caught or landed, their length, age (obtained from skeletal structures such as otoliths and scales), sex and maturity stage (obtained from macroscopic or microscopic analysis) (Begg and Waldman, 1999). Fishery-independent data comes from non-commercial or recreational activities such as research surveys at sea conducted in either research or commercial vessels. These can include for example fishing, acoustics, visual census, video recordings, and tagging among others, usually conducted by national and scientific institutes (Cotter *et al.*, 2004; ICES, 2022a).

Fishery-dependent data is obtained through various types of methods. One of the methods to obtain official fishery-dependent data are logbooks and catch reports, which are maintained by fishers and fishing vessels to detail their fishing activities (in what concerns geographical location, date and time, gear used, and fishing effort e.g., in duration of employment of the fishing gear, number of hooks, gear dimension) as well as species caught and their quantity (Cotter *et al.*, 2004; McCluskey and Lewison, 2008). Vessel-monitoring systems also provide automatic geographical positional official data on fishing vessels (Watson *et al.*, 2018). Also, official data on landings and sales can be obtained at the fish landing ports and or first sale markets (Correia *et al.*, 2016). For example, in Portugal, most of the fishing fleet land their catch at fishing ports managed by a public company (DocaPesca) that weighs and auctions the fish landed. In these ports landing records can be collected and can include species and weight (Seixas *et al.*, 2024). Another method is through control observer programs, where control observers are placed on fishing vessels to monitor and record fishing activities and species composition of catch for control purposes (Faunce *et al.*, 2015). Scientific observers, onboard or in port, can also collect additional data to the already available one from official sources, namely biological data such as species composition, length, weight, and sex of caught or landed specimens, including bycatch in the case of catch (McCluskey and Lewison, 2008; ICES, 2022a). In addition, questionnaires and interviews to fishers can also be used for control or scientific purposes, with qualitative and quantitative information describing their fishing activities, target species and fishing areas are collected (Silver and Campbell, 2005).

Another method that has been increasingly employed for obtaining fishery-dependent control or scientific data is electronic monitoring (EM), which mainly uses cameras and sensors on fishing vessels to automatically record fishing catches and effort without the need for an observer on site and provides continuous and objective data acquisition (Gilman *et al.*, 2019; van Helmond *et al.*, 2020).

The reliability of data obtained from fisheries has been a subject of consistent inquiry (Cotter and Pilling, 2007). For example, landings fail to capture data on every fish caught, as a portion of the catch is often discarded at sea, therefore port sampling initiatives solely gather information on landed catch, neglecting discarded catch (including live releases and dead discards) (Gilman *et al.*, 2019; van Helmond *et al.*, 2020). Misreporting may occur when fishers fail to accurately report fisheries catches and/or effort. This can have significant implications for the management and conservation of fish populations, distorting our understanding of the impact of fishing activities on vulnerable species (Borges, 2015). Consistent data collection is essential for accurately assessing fish stock development (Ovando *et al.*, 2021). Different data collection methods require varying frequencies, with different implications in terms of budget, time, and human resources. Consequently, there has been an increased use of electronic tools in fisheries to enhance effectiveness and expand the scope of collected data (van Helmond *et al.*, 2020).

The challenges associated with the adoption of innovations in fisheries management encompass the transition from conventional paper-based methods to digital tools, ensuring the timely submission of reports, and identifying cost-effective solutions to improve the monitoring, for instance of small-scale fisheries and long-distance fisheries among others (Mangi *et al.*, 2015; Kharin *et al.*, 2019).

1.4 Electronic monitoring

In the fishing industry, EM is often described as an advanced system that captures fishing data directly from fishing vessels (van Helmond *et al.*, 2020). This innovative technology, also referred to as remote electronic monitoring (REM), operates through electronic devices, eliminating the need for direct human involvement in data collection. The collected data is transmitted remotely and stored in specialized scientific and management databases, where it undergoes thorough evaluation and analysis by skilled experts (van Helmond *et al.*, 2017; Bartholomew *et al.*, 2018). The EM system can integrate and encompass different electronic devices such as high-definition video cameras, global positioning systems (GPS), movement sensors, environmental sensors, and computer hardware to comprehensively capture and record a wide range of data related to fishing activities (Lee *et al.*, 2010; Gilman *et al.*, 2014, 2019; van Helmond *et al.*, 2020). Video cameras can capture crucial aspects of fishing activities like gear deployment, catch handling and discard practices, while sensors track vessel positioning, speed, course, and gear performance, offering insights into fishing effort and operational patterns (Kindt-Larsen *et al.*, 2011; Stanley *et al.*, 2011). Environmental data, such as on sea surface temperature and depth, contribute to understanding the habitat conditions where fishing occurs (Gilman *et al.*, 2019; Brown *et al.*, 2022; Chakraborty *et al.*, 2022). Vessel monitoring system (VMS) and Automatic Identification System (AIS) as well as e-logbooks to register fishing vessel activities can also be considered here (Watson *et al.*, 2018; Gilman *et al.*, 2019; Campos *et al.*, 2023).

Although not as disseminated as the on board / at sea counterparts, collection of data at fishing ports through electronic devices can also be considered as EM or REM, since it follows the same path or chain of data collection and analyses, with the main difference being the place of collection and sometimes the type of data collected (Mangi *et al.*, 2015; Maia *et al.*, 2016; Bradley *et al.*, 2019; van Helmond *et al.*, 2020; Palmer *et al.*, 2022). The lack of explicit reference to EM in articles about data collection at fishing ports could be due to the focus on specific technologies or methods rather than categorizing the studies under EM (Maia *et al.*, 2016; Álvarez-Ellacuría *et al.*, 2020; Palmer *et al.*, 2022). Authors may use different terms like remote sensing or automated data collection. They may also assume the audience is familiar with EM and choose to focus on specific applications or outcomes of the technology (Mangi *et al.*, 2015; Palmer *et al.*, 2022). Despite the absence of the term EM, the underlying principles of using electronic technologies to collect data and monitor fishing activities can still be present in the studies, contributing to the broader understanding of EM in fisheries management (Mangi *et al.*, 2015; van Helmond *et al.*, 2020).

Great advances in technology and computer sciences have prompted significant advances in the use of EM (Gilman *et al.*, 2019; van Helmond *et al.*, 2020; Garren *et al.*, 2021). And for instance, the adoption of EM systems has been accelerated by the challenges posed by the COVID-19 pandemic, due to the additional health and safety protocols applied during the pandemic (FAO, 2022; Seixas *et al.*, 2024). EM systems are increasingly being enhanced with machine learning and artificial intelligence to analyze the vast amounts of data collected, providing near-real-time information to stakeholders (Qiao *et al.*, 2021; Bonofiglio *et al.*, 2022). This technology can potentially not only reduce costs but also increase the efficiency and effectiveness of monitoring activities (Gilman *et al.*, 2019; Plet-Hansen *et al.*, 2019; van Helmond *et al.*, 2020). Additionally, cloud-based platforms are being developed to facilitate the transfer, storage, analysis, and reporting of EM data across different regions and programs (Bradley *et al.*, 2019; Merrifield *et al.*, 2019).

These systems can be used for data collection for official control and compliance purposes, as well as for monitoring purposes provide a comprehensive understanding of fishing operations (Gilman *et al.*, 2020). Logbook and reporting data collected electronically through systems like AIS and electronic logbooks can contribute to ensure accuracy and transparency in reported data (James *et al.*, 2018; Emery *et al.*, 2019). The adoption of EM has proven effective in various pilot projects worldwide, demonstrating its value in ensuring compliance, fighting illegal, unreported, and unregulated (IUU) fishing, and providing verifiable data that supports sustainable fisheries management (Monteagudo *et al.*, 2015; van Helmond *et al.*, 2020; Willette *et al.*, 2023). By integrating these advanced technologies, the fishing industry can achieve better management, conservation, and regulatory compliance, ultimately promoting sustainable fishing practices and protecting marine ecosystems (Bradley *et al.*, 2019; Gilman *et al.*, 2019; Ditria *et al.*, 2022).

In a global review of EM in fisheries between 1999 and 2018, data was collected from 100 electronic monitoring trials and 12 fully implemented electronic monitoring programs worldwide, as seen in Figure 1.1, covering a variety of fishing gears. The review found that EM is mainly employed in Canada and the United States (including Alaska, West Coast and East Coast), as well as in Oceania, Europe, and West Pacific. Since 1999, there has been a consistent increase in the number of deployed EM systems due to the implementation of monitoring programs. Most programs were initiated to address the need for detailed effort and catch monitoring (van Helmond *et al.*, 2020).

Figure 1.1 –Map showing EM trials and fully implemented programs around the world. From van Helmond et al., 2020.

Electronic monitoring at landing ports has also been studied and tested to monitor and document landings (Palmer *et al.*, 2022; Wibowo *et al.*, 2023). Video-based systems, often combined with AI-powered image recognition or deep learning algorithms, were employed to identify species and record fish size (Maia *et al.*, 2016; Álvarez-Ellacuría *et al.*, 2020; Silva *et al.*, 2020; Palmer *et al.*, 2022; Wibowo *et al.*, 2023). These systems can not only improve regulatory compliance but can also facilitate data collection, allowing for more accurate species identification and catch estimation for better stock assessments (Mangi *et al.*, 2015; Palmer *et al.*, 2022; Wibowo *et al.*, 2023).

EM systems are designed to reduce the requirement for additional personnel, except for instances where supplementary biological data needs to be collected, such as the sampling of otoliths for age determination and growth analyses (Needle *et al.*, 2015; Ulrich *et al.*, 2015). This streamlined approach can potentially reduce costs and improve efficiency in fisheries monitoring and management (Watson *et al.*, 2018; van Helmond *et al.*, 2020).

Overall, EM systems can potentially enhance transparency, improve data accuracy, and support sustainable fishing practices by providing detailed information on species composition, catch numbers, volumes, and lengths (Gilman *et al.*, 2019; van Helmond *et al.*, 2020). This can contribute to enable better management, conservation, and regulatory compliance in fisheries (Plet-Hansen *et al.*, 2019).

1.5 Case study area, species and fisheries

1.5.1 Case study area

The data utilized in this study was sampled from skate landings at Portuguese fishing ports. The Portuguese continental national fishing fleet mostly operates in Portuguese waters in the more coastal area and the fleet is dominated by small vessels (about 91% under 12 m) that use several fishing gears in the same or different fishing trips (DGRM, n.d.; Duarte et al., 2009; Oliveira et al., 2015; Government of Portugal, 2020; Instituto Nacional de Estatística, 2023). For the current study, the study area includes the specified fishing area and is designated as the International Council for the Exploration of the Sea (ICES) Subdivision 27.9.a, which is the subarea 9.a assigned by ICES, within the area 27 by the Food and Agriculture Organization (FAO) (FAO, n.d.; ICES, 2022b).

This area in the Northeast Atlantic, encompassing the waters along the western coast of the Iberian Peninsula, is characterized by diverse marine ecosystems and dynamic oceanographic conditions (Relvas *et al.*, 2007; Gomes *et al.*, 2018), extending from the Strait of Gibraltar in the south to the northern boundary at the 43°N latitude (FAO, n.d.; ICES, 2022b). This region is of considerable ecological and economic importance due to its rich biodiversity and significant fisheries (Teixeira *et al.*, 2014; Gomes *et al.*, 2018; Baptista *et al.*, 2022). The continental shelf of Portugal (ICES Subdivision 27.9.a) is generally narrow, except for the region between the Minho River and the Nazaré Canyon, and in the Gulf of Cádiz, where it expands. The incline is steep, with an irregular bottom characterized by canyons and cliffs (Lastras *et al.*, 2009; Masson and Tyler, 2011; ICES, 2022b). It features diverse oceanographic processes, including the convergence of the northward-flowing Portugal Current and the southward-flowing Canary Current, creating a complex hydrodynamic environment with seasonal variability in temperature, salinity, and nutrient distribution (Santos *et al.*, 2004; Relvas *et al.*, 2007). The bathymetry varies from shallow coastal shelves to the deep Nazaré Canyon, enhancing local hydrodynamics and biological productivity through nutrient-rich upwelling (Sousa *et al.*, 2005; Gomes *et al.*, 2018). The area includes a variety of habitats such as sandy and rocky shores, seagrass beds, and kelp forests, which are crucial for supporting diverse marine life, including numerous commercially important fish species (Cattrijsse and Hampel, 2006; Gomes *et al.*, 2024). Coastal and estuarine zones, like the Tejo estuary, are highly productive due to nutrient inputs from terrestrial runoff and river discharges, serving as important nurseries for many marine fish species (Vasconcelos *et al.*, 2010). Seasonal variations driven by climate and oceanography include spring and summer upwelling events along the western Iberian coast (Alvarez *et al.*, 2008), enhancing primary production and directly supporting fisheries of small pelagic fishes (Alvarez *et al.*, 2011). Autumn and winter are characterized by the influence of the Iberian Poleward Current, affecting species distribution and ecosystem dynamics and even the occasional winter upwelling (Ríos *et al.*, 1992; Vitorino *et al.*, 2002). Sea surface temperatures range from 12°C to 25°C, influenced by upwelling events and the mixing of different water masses (Alvarez *et al.*, 2005; Pessanha Santos *et al.*, 2024). Salinity is around 35 (subsurface salinity) but can be lower near river mouths due to freshwater inputs, impacting marine organism distributions (Relvas *et al.*, 2007).

The study area supports a wide array of marine species and high biodiversity and is a critical area for fisheries (Moura *et al.*, 2020), especially for Portugal and also Spain. Sustainable management practices are crucial to balance resource exploitation with biodiversity conservation, requiring a deep understanding of the ecosystem dynamics (Baudron *et al.*, 2014).

1.5.2 Chondrichthyes

Chondrichthyes, also referred to as cartilaginous fishes, constitute a class of fishes characterized by their skeletons primarily comprised of cartilage, distinguishing them from bony fishes (Compagno, 2002; Nelson *et al.*, 2016). The class splits into two subclasses: Elasmobranchii, encompassing sharks, rays, and skates, and Holocephali, which comprises chimaeras or ghost sharks, presenting a diverse distribution across marine and freshwater environments (Awruch, 2018). With a rich evolutionary history dating back to the Silurian period, exceeding 400 million years (Coates *et al.*, 2018), Chondrichthyes have exhibited persistence through multiple mass extinction events (Inoue *et al.*, 2010; Sallan and Coates, 2010). The phylogeny of Chondrichthyes has been a topic of intense research and discussion (Martin, 2001; Human *et al.*, 2006), with recent molecular studies providing crucial insights into their evolutionary relationships (Rocco *et al.*, 2007; Kousteni *et al.*, 2021). These studies have confirmed the monophyly of Elasmobranchii and Holocephali, suggesting a shared common ancestor for these groups (Inoue *et al.*, 2010; Lovejoy *et al.*, 2018). Molecular phylogenetics has also played a key role in clarifying relationships within the Elasmobranchii (Winchell *et al.*, 2004), such as the positioning of skates and rays (Batoidea) as a monophyletic group (Pavan-Kumar *et al.*, 2014), representing the sister group to all other sharks (Selachii).

One of the most distinctive features of Chondrichthyes is their skeleton, which is composed primarily of cartilage rather than bone (Atake and Eames, 2021). This cartilaginous structure is often reinforced by a unique type of tissue known as tessellated calcified cartilage, providing both flexibility and strength (Maisey et al., 2020). Additionally, Chondrichthyes possess placoid scales or dermal denticles, which are tiny, tooth-like structures embedded in their skin, contributing to their hydrodynamic efficiency and protection against predators (Dillon *et al.*, 2017; Lloyd *et al.*, 2021). Furthermore, the group exhibits a wide range of sensory adaptations (Slobodian *et al.*, 2021), including highly developed electroreceptive systems that enable them to detect the electric fields produced by other organisms, aiding in their hunting and navigation endeavors (Freitas *et al.*, 2006; Bellono *et al.*, 2018). Their respiration process involves multiple gill slits, generally numbering between four to seven on each side of their body (Stedman and Garner, 2018), and they exhibit internal fertilization, with males possessing claspers, modified pelvic fins used to transfer sperm to females (Wourms, 1977; O'Shaughnessy *et al.*, 2015). Their reproductive strategies vary, encompassing oviparity (egg-laying) and various forms of viviparity (live-bearing) (Awruch, 2018; Yoshida and Asturiano, 2020), with certain species demonstrating remarkable parental investment (Hussey *et al.*, 2010; Mull *et al.*, 2020). Also, regarding reproduction, Chondrichthyes have very low fecundity, late maturity and slow growth rates, which vary among species (Wourms, 1977; Cailliet *et al.*, 2005; Pardo *et al.*, 2016). Additionally, the group has displayed adaptability to a range of ecological niches, from deep-sea environments to coastal waters (Shipley *et al.*, 2017; Awruch, 2018; Johri *et al.*, 2019).

Chondrichthyes are facing critical threats due to overfishing, habitat loss, climate change and pollution (Dulvy *et al.*, 2021). Extensive studies have assessed their global conservation status and underscored the urgent need for effective management and conservation strategies, with roughly a quarter of Chondrichthyes species at risk of extinction (Dulvy *et al.*, 2014). Conservation efforts are underway in various regions, but their effectiveness varies widely (Lucifora *et al.*, 2019; Cortelezzi *et* *al.*, 2022). Particularly, the Indo-Pacific Biodiversity Triangle and parts of the Atlantic Ocean (Dulvy *et al.*, 2014), the Arabian Sea and adjacent waters (Jabado *et al.*, 2018), and the Aegean Sea in the Eastern Mediterranean (Damalas and Vassilopoulou, 2011), face high fishing pressure, habitat degradation, and issues in regulatory enforcement, exacerbating the decline of Chondrichthyes populations. To secure the long-term survival of these crucial marine organisms, improvement in regulations, enforcement of existing protection measures, and comprehensive international cooperation are urgently needed (Dulvy *et al.*, 2014, 2021; Davidson *et al.*, 2016). Effective management and regional collaboration are vital for their protection (Sabadin *et al.*, 2020); however, efforts face significant challenges as they require an integrated blend of socio-economic development, scientific monitoring and research, and conservation (Espinoza *et al.*, 2018; Lucifora *et al.*, 2019).

Elasmobranchii, the subclass containing sharks, rays and skates, is further divided into two superorders: Selachimorpha or Selachii (sharks) and Batoidea (rays and skates) (Vélez-Zuazo and Agnarsson, 2011; Amaral *et al.*, 2018; Villalobos-Segura *et al.*, 2022). Selachimorpha (sharks) are characterized by their streamlined bodies and primarily pelagic lifestyles, though some species inhabit benthic environments (Compagno, 1990; Dolce and Wilga, 2013). Batoidea (rays and skates) includes more than 600 species (Weigmann, 2016), which are typically dorsoventrally flattened and have enlarged pectoral fins fused to their heads, forming a disk-like shape (Franklin *et al.*, 2014; Martinez *et al.*, 2016b). They are primarily benthic, meaning they live on or near the bottom of bodies of water (Bezerra *et al.*, 2021). Within Batoidea, there are four orders: one order of skates (Rajiformes), and three orders of rays [Myliobatiformes (stingrays), Torpediniformes (electric rays), and Pristiformes (sawfishes)] (Weigmann, 2016; Moreira and de Carvalho, 2018).

1.5.3 Rajiformes

Rajiformes, which include skates and rays, have flat bodies and large pectoral fins (Fontanella *et al.*, 2013). Skates are distinguishable by their larger tails and the absence of venomous spines found in many rays (Aschliman *et al.*, 2012; Smith *et al.*, 2016). Despite their relatively limited distribution and similar body shapes and habitat preferences, rays and skates exhibit remarkable species diversity (Ebert and Compagno, 2007). Skates have backs and tails often with multiple thorns or spines (McEachran and Konstantinou, 1996). Skates have electroreceptors like other elasmobranchs, allowing them to detect the weak electrical signals produced by prey (Camperi *et al.*, 2007). Unlike rays, skates reproduce by laying eggs enclosed in capsules instead of giving birth to live young (Dulvy and Reynolds, 1997; Chiquillo *et al.*, 2014; Awruch, 2018). Skates are more diverse at higher latitudes and in deeper waters, and they generally live in shallower waters toward the poles but prefer deeper depths in warm temperate and tropical regions (Ebert and Compagno, 2007; Bizzarro *et al.*, 2014; Barbini *et al.*, 2018).

Some confusion is created by the fact that several skate species have ray in their common name (Walker and Hislop, 1998; Griffiths *et al.*, 2013), such as the ones in the present study.

The phylogeny of skates reflects a rich evolutionary history characterized by diversification and adaptation to various marine environments (Aschliman *et al.*, 2012; Crobe *et al.*, 2021).

The family Rajidae is the largest within Rajiformes and includes true skates, found primarily in cold and temperate waters (McEachran and Dunn, 1998; Ebert and Compagno, 2007). Skates typically have two dorsal fins on the tail and lack a stinging barb, which sets them apart from some rays (Last *et al.*, 2016). They are bottom dwellers, often concealing themselves in sediment to ambush prey and primarily feed on small invertebrates and fish (Ebert and Bizzarro, 2007a). Rajidae are characterized by elongated snouts, small dorsal fins near the tail tip, and typically thorny bodies (McEachran and Dunn, 1998; Last *et al.*, 2016). Genera within Rajidae include for example *Raja*, *Dipturus* and *Leucoraja* (McEachran and Dunn, 1998). Molecular studies generally support the monophyly of the family

Rajidae, indicating a common ancestor for all skates (McEachran and Dunn, 1998; Chiquillo *et al.*, 2014; Crobe *et al.*, 2021).

Several members of the Rajidae family also face significant conservation challenges due to their life history traits, which make them particularly vulnerable to overfishing and habitat degradation (Dulvy and Reynolds, 2002; Lago *et al.*, 2012; Barbini *et al.*, 2020).

These species have been targeted for conservation efforts in certain regions, with varying degrees of success (Tinti *et al.*, 2003; Lago *et al.*, 2012; Silva *et al.*, 2012; Simpson *et al.*, 2020). Regions under significant threat include the Northeast and Northwest Atlantic (Dulvy *et al.*, 2000; Mcphie and Campana, 2009; Knotek *et al.*, 2018), the Northwestern Pacific (Orlov and Volvenko, 2022) and the Mediterranean Sea (Barausse *et al.*, 2014), where factors such as intense fishing pressure, habitat degradation and issues in regulatory measures are contributing to the decline of Rajidae populations.

Skates in ICES Subdivision 27.9.a include the thornback ray *Raja clavata*, the cuckoo ray *Leucoraja naevus*, the blonde ray *Raja brachyura*, the small-eyed ray *Raja microocellata*, the brown ray *Raja miraletus*, the spotted ray *Raja montagui*, the undulate ray *Raja undulata*, the shagreen ray *Leucoraja fullonica*, the common skate *Dipturus batis*-complex, (recently split into *D. batis* and *D. intermedius*) (Garbett *et al.*, 2023), the long-nosed skate *Dipturus oxyrinchus*, the sandy ray *Leucoraja circularis*, the white skate *Rostroraja alba*, the mediterranean starry ray *Raja asterias* and the Iberian pygmy skate *Neoraja iberica* (Coelho *et al.*, 2005; Figueiredo *et al.*, 2007; Serra-Pereira *et al.*, 2011; ICES, 2022b; Villagra *et al.*, 2022), with the majority of the mentioned species shown in Figure 1.2.

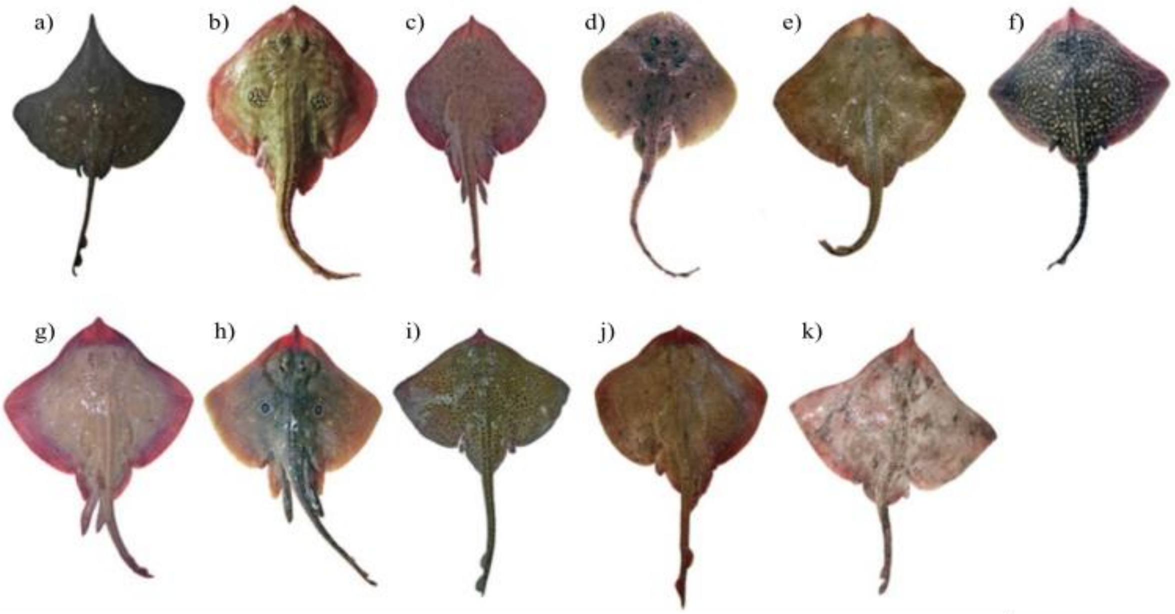

Figure 1.2 – Skates from Portugal: a) longnosed skate (*Dipturus oxyrinchus*), b) cuckoo ray (*Leucoraja naevus*), c) sandy ray (*Leucoraja circularis*), d) Iberian pigmy skate (*Neoraja iberica*), e) blonde ray (*Raja brachyura*), f) thornback ray (*Raja clavata*), g) small-eyed ray (*Raja microocellata*), h) brown ray (*Raja miraletus*), i) spotted ray (*Raja montagui*), j) undulate ray (*Raja undulata*) and k) bottlenosed skate (*Rostroraja alba*). Adapted from Serra-Pereira, 2010.

1.5.4 Portugal fishing trends on skates

Portugal has a significant fishing industry due to its extensive coastline and rich maritime tradition. Skates (family Rajidae) are among the various fish species harvested, and Portugal is a significant player in the elasmobranch fisheries within the EU, which includes skates. A study analyzing Portuguese elasmobranch commercial landings from 1986 to 2017 revealed significant declines and changes in the composition of landings. Notably, demersal skates (*Raja* spp.) were among the most landed taxa, showing a marked decrease over the study period (Alves *et al.*, 2020). The decline of skate landings in Portugal has been attributed to a combination of factors, including overfishing, bycatch, and the introduction of various management measures (Alves *et al.*, 2020; Figueiredo *et al.*, 2020; Silva *et al.*, 2021). However, as for other species, the sector has faced increased regulation due to sustainability concerns. These species are characterized by biological parameters that make them particularly susceptible to fishing pressure, such as slow growth and low reproductive rates.

In the EU, the CFP, established in 1983 and reformed in 2013, aims to ensure sustainable fishing practices across EU member states and includes measures such as TACs and quotas designed to maintain fish stocks at sustainable levels (Symes, 1997; Penas Lado, 2019). The definition of TACs is primarily based on scientific advice provided by ICES, but due to socioeconomic considerations, the final setting of TACs can be above the levels recommended (O'Leary *et al.*, 2011; Villasante *et al.*, 2011). For example, from 2010 to 2017, 60% of the TACs were set above the recommended levels, undermining efforts to reduce overfishing (Borges, 2018). The 2013 CFP reform introduced the landing obligation (LO), requiring all catches of regulated species to be landed. This policy aimed to reduce discards and promote more selective fishing practices (Guillen *et al.*, 2018). However, its implementation has been challenging, particularly for small-scale fisheries facing significant socioeconomic impacts (Catchpole *et al.*, 2017; Villasante *et al.*, 2019). These factors and the general decline in fishing effort, while intended to reduce discards, may have contributed to the observed changes in the Portuguese elasmobranch landings over the past three decades and their composition (Monteiro, 2016; Alves *et al.*, 2020; Silva *et al.*, 2021).

Increased scientific research and monitoring have provided deeper insights into the population dynamics and ecological significance of skates in Portuguese waters (Farias *et al.*, 2006; Serra-Pereira *et al.*, 2011; Serra-Pereira *et al.*, 2014; Marandel *et al.*, 2018; Elliott *et al.*, 2020; Figueiredo *et al.*, 2020).

One of the main scientific advisory bodies that provides advice on the status of EU fish stocks and the management measures needed to ensure their sustainability is ICES. The advice aims at providing the basis for setting TACs and quotas to achieve Maximum Sustainable Yield (MSY) for various fish stocks (Stokke and Coffey, 2004; Ballesteros *et al.*, 2018). Despite this, adherence to ICES advice has been inconsistent (Hauge *et al.*, 2007). In the case of skates, ICES provides routine advice for Rajiformes on a species-specific basis (ICES, 2022b), and these assessments have been critical in informing management decisions and conservation strategies (ICES, 2022b).

European legislation has prohibited EU vessels from fishing, retaining on board, transhipping, or landing certain species in specific ICES areas since 2010, including the common skate, undulate ray and white skate (EU, 2010). Continued efforts to align policy decisions with scientific advice and improve compliance are essential to ensure the sustainability of skate populations and the broader marine ecosystem (Machado *et al.*, 2004).

1.5.5 Case study species

The present study focuses on the species of the family Rajidae which are most commonly landed in Portuguese ports, namely: *Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Leucoraja naevus*, *Raja montagui*, *Raja undulata* (Machado *et al.*, 2004; Correia *et al.*, 2016; Alves *et al.*, 2020). A summary of their life history characteristics, habitat use, and conservation status is presented below.

Raja brachyura, commonly known as the blonde ray, is a species of skate found predominantly in the northeastern Atlantic Ocean and western Mediterranean Sea (Farias *et al.*, 2006; Catalano *et al.*, 2007; Thys *et al.*, 2022). This species is characterized by its broad, diamond-shaped pectoral fins, a tail with rows of small thorns, blunt snout, with a coloration from ochre to pale greyish-brown and numerous dark spots, and a white ventral surface (Ebert and Stehmann, 2013). *Raja brachyura* prefers sandy and muddy substrates in coastal and shelf areas, typically at depths ranging from 10 to 300 meters, but is most found down to 150 meters (Catalano *et al.*, 2007; Follesa *et al.*, 2010; McCully *et al.*, 2015). Females generally attain larger sizes than males (Porcu *et al.*, 2014). The maximum recorded size for *R. brachyura* is approximately 120 cm in total length (McCully *et al.*, 2015). Males generally mature at a length of about 55-84 cm, while females mature at a length of around 60-93 cm (Gallagher *et al.*, 2004; Figueiredo *et al.*, 2007; McCully *et al.*, 2012, 2015; Porcu *et al.*, 2014; Thys *et al.*, 2022). The species exhibits a seasonal reproductive cycle, with peak egg-laying occurring in spring and summer (Gallagher *et al.*, 2004; Porcu *et al.*, 2014; McCully *et al.*, 2015). According to the latest assessment by the International Union for Conservation of Nature (IUCN), *R. brachyura* is currently classified as "Near Threatened" in the European area (McCully *et al.*, 2015). And according to this assessment, the population trend of this species in the same area is also classified as “Decreasing” with no severe fragmentation (McCully *et al.*, 2015), with declining population trends due to overfishing and habitat degradation supported by other studies (Follesa *et al.*, 2010; McCully *et al.*, 2015; Simpson *et al.*, 2020). The species is particularly vulnerable to bycatch in trawl and gillnet fisheries (Figueiredo *et al.*, 2020; Amelot *et al.*, 2021). These threats are exacerbated by the species’ slow growth and low reproductive rate, making recovery difficult (Gallagher *et al.*, 2004; Thys *et al.*, 2022). Based on the latest ICES assessment and advice regarding *R. brachyura* stock (rjh.27.9a) in the study area, the stock size exceeds the level that requires a reduction in fishing mortality, and the fishing pressure is at the level of MSY (ICES, 2022c, 2022d).

Raja clavata, commonly known as the thornback ray inhabits coastal and shelf waters of the northeastern Atlantic and the Mediterranean Sea (Chevolot *et al.*, 2006; KrstulovićŠifner *et al.*, 2009; Santos *et al.*, 2021). *Raja clavata* is distinguished by its rhomboid-shaped pectoral fins and the presence of numerous small, thorn-like spines across its dorsal surface, especially along the midline of its back and tail (Ebert and Stehmann, 2013). Dorsal coloration variations range from brown to grey with yellow marbling and tail with alternated light and dark bands (Ebert and Stehmann, 2013). *Raja clavata* is commonly found on sandy, muddy, or gravel substrates, typically at depths ranging from 10 to 300 meters (KrstulovićŠifner *et al.*, 2009; Serena *et al.*, 2016; McAllister *et al.*, 2024). The maximum recorded size for this species is approximately 118 cm for females and 98 cm for males (Whittamore and McCarthy, 2005; Serena *et al.*, 2016). Males generally mature at a length of about 59-72 cm, while females mature between 59-78 cm (Serra-Pereira *et al.*, 2011; Kadri *et al.*, 2014b; Serena *et al.*, 2016; Bilgin and Onay, 2020). This species exhibits a continuous or nearly continuous reproductive cycle, with regional variations of its peak (Serra-Pereira *et al.*, 2011; Bilgin and Onay, 2020). According to the latest assessment by the IUCN, *R. clavata* is currently classified as “Near Threatened” in the European area (Serena *et al.*, 2016). Additionally, this assessment rated its population trend as “Stable” with no severe fragmentation (Serena *et al.*, 2016). Based on the latest ICES assessment and advice regarding *R. clavata* stock (rjc.27.9a) in the study area, the stock size exceeds the level that requires a reduction in fishing mortality, and the fishing pressure is above the level of MSY (ICES, 2022c, 2022e).

Raja microocellata, commonly known as the small-eyed ray, is a species of skate found in the northeastern Atlantic (Ryland and Ajayi, 1984; Ellis et al., 2005; Ellis and Walls, 2015b). This species is characterized by its short blunt snout, a smaller tail and about the same diamond-shaped pectoral fins as the previous species, with a dorsal coloration of greyish or olive color, but mostly pale sandy brown, patterned with light spots and bands arranged nearly parallel to margins of the disc (Ebert and Stehmann, 2013). *Raja microocellata* prefers coastal and shelf areas with sandy or gravel substrates, typically at depths ranging from 10 to 150 meters (Ellis and Walls, 2015b; Serra-Pereira et al., 2014). The species can reach a maximum size of 91 cm in total length (Ryland and Ajayi, 1984). Males generally mature at a length of approximately 58-69 cm, while females mature at slightly larger sizes, around 68-78 cm (Ryland and Ajayi, 1984; Ellis *et al.*, 2011; McCully *et al.*, 2012). The reproductive biology of *R. microocellata* is influenced by environmental factors such as temperature, which can affect developmental rates and hatching sizes (Hume, 2019). The species exhibits a seasonal reproductive cycle, with peak egg-laying occurring between June and September (Ellis and Walls, 2015b). According to the latest assessment by the IUCN, *R. microocellata* is currently classified as “Near Threatened” in the European area (Ellis and Walls, 2015b). Additionally, this assessment rated its population trend as “Stable” (Ellis and Walls, 2015b). Based on the latest ICES assessment and advice regarding elasmobranchs, ICES does not provide assessment or advice for *R. microocellata* in the study area and reports low landing numbers for the region concerning Portuguese fisheries (ICES, 2022c, 2022b).

Raja montagui, commonly known as the spotted ray, inhabits the northeastern Atlantic Ocean, including the North Sea, Irish Sea, and parts of the Mediterranean Sea (Ellis et al., 2015c; ICES, 2022b). *Raja montagui* is identifiable by its diamond-shaped pectoral fin disc and the presence of dark spots scattered across its dorsal surface not extending to the disc margins (Ebert and Stehmann, 2013). *Raja montagui* prefers coastal and shelf areas with sandy or coarse sand-gravel sediments (Ellis *et al.*, 2004; Serra-Pereira *et al.*, 2014), typically at depths ranging from 8 to 283 meters, but more abundant above 100 meters (Ellis *et al.*, 2004). The maximum recorded size for this species is about 80 cm in total length (Ellis *et al.*, 2004). Males typically mature at a length of around 40-60 cm, whereas females mature around 49-64 cm (Ryland and Ajayi, 1984; Gallagher *et al.*, 2004; McCully *et al.*, 2012). According to the latest assessment by the IUCN, *R. montagui* is currently classified as "Least Concern" in the European area (Ellis et al., 2015c). Additionally, this assessment rated its population trend as “Stable” (Ellis et al., 2015c). Based on the latest ICES assessment and advice regarding *R. montagui* stock (rjm.27.9a) in the study area, the stock size exceeds the level that requires a reduction in fishing mortality, and the fishing pressure is below the level of MSY (ICES, 2022c, 2022f).

Leucoraja naevus, commonly known as the cuckoo ray, inhabits the northeastern Atlantic Ocean and the Mediterranean Sea (Valls *et al.*, 2011; Maia *et al.*, 2012; Nykänen *et al.*, 2020). This species is characterized by its small size, subcircular disc and larger tail. Dorsal coloration from light grey to brown with the presence of 2 distinct dark spots on its dorsal surface (Ebert and Stehmann, 2013). *Leucoraja naevus* prefers coastal and shelf areas with sandy or gravel substrates, typically at depths ranging from 20 to 700 meters (Figueiredo *et al.*, 2007; Ellis *et al.*, 2015a). The maximum recorded size for *L. naevus* is 72 cm in total length (Ellis *et al.*, 2015a). Males typically mature at a length of about 48-57 cm, while females mature at around 45-59 cm (Gallagher *et al.*, 2004; Maia *et al.*, 2012; McCully *et al.*, 2012). *Leucoraja naevus* exhibits a continuous reproductive cycle with a peak around February (Maia *et al.*, 2012). According to the latest assessment by the IUCN, *L. naevus* is currently classified as “Least Concern” for the Global and European area (Ellis *et al.*, 2015a). Additionally, this assessment rated its population trend as “Unknown” with no severe fragmentation (Ellis *et al.*, 2015a). Based on the latest ICES assessment and advice regarding *L. naevus* stock (rjn.27.9a) in the study area, the stock size exceeds the level that requires a reduction in fishing mortality, and the fishing pressure is below the level of MSY (ICES, 2022c, 2022g).

Raja undulata, commonly known as the undulate ray, inhabits the northeastern Atlantic Ocean and the Mediterranean Sea (Ellis *et al.*, 2012; Fitori *et al.*, 2023). *Raja undulata* is distinguished by its broad, diamond-shaped disc with undulating dorsal patterns, which consist of dark, wavy lines edged by white spots (Ebert and Stehmann, 2013). *Raja undulata* prefers coastal areas habitats, with preference around estuaries, rias and bays with sandy or coarse substrates (Coelho and Erzini, 2002; Ellis *et al.*, 2012; Serra-Pereira *et al.*, 2015), at depths of 1 to 200 meters, but most common at shallow depths less than 50 meters (Coelho and Erzini, 2006; Baeta et al., 2010; Ellis et al., 2015d). This species can grow to a maximum size of approximately 114 cm in total length (Ellis *et al.*, 2012). Males typically reach maturity at a total length of approximately 74-82 cm, while females mature at around 76-86 cm (Coelho and Erzini, 2006; Moura *et al.*, 2007; Ellis *et al.*, 2012; McCully *et al.*, 2012; Serra-Pereira *et al.*, 2015). The species exhibits a seasonal reproductive cycle, with peak egg-laying occurring around late spring and early summer (Coelho and Erzini, 2006; Moura *et al.*, 2007), with differences between different populations (Ellis et al., 2015d). According to the latest assessment by the IUCN, *R. undulata* is currently classified as “Near Threatened” in the European area (Ellis et al., 2015d). Additionally, this assessment rated the population trend of this species as “Unknown” (Ellis et al., 2015d). Based on the latest ICES assessment and advice regarding *R. undulata* stock (rju.27.9a) in the study area, ICES, 2022f stated the following: "ICES cannot assess the stock and exploitation status relative to MSY and precautionary approach (PA) reference points because information to define reference points is not available.".

These six species play a relevant ecological role in marine ecosystems as predator and prey and feed mostly on benthic invertebrates and small fish (Ajayi, 1982; Ebert and Bizzarro, 2007a; Moura *et al.*, 2008), contributing to the regulation of these populations and maintaining ecological balance. Additionally, their presence indicates healthy benthic habitats, emphasizing their ecological importance (Moura *et al.*, 2008; Simpson *et al.*, 2021)

1.5.6 Portuguese skates’ landings legislation

In Portugal, the management and conservation of elasmobranchs, including skates, are governed by national legislation and EU regulations. This set of statutes specifies a list of prohibited species, including certain vulnerable skates, where their capture, retention, and sale are strictly forbidden to prevent further population decline (EU, 2019; Government of Portugal, 2021; EU, 2023). For species that are not entirely prohibited, Portuguese law sets minimum landing sizes to ensure that individuals have had the opportunity to reach sexual maturity and reproduce before being caught (Government of Portugal, 2022). According to this statute from Portugal, all skates in this study, *Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui* and *Leucoraja naveus*, apart from *Raja undulata*, have the minimum landing size set for 600 mm. Additionally, closed seasons are established during key reproductive periods to further protect skate populations by reducing fishing pressure when these species are most vulnerable. Except for *R. undulata*, all mentioned skate species cannot be caught in quantities greater than 5% of the total on board during the months of May and June in continental Portugal Exclusive Economic Zone (EEZ), independent of fishing art (Government of Portugal, 2016). For *R. undulata*, special rules are employed for the Instituto Português do Mar e Atmosfera (IPMA) to secure the collection of information on the abundance of this species in the zone 9 of ICES (Government of Portugal, 2019). As stated in this statute, the minimum landing size for this species is 780 mm and the maximum is 970 mm. The capture, maintenance on board and landing of this species is permitted only for fishing vessels with a special license and limited to 30 kg of daily live weight. Fishing vessels with no special license can only land, per tide, one exemplar, with additional obligatory documentation. Furthermore, the capture of this species, even with a special permit, is not allowed in the months of May, June and July.

1.5.7 Morphometrics in skates and morphometric relationships studies

Knowledge of morphometrics on skates is essential for better understanding their taxonomy, evolutionary biology and ecological adaptations as well as indispensable for ecological assessments and fisheries management (Serra-Pereira *et al.*, 2010; Thys *et al.*, 2022). Morphometric studies involve quantitatively measuring and analyzing shape and size variations which aid in distinguishing between species, and also populations of a given species, and understanding their ecological niches (Ferreira *et al.*, 2023).

For instance, based on differences in body proportions and meristic characters, it was possible to identify distinct populations of the thorny skate, *Amblyraja radiata*, in the Northwest Atlantic (Templeman, 1987). Research on the blonde ray (*R. brachyura*) and the thornback ray (*R. clavata*) has revealed significant differences in morphometric measurements, which are correlated with variations in growth rates and sexual maturity (Thys *et al.*, 2022). These findings underscore the necessity for species-specific management in skate fisheries. Even morphologically similar species may exhibit diverse growth and reproductive patterns (Thys *et al.*, 2022). Another study focused on six skate species from the Portuguese continental shelf and highlighted the effectiveness of morphometric ratios in identifying species, especially in the case of closely related species like *R. brachyura* and *Raja montagui*. The study emphasized the importance of using morphometric data to enhance species discrimination, thereby improving the precision of species-specific landings in fisheries (Serra-Pereira *et al.*, 2010).

Sexual dimorphism in skates is a topic of interest in morphometric analysis. Studies on *Leucoraja erinacea* and *Leucoraja ocellata* have uncovered significant differences in pectoral fin shape between males and females. These differences are associated with reproductive strategies and provide valuable insights into the evolutionary adaptations of skates related to reproduction and habitat utilization (Martinez *et al.*, 2016a).

These examples underscore the importance of morphometrics in resolving taxonomic ambiguities and comprehending the ecological and evolutionary dynamics of skate species. By focusing on variations in shape, size, and structural relationships, morphometric studies contribute to a better understanding of the biology, ecology, and management of skates (Serra-Pereira *et al.*, 2010).

1.6 Objectives

The primary objective of this dissertation is to enhance the methodologies used for biological data collection and analysis in the fisheries sector, particularly focusing on skate species. By integrating electronic monitoring and sampling technologies and comparing them with traditional data collection methods, this study aims to address the following specific objectives:

1. Verify the Functionality of Electronic Monitoring

One of the specific objectives is to assess the efficacy of utilizing fisheries data collected through electronic monitoring technologies. The study aims to evaluate how effectively EM at fishing ports can obtain accurate and comprehensive data on skate species' landings, in contrast with manual measurements collected through conventional approaches. This entails examining the reliability, precision, and practicality of EM for sampling fisheries-related biological data.

2. Test Morphometric Relationships

Another specific objective is to investigate the morphometric relationships of six commercially important species of skates in the northeastern Atlantic, more precisely of the Portuguese coast. This involves analyzing the relationships between various body measurements and how they correlate with total length, which is the main biological parameter for assessing fish populations. By understanding these relationships, the study aims to develop models or equations that can accurately estimate total length from alternative measurements (e.g. disc width, disc length and other morphometric parameters) to identify which provide the most accurate estimates of total length, since these alternative measures are often easier to obtain through electronic monitoring and sampling.

Overall, the study seeks to contribute to enhance the data collection methodologies used in fisheries management by providing means for integrating EM in the data collection and validating their effectiveness and thus aims to contribute to more efficient and accurate monitoring of fish populations and ultimately better-informed management and policies that can help in maintaining healthy fish stocks and safeguarding marine ecosystems.

Electronic monitoring can potentially help in overcoming the challenges associated with traditional data collection methods, such as manual errors, misreporting, and incomplete data, leading to more sustainable and effective fisheries management. Lastly, the dissertation aims to expand the scientific basis for the use of electronic monitoring and sampling technologies in the fisheries sector. By demonstrating the benefits and practical applications of these technologies, this information being useful for stakeholders, including fishers, regulatory bodies, and policymakers.

2 MATERIAL AND METHODS

2.1 Literature review

A bibliographic search was carried out on morphometric relationships, in particular, length and weight measures of several skate species frequently landed by the commercial fishing fleet in Portugal: *Raja brachyura* (Blonde ray, FAO code: RJH), *Raja clavata* (Thornback ray, FAO code: RJC), *Raja microocellata* (Small-eyed ray, FAO code: RJE), *Raja montagui* (Spotted ray, FAO code: RJM), *Leucoraja naevus* (Cuckoo ray, FAO code: RJN) and *Raja undulata* (Undulate ray, FAO code: RJU). The bibliographic searches were undertaken on Google Scholar between mid-October 2022 and early January 2023 using combinations of the following keywords: “morphometric(s)”, “morphometry”, “relation(s)”, “relationship(s)”, “total length”, “disc width” and species names. The found literature was screened for relevant morphometric data, specifically morphometric ratios between disc width and total length, tail length and total length, disc length, and disc width as well as disc length and total length. Furthermore, information on relationships in the form of functions correlating total length with disc width, tail length, disc length, snout tip to the eye, snout tip to the first dorsal, mouth width, total weight, and gutted weight, as well as disc width with disc length and total weight was compiled (relevant measurements shown in Figure 2.1). Information regarding data transformation, statistical relevance of the reported relationships (coefficient of determination: r^2), and statistical models used were also extracted from the publications.

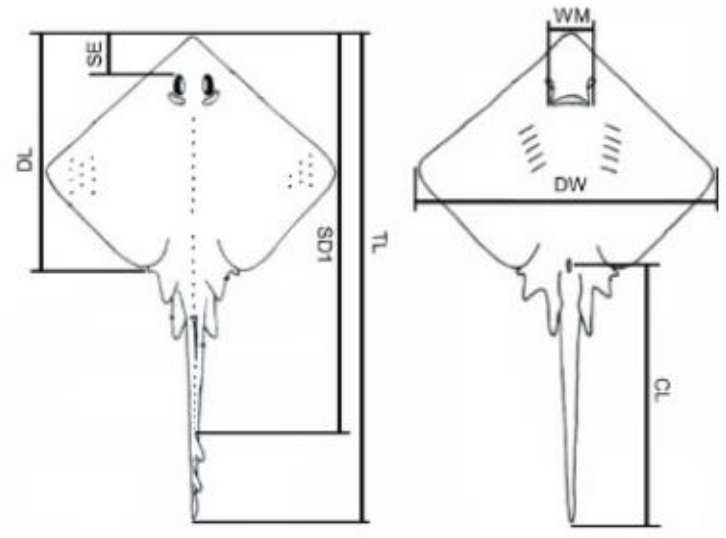

Figure 2.1 – Measurements described in the analyzed scientific publications: total length (distance from the tip of the snout to the end of the tail, TL), disc width (maximum distance between the wing tips, DW), disc length (distance from the tip of the snout to the posterior edge of the disc, DL), tail length (distance from the cloaca to the end of the tail, Cl),pre-orbital length (distance from snout tip to the anterior edge of the eye, SE), pre-dorsal length (distance from snout tip to the beginning of the first dorsal fin, SD1), and mouth width (width of the mouth, WM)

2.2 Fish market sampling

2.2.1 Collection of morphometric data

To confirm the existence of relationships between morphometric measurements in selected species of commercially important skates in Portugal, sampling was carried out at the harbor of Peniche. The skates sampled were landed at Peniche from March 16 to April 27, 2023, in a total of 8 sampling days. Most of the measurements were taken *in situ*, yet a few specimens were frozen, transported to the biological laboratory of IPMA in Algés and measured later. The same six species (*Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui*, *Leucoraja naevus*, and *Raja undulata*), that were previously mentioned, were sampled and different commercial size categories (T1, T2, T3 and T4) were included. To achieve representation of the different commercial size categories per species, a minimum target of 25 individuals per species and commercial size category was set and a selective search was executed by species and size category to best accomplish that goal. For each specimen the species and sex were identified, using the presence or absence of claspers as the identifiable characteristic and the following measurements were recorded to the nearest millimeter (mm; Figure 2.2): total length, disc width, disc length, pre-orbital distance, spiracle posterior edge distance, and interspiracle distance. If the main measurement, total length, was prevented from being accurately obtained, due to some type of damage or injury, fresh or healed, the specimen was excluded from the study. All variables were measured as direct distances between the points/landmarks that define them and not as a measure along the longitudinal axis of the specimen, to be comparable with the data originated from FishMetrics. To measure the larger variables (total length, disc width and disc length), an ichthyometer with a scale in metal with 1 meter was used. Moreover, for measurements that exceeded the scale of the ichthyometer, a soft plastic measuring tape with 1,5 m was utilized to measure the specimens. The smaller variables (pre-orbital distance, posterior edge of the spiracle distance and interspiracle distance) were taken using a metal vernier caliper with a scale up to 200 mm. Additionally, for measurements exceeding the scale of the caliper, the plastic measuring tape was used.

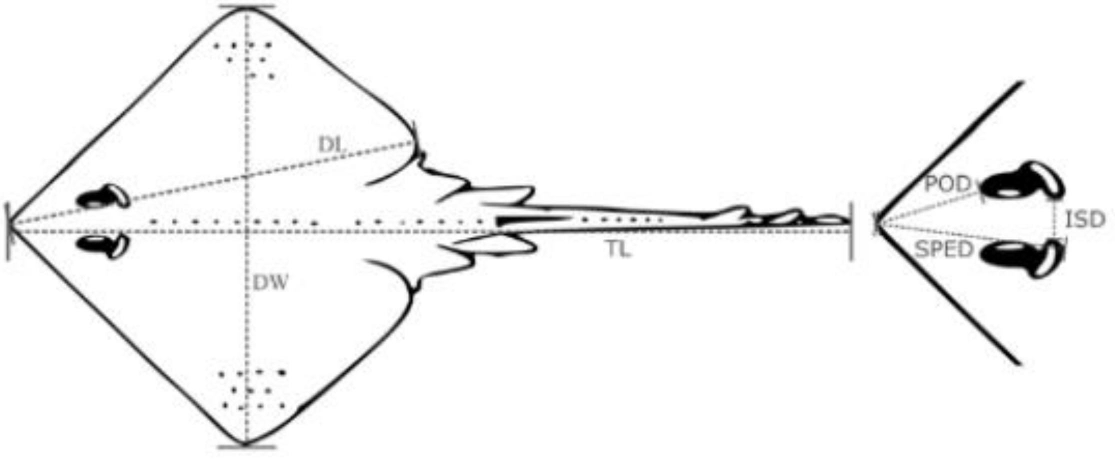

Figure 2.2 – Measurements recorded for each specimen: total length (TL), i.e. distance from the tip of the snout to the end of the tail; disc width (DW), i.e. distance between the wing tips; disc length (DL), i.e. distance from the tip of the snout to the posterior edge of the disc; pre-orbital distance (POD), i.e. distance from the tip of the snout to the anterior edge of the eye; spiracle posterior edge distance (SPED), i.e. distance from the tip of the snout to the posterior edge of the spiracle; and interspiracle distance (ISD), i.e. distance between each inner edge of the spiracles.

2.2.2 Data analysis

Apart from undulate ray for which only 2 individuals were sampled, for all the species considered that had an overall number of samples (n) above 25, the relationships between total length and all other measures were analyzed and subsequently, their linear regression equations and coefficient of determination (r^2) were calculated, using R software (version 4.2.2, October 2022) with the aid of the following packages: readxl (Wickham and Bryan, 2023), tidyverse (Wickham *et al.*, 2019), ggpubr (Kassambara, 2023) and ggpmisc (Aphalo, 2024). Furthermore, for each species these linear regressions were used to predict total length based on the observed values of each secondary measurement (disc width, disc length, pre-orbital distance, spiracle posterior edge distance and interspiracle distance). These predicted total length values were then compared with the observed total length values, aiming to assess the use of the secondary measures as a proxy to infer the total length values. R software was also used for this purpose, to calculate the predicted total length values and the linear regression equations between observed and predicted total length.

2.3 Electronic monitoring sampling

2.3.1 Image selection and collection of morphometric data

With the aim of testing the presence of relationships of morphometric measurements with total length, on the selected species of commercially relevant skates (*R. brachyura*, *R. clavata*, *R. microocellata*, *R. montagui*, *L. naevus*, and *R. undulata*) in Portugal, sampling was conducted through the online platform of FishMetrics (FishMetrics, n.d.). Employing this platform, images of species landed in a fishing port and waiting for the sales auction in DocaPesca (in this case Aveiro) can be measured, more precisely, the distance between two points or along a sequence of points if the individual was not straightly positioned (even if the points are at a different depth from the camera) to 0.01 millimeter (mm). This process allows to obtain measurements of the specimens present in each box, along with relevant information such as box number and the information assigned by DocaPesca during the weighing process to that box number, including vessel identification, box weight, commercial species and commercial size category, capture date; in addition to the date of image recording, picture ID and measure ID automatically assigned by the platform.

To allow the measurement of individuals in the FishMetrics platform, we first implemented a procedure of image pre-selection. We extracted the data (referred to in the previous paragraph) from all images captured between 23 May 2022 to 6 March 2023.

Data analysis was executed using R software (version 4.2.2, October 2022) with the aid of the following packages: dplyr (Wickham *et al.*, 2023), readxl (Wickham and Bryan, 2023), xlsx (Dragulescu and Arendt, 2020), tidyr (Wickham *et al.*, 2024), tidyverse (Wickham *et al.*, 2019), ggpubr (Kassambara, 2023), ggpmisc (Aphalo, 2024). The extracted data was filtered by the species mentioned before (except for *L. naevus* which was not available) and by Raja spp. (which was also attributed by DocaPesca). Next, the objective of randomly selecting 50 samples (images) was set per commercial species and commercial size category, provided that the samples had the commercial species correctly identified. The images/samples selected through this method were then analyzed to see if the species identification was accurate. As a note, a sample could present one or more individuals.

When no misidentifications were detected, and measures could be assessed, the following measurements were taken from the eligible specimens in the sample: total length (TL), disc width (DW), disc length (DL), pre-orbital distance (POD), spiracle posterior edge distance (SPED), and interspiracle distance (ISD), as represented in Figure 2.2. As in the case of sampling *in situ* at the fish market (see Section 2.2.1), if the total length could not be precisely obtained, the specimen was not measured. When necessary, the total length was taken using a sequence of points along the specimen's longitudinal axis, due to the irregular orientation of the specimens. All other variables were measured as direct distances between the defined landmarks. However, when appeared slightly folded in the images, disc width was obtained only when a line from one edge of the disc to the other could be traced, and the method of sequential points was used. It was not always possible to sample all measurements per specimen. During the sampling process, all sampled images were categorized according to a set of classifications (Table 2.1).

Table 2.1 – List of classifications and their descriptions used for categorization of the analyzed samples.

Classifications	**Description**
Measured	Sample correctly identified and measurements were taken
Measure not possible	Commercial species was correct, but the measurement process was not possible
Wrong ID - Not study skate	Commercial species was incorrect, and the species was not one of the skate species considered in this study
Wrong ID - Study skate	Commercial species was incorrect, but it belonged to one of the skate species considered in this study
ID not possible	Commercial species attributed by DocaPesca during the weighing process was not possible to be confirmed
Duplicate	All samples that were duplicates from already pre-selected samples
System Error	Image did not correspond with sample and system information
Blank	Image with no sample

In some cases, the randomly pre-selected images were not selected for measurements, namely when: they were duplicates of already sampled images; they were not of the intended/pre-selected species (i.e. the commercial species assigned by DocaPesca was not correct); it was not possible to identify correctly the species due to low quality of the image, stacked individuals, individuals positioned with the ventral side facing up, partial view of the box/species, or other causes; or image without sample (blank image). In these cases, additional random draws of images were done until the goal of 50 random samples per corrected species and size category was attained. For some species and commercial size categories, all the available samples were analyzed. Furthermore, when the commercial species assigned to a sample was incorrect, but the species in that sample was one of the skate species included in this work, and if the measuring process was possible, then the sample was given its correct identification and measured. Also, in cases where a sample presented a mixture of species and the secondary species was one of the skate species included in this work, and if the measuring process was possible, then an additional sample was created, assigned to the secondary species, and measured. These types of samples were added as extra to the 50 randomized samples of correct species, to add extra measurement data, however, these samples were not included in the first analysis, since it would create modified duplicates of already existing samples.

2.3.2 Analysis of morphometric data

Following the procedures for the selection of samples in the FishMetrics platform, and for species classification and measurement, all eligible individuals of the studied skate species with at least the total length and one additional measure were considered for further analysis. This also included individuals from samples (boxes) that had the species misclassified or mixed in the weighing procedure. For each species, linear regression between total length and all other measures were determined and subsequently, their linear regression equations and coefficient of determination (r^2) were calculated.

Furthermore, as in the fish market data analysis (Section 2.2.2), for each species, these linear regressions were used to predict total length based on the observed values of each secondary measurement (disc width, disc length, pre-orbital distance, spiracle posterior edge distance and interspiracle distance). These predicted total length values were then compared with the observed total length values, aiming to assess the use of the secondary measures as a proxy to infer the total length values. R software was also used for this purpose, to calculate the predicted total length values and the linear regression equations between observed and predicted total length.

3 RESULTS

3.1 Literature review

During the bibliographic search, a total of 34 articles, reports, books, and other scientific publications were found to have relevant information describing different morphometric relations and/or ratios on the referred species. *Raja clavata* had more published data compared with the other species, with 27 publications referring to it, more than double the second species with the most data, which was *R. brachyura* (12 publications). The species with less data from the group was *R. microocellata* with five references. The remaining species, *R. montagui*, *L. naevus*, and *R. undulata*, were studied in ten, nine, and eight publications, respectively. Length data was mainly measured in millimeters (mm), or centimeters (cm) and weight data was presented in grams (g).

In terms of the morphometric relationships presented in the reviewed publications, two ratios (between disc width and total length, as well as disc width and disc length) were used in two articles, while other ratios (between tail length and total length, along with disc length and total length) were only used on one occasion. For the remaining relationships, presented as functions, the most often one was the relationship between total weight and total length (found in 29 of the 34 publications), the second most often used was total length and disc width relationship (found in 17 publications), followed by total weight and disc width relationship (found in 3 publications), while all other relationships were exclusive to a single use. The morphometric relationships relevant to the present study can be found in Annex 1.

Concerning the statistical relevance of the morphometric relationships mentioned, regarding ratios between variables, all the coefficients of determination (r^2) were > 0.51 with a maximum of 0.72. Only one article presented r^2 for ratios and considered interactions between sex, area, and size category, for the statistically significant nested models, but not in a complete manner for all cases, i.e., not all the 5 species studied had the same statistically relevant ratios, for all the size categories, and areas.

In what concerns the functions (models) between variables, the total length - disc width relation was represented mainly by a linear model, apart from two articles that logarithmized this relation. Values of r^2 were, for the most part, superior to 0.92, with a few lower values (0.87; 0.88). Some of those studies found a significant difference between males and females. The relationships between total length and tail length, disc length, snout tip to the eye, snout tip to the first dorsal, and width of the mouth as well as between disc width and disc length were each represented in less than 5 publications, all with $r^2 > 0.91$, although the total length - tail length relation was represented in only one publication (with $r^2 = 0.98$), for *R. undulata*. The article that referred to the association between total length and snout tip to the eye, between total length and snout tip to the first dorsal, and between total length to width of the mouth, presented a statistical difference among sexes, but only for *R. clavata*.

All relationships involving weight (total or gutted) were logarithmized, and a single article used base e while all others used base 10. Concerning the total weight-total length relationship, the majority had $r^2 > 0.91$ with a few lower values (between 0.73 and 0.88). Several studies found statistically significant differences between sexes in this relationship and even some significant differences among capture locations were reported. Regarding total weight - disc width and gutted weight - total length relationships, only the first r^2 values were presented, all > 0.92, for *R. clavata* and *R. montagui*, and all articles that presented these relationships found significant differences between sexes.

From a species-focused perspective, for all statistically relevant relationships found, most species had $r^2 > 0.91$, *R. undulata* had $r^2 > 0.96$ except for one value (0.72), *R. brachyura* had $r^2 > 0.97$ except for a few lower values (0.54; 0.51; 0.88), *R. montagui* had $r^2 > 0.93$ with two lower values (0.51; 0.52) on ratios, *R. microocellata* had $r^2 > 0.92$ with one lower value (0.73), *L. naevus* had $r^2 > 0.91$ with also one lower value (0.51) on a ratio, and finally *R. clavata* had the lowest overall $r^2 > 0.87$ with some lower values (0.56; 0.56; 0.76). It is noteworthy that the lowest values of r^2 (around 0.50) were only for ratios.

3.2 Fish market sampling

During the fish market sampling, 502 specimens of skates landed from a total of 23 different vessels from the multi-gear and trawl fleets were sampled, from a total of 35 fishing trips. The sampled specimens consisted of 139 *R. brachyura* (73 males and 66 females), 163 *R. clavata* (64 males and 99 females), 126 *R. microocellata* (46 males and 80 females), 45 *R. montagui* (7 males and 38 females), 29 *L. naevus* (9 males and 20 females), and lastly 2 *R. undulata* (1 male and 1 female) (Table 3.1). All *R. montagui* sampled were misidentified at landing, namely, 44 were landed as *R. brachyura* and 1 as *R. clavata*. Although a minimum number of individuals per commercial size category was set, it was not achieved for all species and commercial size categories. For *R. brachyura*, the minimum of 25 specimens per commercial size category was achieved except for one of the smaller commercial size categories (T3; n=24 specimens). For *R. clavata*, the minimum sample size in all commercial size categories was achieved. For *R. microocellata*, the minimum sample size in all commercial size categories was achieved except for the smallest size category (T4; n=3 specimens). For *R. montagui*, the minimum sample size was not achieved in any of the commercial size categories (n=1, n=7, n=24, and n=13 specimens, from the biggest to the smallest commercial size category, respectively). For *L. naevus* minimum sample size was only achieved for the smallest size category and the other size categories had no samples. Lastly, for *R. undulata*, only 2 individuals were measured, and data was not used for further analysis, due to the very low number of individuals measured.

Table 3.1 – Main data collected by species, size category (T) and sex excluding *R. undulata*. Also presented are the number of samples (NS) per sex (F-Female or M-Male), per size category (NT), and total length range per species and size category.

Species	Size Category (T)	Sex	N_S	N_T	Total length range (cm)
Raja brachyura	1	F	28	55	78.3 - 110.0
		M	27		
	2	F	9	28	66.8 - 83.1
		M	19		
	3	F	13	24	58.0 - 73.5
		M	11		
	4	F	16	32	57.3 - 71.5
		M	16		
Raja clavata	1	F	41	47	56.3 - 95.5
		M	6		
	2	F	30	44	62.8 - 84.1
		M	14		
	3	F	10	36	57.1 - 78.4
		M	26		
	4	F	18	36	55.0 - 74.1
		M	18		
Raja microocellata	1	F	39	39	73.7 - 85.6
		M	0		

Table 3.1 continued

Species	Size Category (T)	Sex	N_S	N_T	Total length range (cm)
Raja microocellata	2	F	28	51	69.5 - 82.6
		M	23		
	3	F	12	33	58.3 - 75.4
		M	21		
	4	F	1	3	60.2 - 63.9
		M	2		
Raja montagui	1	F	1	1	62.9 - 62.9
		M	0		
	2	F	7	7	60.7 - 71.3
		M	0		
	3	F	20	24	58.7 - 69.4
		M	4		
	4	F	10	13	56.6 - 64.4
		M	3		
Leucoraja naevus	4	F	20	29	54.9 - 64.6
		M	9		

In the collected morphometric data, 2 outlier values were observed [one disc length from a male *R. brachyura* of the largest commercial size category (T1) and one total length from a male *L. naevus* of the smallest commercial size category (T4)], possibly due to measuring or recording errors, and were excluded.

Out of the 5 species analyzed, *R. brachyura* had the most variability for all measures and *R. montagui* and *L. naevus* had the smaller variability compared with the other species, with the remaining species having an intermediate placement between these groups (Figure 3.1).

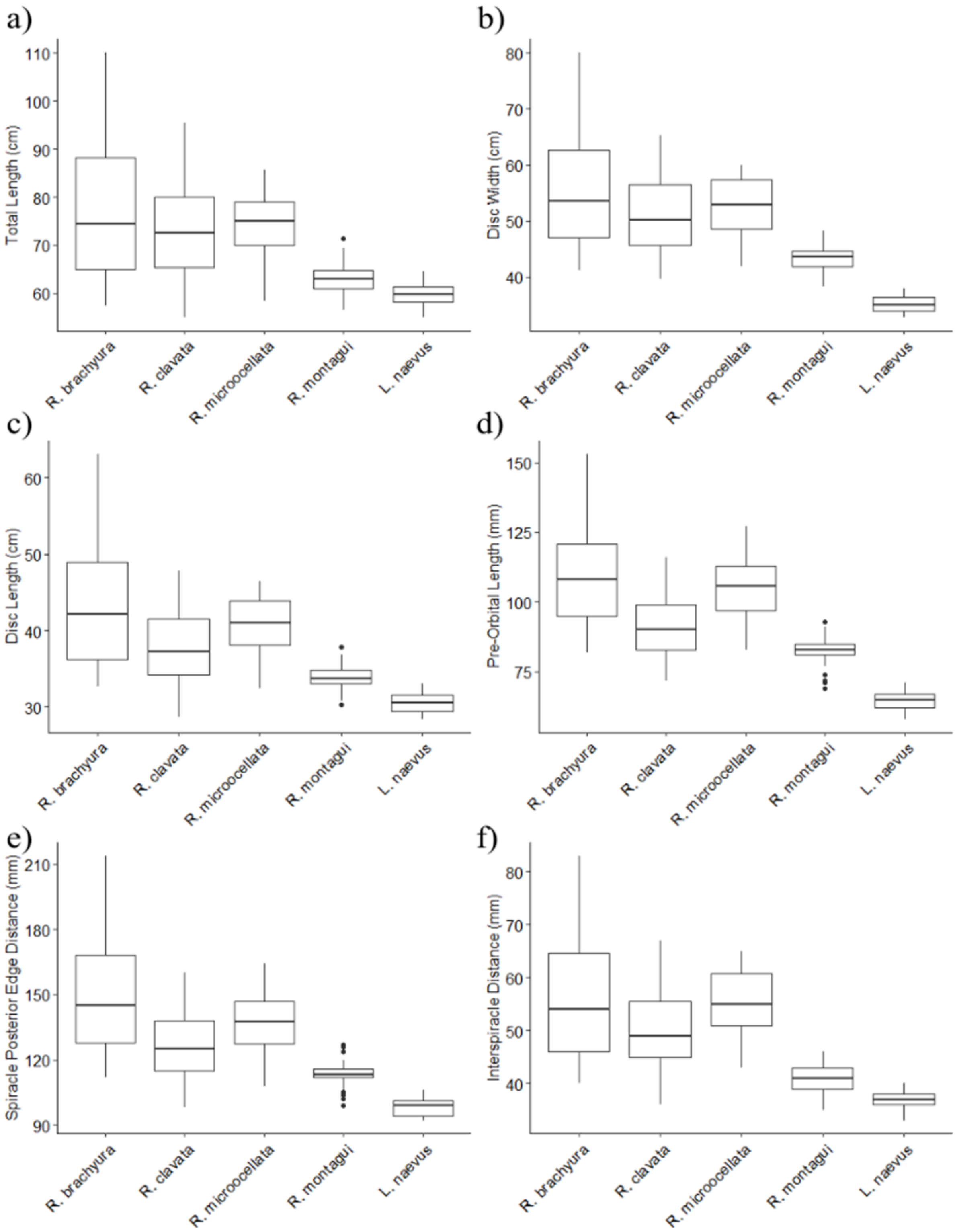

Figure 3.1 – Boxplots showing the variation in species-specific measures sampled at the fish market in the port of Peniche, excluding *R. undulata*: a) Variation of Total length; b) Variation of Disc width; c) Variation of Disc length; d) Variation of Pre-orbital length; e) Variation of Spiracle posterior edge distance; f) Variation of Interspiracle distance; by species. Boxplot statistical entries: minimum, first quartile (25%, Q1), median (Q2), third quartile (75%, Q3), maximum, and the black dots represent possible outliers.

Overall, the linear regressions between total length and all other measures (Table 3.2; Figure 3.2 – Figure 3.6) had the highest coefficients of determination (r^2) for *R. brachyura*, *R. clavata* and *R. microocellata* (all above 0.81), while the remaining species had more variability for the same analyzed relationships. The relationship between total length and disc length showed the highest coefficients of determination in the linear regressions (0.97 – 0.78) for all skate species studied. Inversely, the relationship between total length and pre-orbital distance, showed the lowest values r^2 for all species (0.94 – 0.28), in comparison with the other relationships, with *L. naevus* having the lowest value. The remaining measures showed intermediate r^2 values, and all relationships for all species were highly significant ($P < 0.001$), only TL – POD for *L. naevus* had a lower significance ($P < 0.01$). The various linear regression slopes and intercepts, as well as the data previously summarized, are available in Table 3.2, for each species and each relationship analyzed.

Regarding the adequacy of inferring total length measures using the secondary measurements taken, we could observe the linear regressions between predicted and observed total length based on those secondary measures taken for all species, except *R. undulata* (Figure 3.7 –Figure 3.11). The coefficients of determination for those relationships presented the same values as the coefficients from the linear regressions between the secondary measures and total length, for all species. This resulted from using the same data pool for both analyses. As a result, the same r^2 was obtained, but in this analysis, all linear regressions had the highest significance ($P < 0.001$) (Table 3.3).

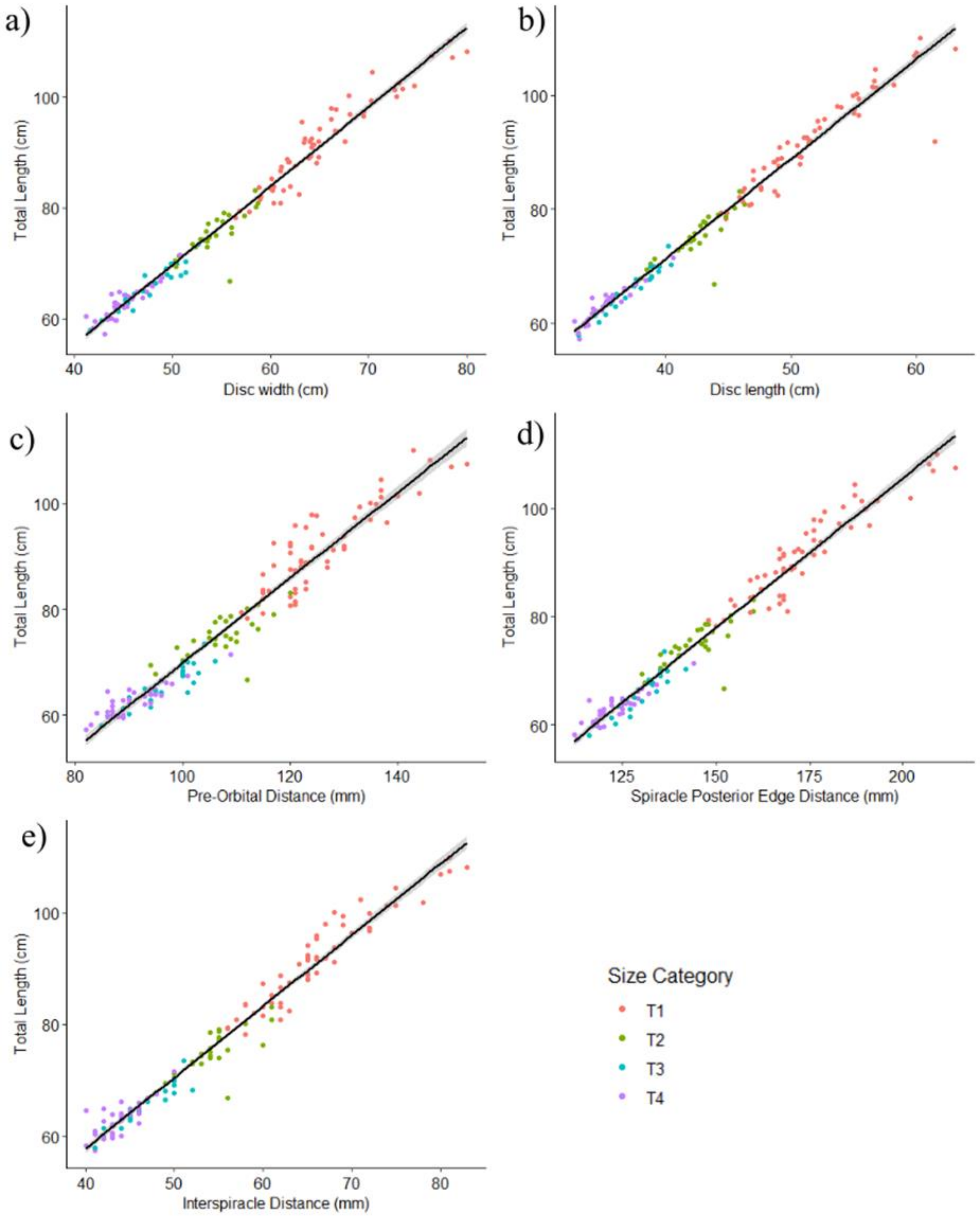

Figure 3.2 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. brachyura*, with the distinction of the different commercial size categories by color: a) Total length – Disc width, b) Total length – Disc length, c) Total length – Pre-orbital distance, d) Total length – Spiracle posterior edge distance and e) Total length – Interspiracle distance.

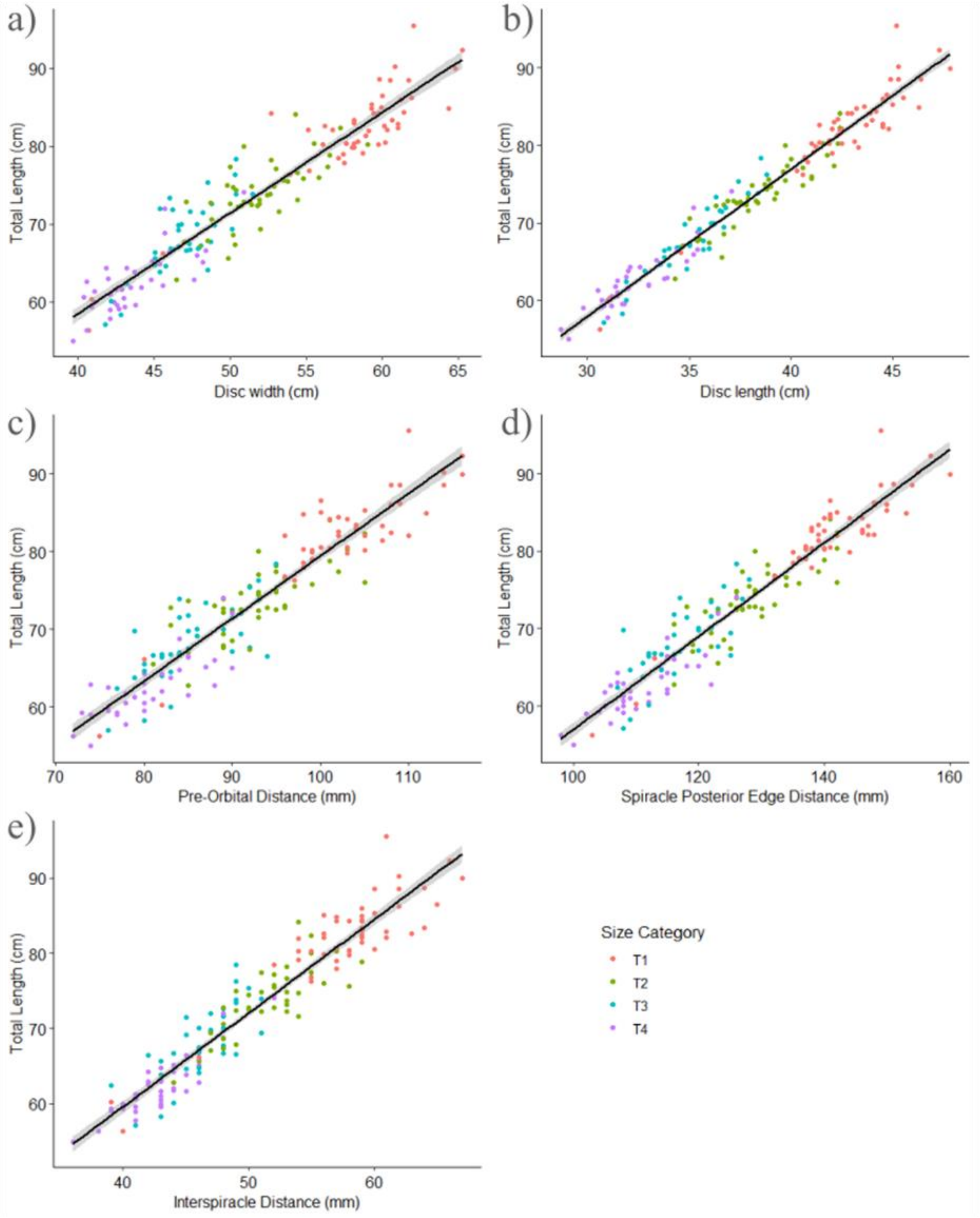

Figure 3.3 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. clavata*, with the distinction of the different commercial size categories by color: a) Total length – Disc width, b) Total length – Disc length, c) Total length – Pre-orbital distance, d) Total length – Spiracle posterior edge distance and e) Total length – Interspiracle distance.

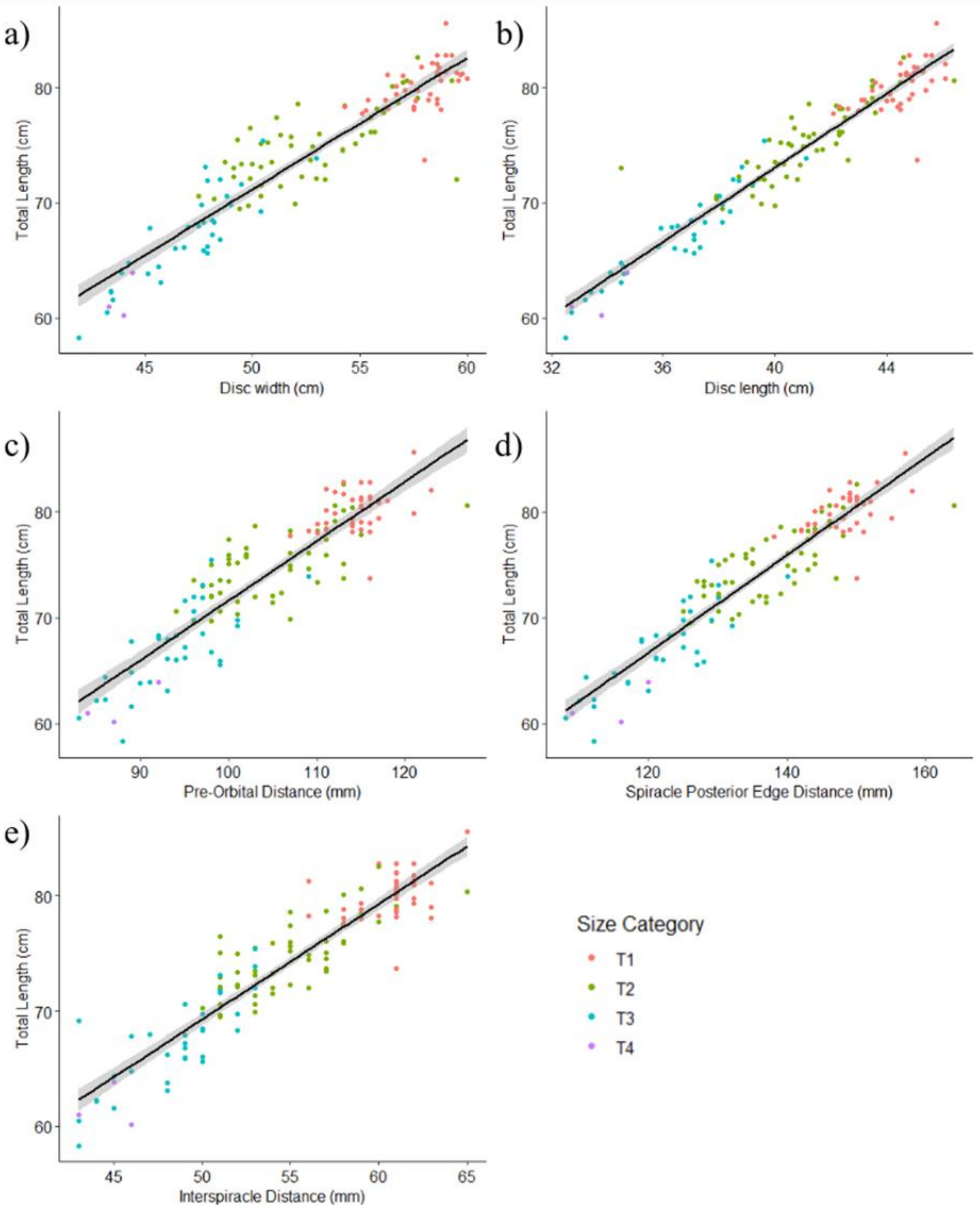

Figure 3.4 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. microocellata*, with the distinction of the different commercial size categories by color: a) Total length – Disc width, b) Total – length Disc length, c) Total length – Pre-orbital distance, d) Total length – Spiracle posterior edge distance and e) Total length – Interspiracle distance.

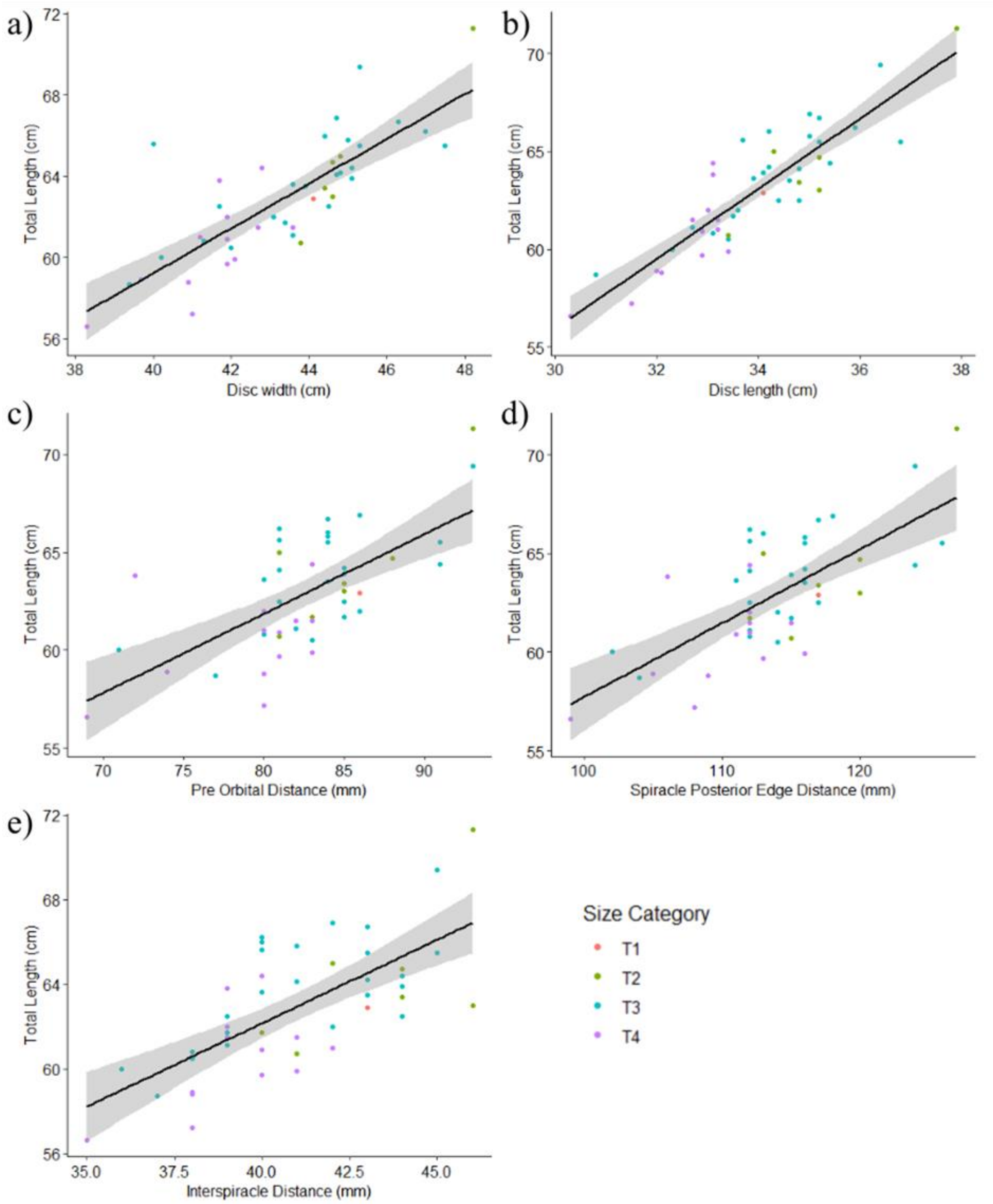

Figure 3.5 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. montagui*, with the distinction of the different commercial size categories by color: a) Total length – Disc width, b) Total length – Disc length, c) Total length – Pre-orbital distance, d) Total length – Spiracle posterior edge distance and e) Total length – Interspiracle distance.

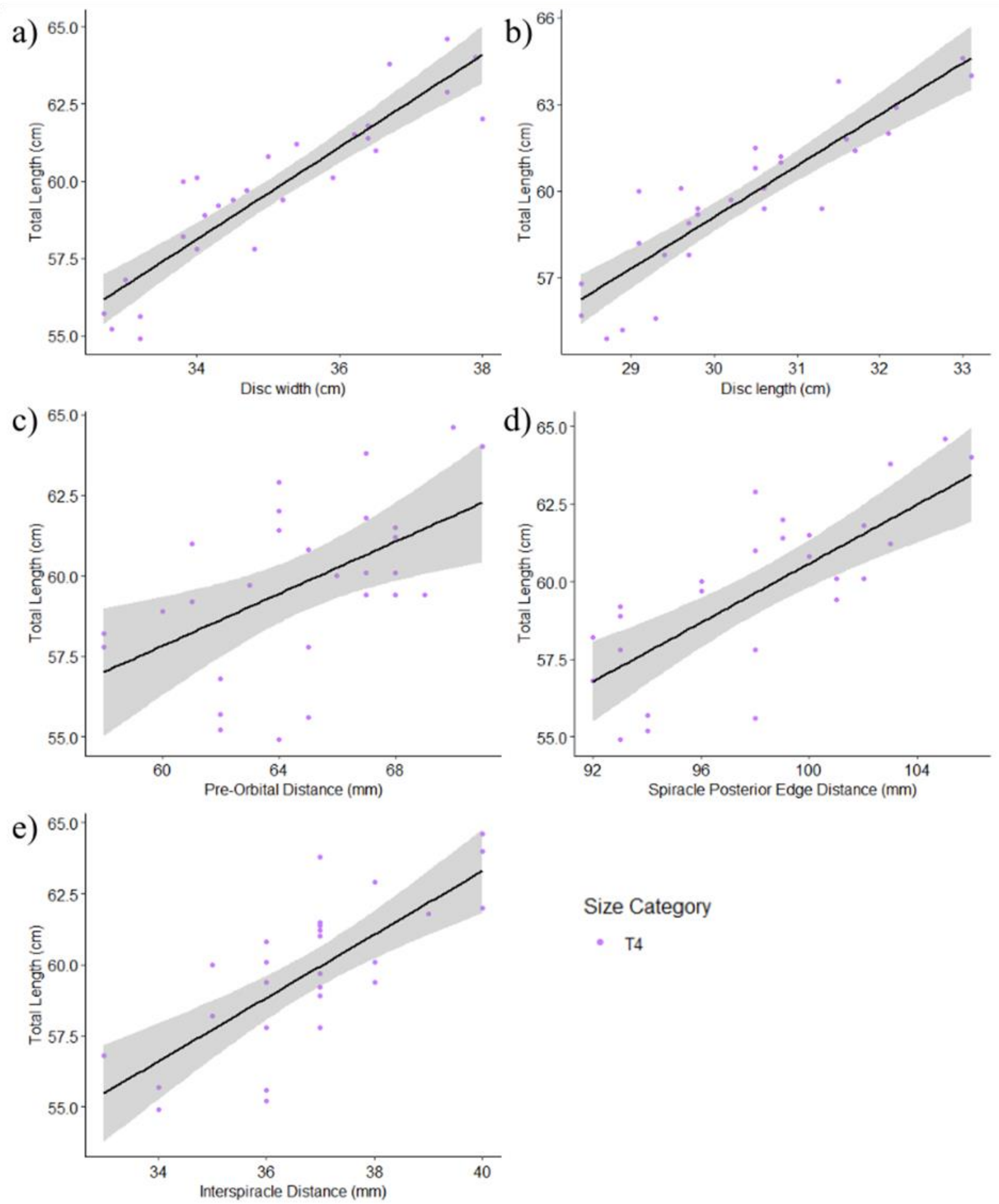

Figure 3.6 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *L. naevus*, with the distinction of the different commercial size categories by color: a) Total length – Disc width, b) Total length – Disc length, c) Total length – Pre-orbital distance, d) Total length – Spiracle posterior edge distance and e) Total length – Interspiracle distance.

Table 3.2 – Parameters of the linear models for the pair of points/landmarks distances (TL - DW, TL - DL, TL - POD, TL - SPED and TL - ISD). (TL, total length; DW, disc width; DL, disc length; POD, pre-orbital distance; SPED, spiracle posterior edge distance; ISD, interspiracle distance; $*P < 0.05$; $** P < 0.01$ and $*** P < 0.001$).

Species	**Parameter**	**DW – TL**	**TL – DL**	**TL – POD**	**TL – SPED**	**TL – ISD**
Raja brachyura	a	-1.61	1.35	-10.6	-4.92	6.68
	b	1.43	1.75	0.805	0.553	1.28
	r^2	0.97	0.97	0.94	0.96	0.97
	P	***	***	***	***	***
Raja clavata	a	6.55	0.865	-0.983	-3.3	9.97
	b	1.3	1.9	0.804	0.603	1.24
	r^2	0.89	0.95	0.87	0.91	0.90
	P	***	***	***	***	***
Raja microocellata	a	14.2	8.78	15.6	11.5	19.3
	b	1.14	1.61	0.56	0.46	1
	r^2	0.86	0.92	0.81	0.86	0.86
	P	***	***	***	***	***
Raja montagui	a	15.1	2.31	29.4	20.3	30.6
	b	1.1	1.79	0.406	0.374	0.79
	r^2	0.64	0.78	0.44	0.49	0.48
	P	***	***	***	***	***
Leucoraja naevus	a	7.31	5.81	33.5	13.1	18.6
	b	1.49	1.78	0.405	0.475	1.12
	r^2	0.82	0.79	0.28	0.55	0.55
	P	***	***	**	***	***

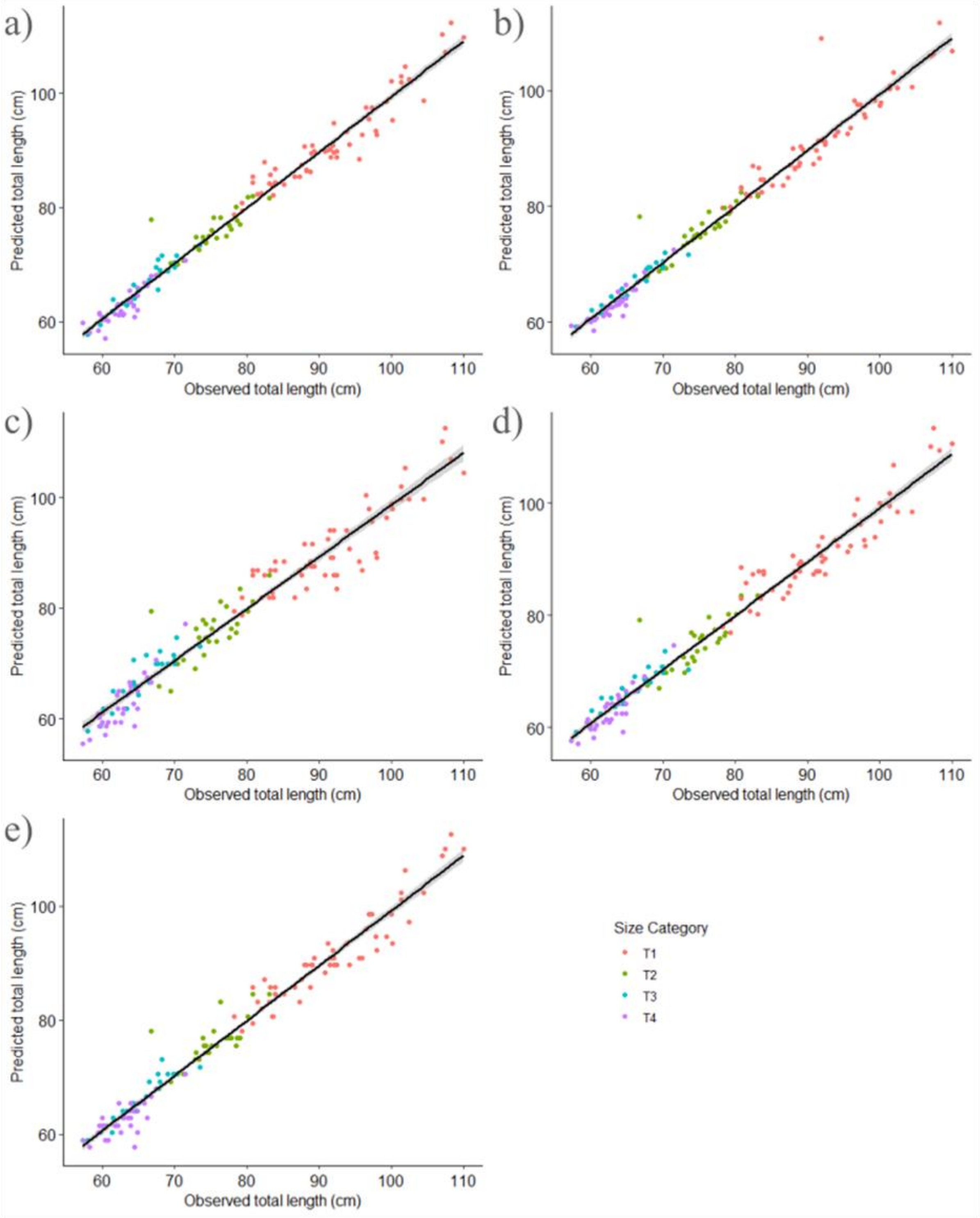

Figure 3.7 – Scatterplots of the relationship between observed and predicted values of total length of *R. brachyura* based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

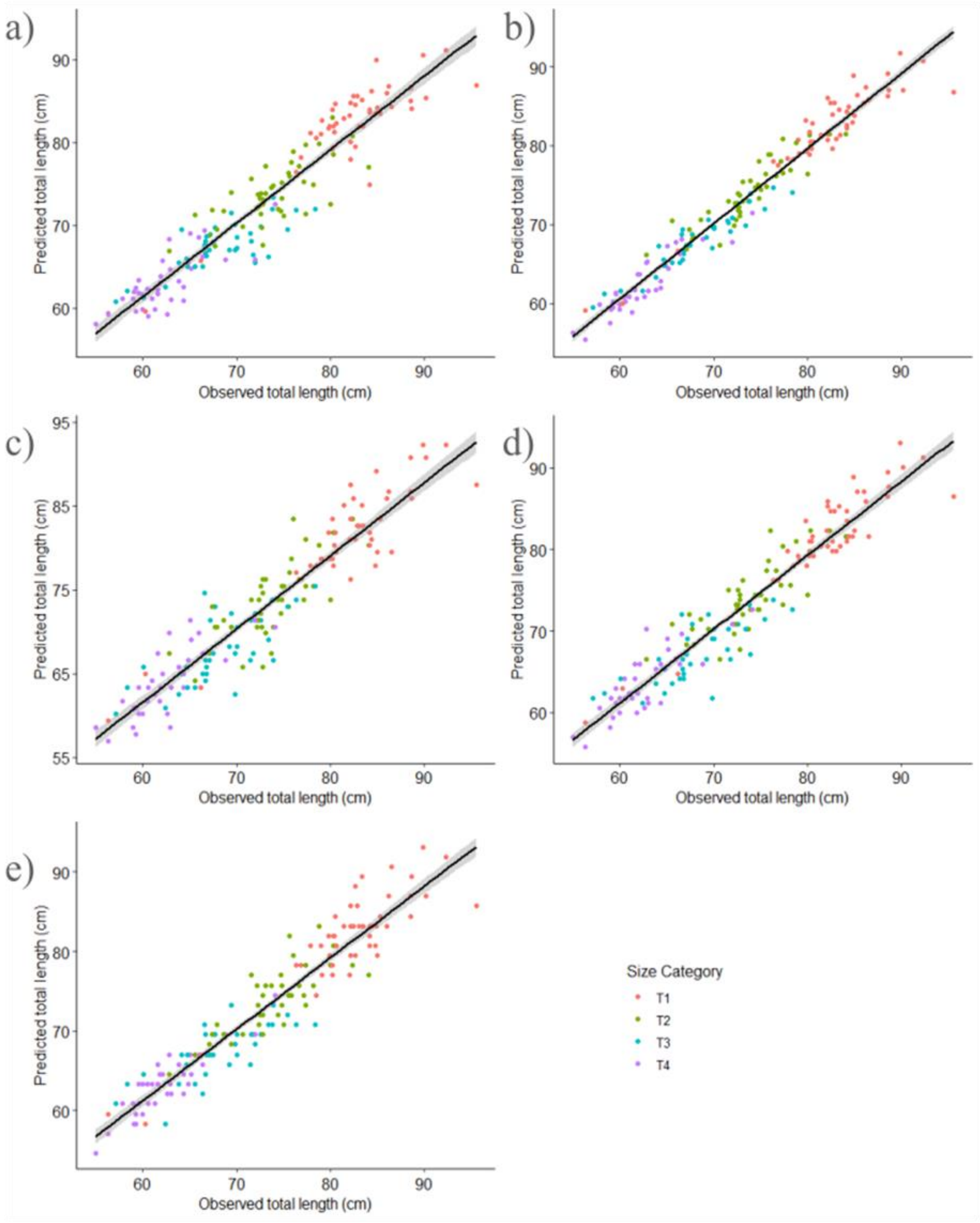

Figure 3.8 – Scatterplots of the relationship between observed and predicted values of total length of *R. clavata* based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

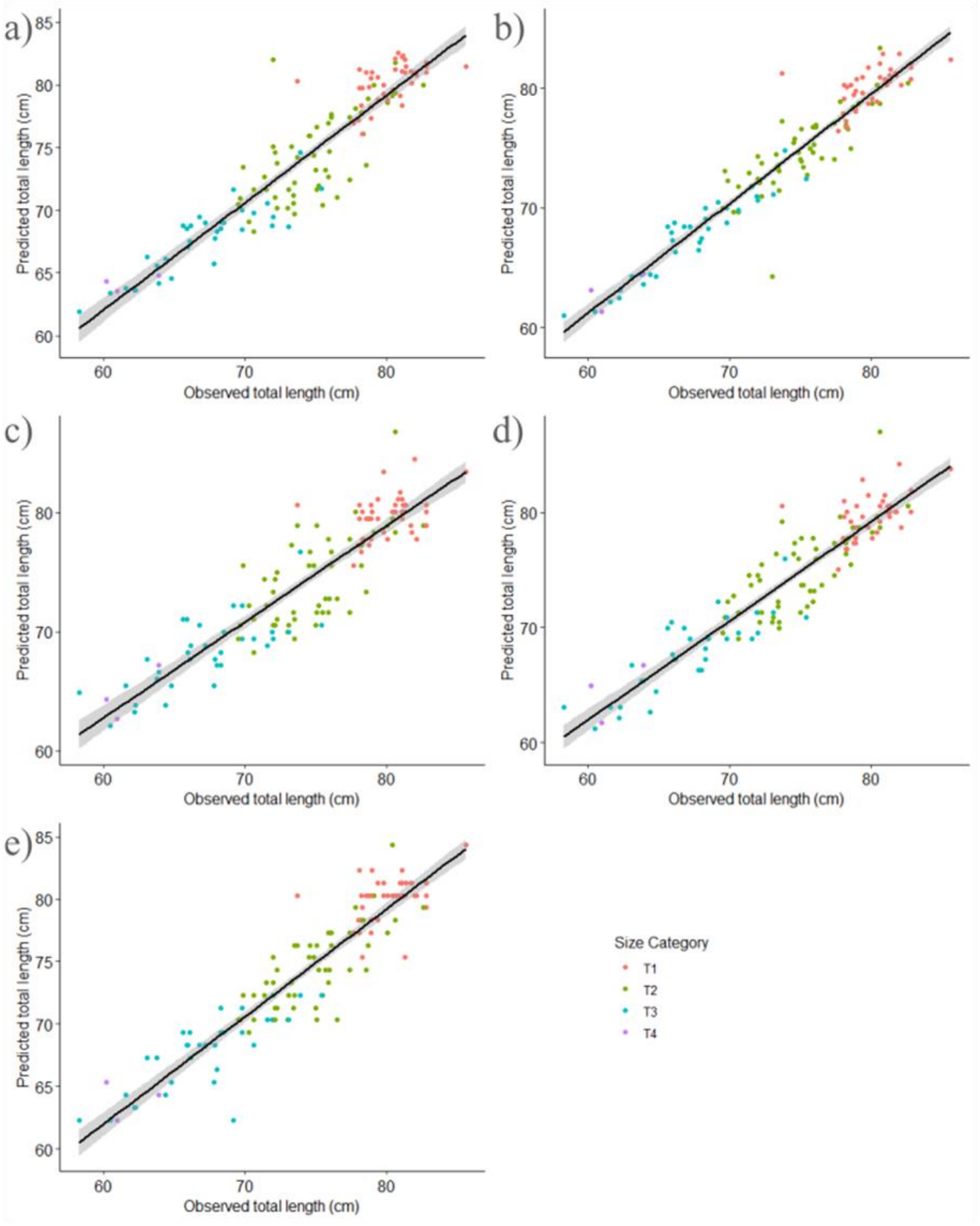

Figure 3.9 – Scatterplots of the relationship between observed and predicted values of total length of *R. microocellata* based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

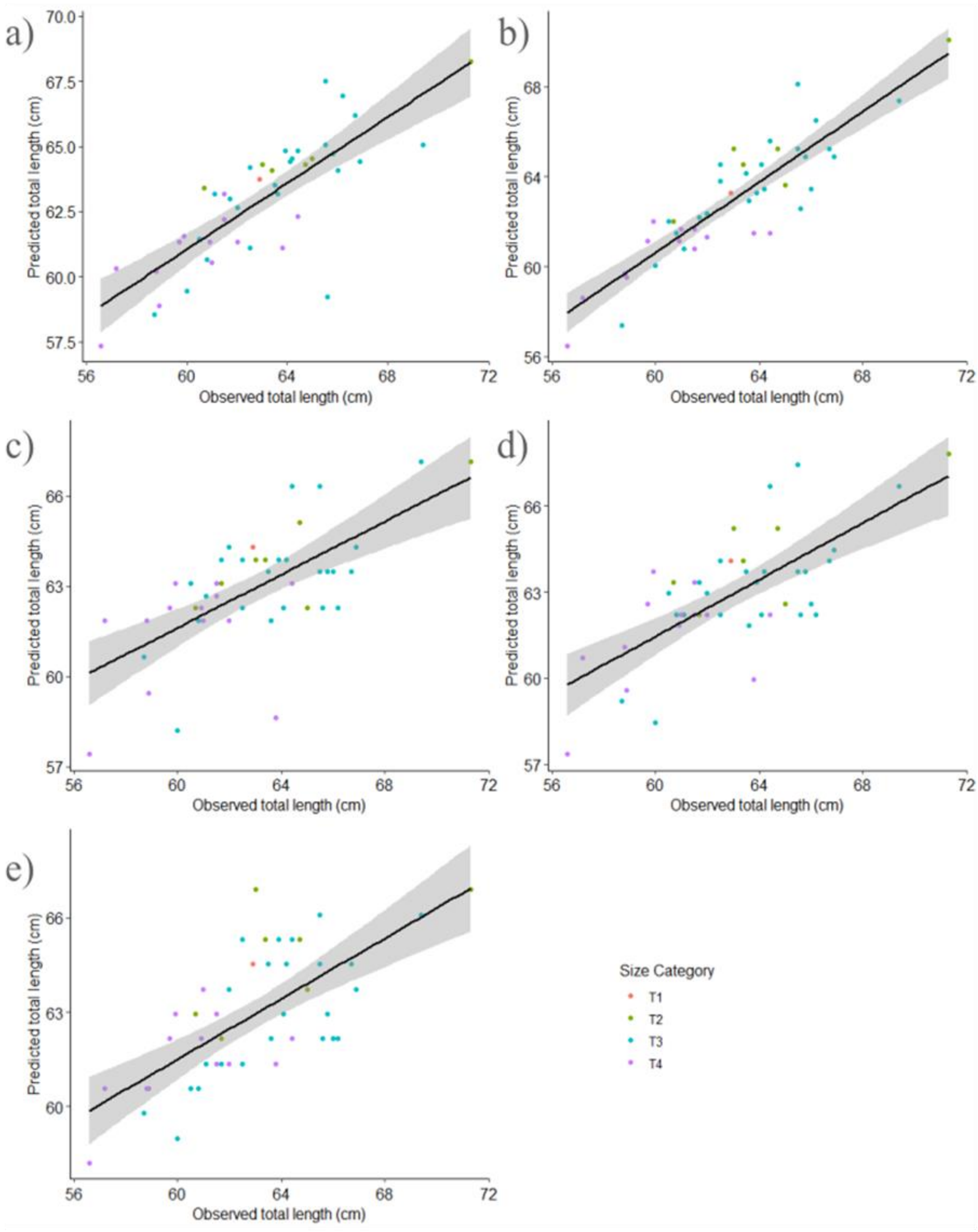

Figure 3.10 – Scatterplots of the relationship between observed and predicted values of total length of *R. montagui* based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

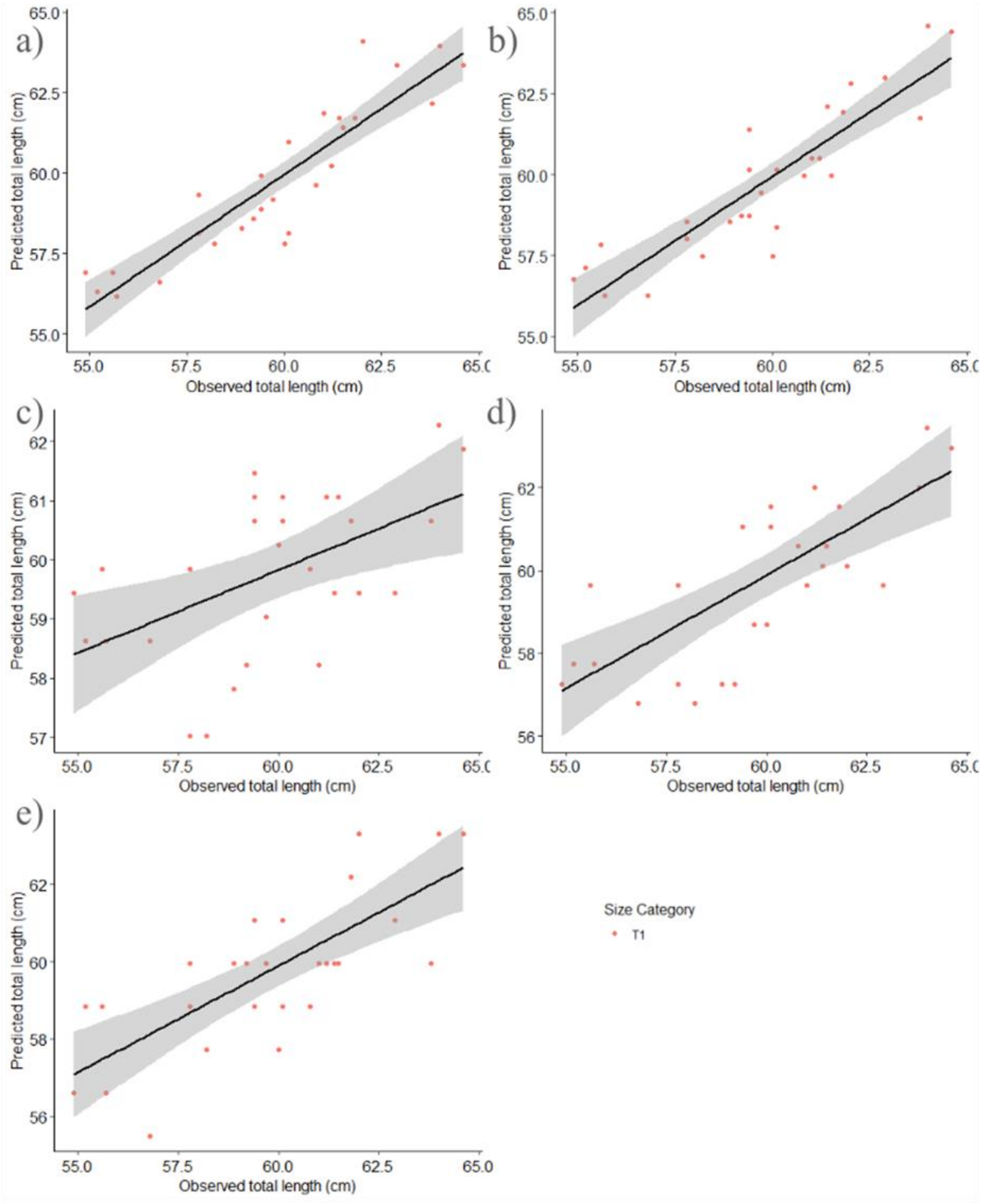

Figure 3.11 – Scatterplots of the relationship between observed and predicted values of total length of *L. naevus* based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

Table 3.3 – Parameters of the linear regression equations between the observed and predicted values of total length using the secondary measures (DW, DL, POD, SPED and ISD). (DW, disc width; DL, disc length; POD, pre-orbital distance; SPED, spiracle posterior edge distance; ISD, interspiracle distance; *$P < 0.05$; ** $P < 0.01$ and *** $P < 0.001$).

Species	Parameter	DW	DL	POD	SPED	ISD
Raja brachyura	r^2	0.97	0.97	0.94	0.96	0.97
	P	***	***	***	***	***
Raja clavata	r^2	0.89	0.95	0.87	0.91	0.90
	P	***	***	***	***	***
Raja microocellata	r^2	0.86	0.92	0.91	0.86	0.86
	P	***	***	***	***	***
Raja montagui	r^2	0.64	0.78	0.44	0.49	0.48
	P	***	***	***	***	***
Leucoraja naevus	r^2	0.82	0.79	0.28	0.55	0.55
	P	***	***	***	***	***

3.3 Electronic monitoring sampling

3.3.1 Image selection

A total of 954 images were pre-selected according to the methods described. From these, the most frequent commercial species was *R. brachyura* (28.93%), followed by *R. clavata* (22.22%), *R. montagui* (16.25%) as well as *R. microocellata* (14.57%), then *R. undulata* (13%), and last was the general categorization of Raja spp. (5.03%; of which 90% had the species *L. naevus*) (Table 3.4).

Table 3.4 – Summary of the samples/images pre-selected for analysis in the FishMetrics platform, per commercial species.

Commercial species	Number of samples (n)	Percentage
R. brachyura	276	28.93%
R. clavata	212	22.22%
R. microocellata	139	14.57%
R. montagui	155	16.25%
R. undulata	124	13.00%
Raja spp.	48	5.03%

In more detail (Table 3.5), the species blonde ray, *R. brachyura* had numerous images of all commercial size categories: the larger size category, T1 with 53 samples (19.2%), T2 with 54 samples (19.57%), T3 with 74 samples (26.81%) and lastly, the smaller size category, T4 with 95 samples (34.42%). More than the aimed 50 images per commercial size category were pre-selected since not all images had been correctly commercially identified. More than half (54.35%) of the samples were correctly identified but measurements were not possible, followed by samples accurately identified that allowed for at least more than one measurement (19.57%) and by samples misidentified and in which the correct species were skate species included in this study (16.3%), with all other possible remaining categories under 4%.

For the species thornback ray, *R. clavata*, the disparity in the numbers of pre-selected images between the four commercial size categories was very small, following the order of the commercial size category, from largest to smallest: 52 samples (24.53%) for T1, 51 samples (24.06%) for T2, 56 samples (26.42%) for T3, and lastly, 53 samples (25%) for T4. Only a few more than the aimed 50 images per commercial size category were pre-selected. Most samples were correctly commercially identified but could not be measured (74.53%), followed by 20.75% of images that were correctly identified and could be measured. All other cases were under the value of 2%.

For species spotted ray, *R. microocellata*, from all pre-selected images T1 had the lowest frequency from all commercial size categories with 7 samples (5.04%). All other commercial size categories were above 20%, T2 with 50 samples (35.97%), T3 with 53 samples (38.13%), and T4 with 29 samples (20.86%). Most samples were correctly commercially identified but could not be measured (71.22%), followed by samples correctly identified and that could be measured (25.18%), and all other possible cases under 2%.

For the species small-eyed ray, *R. montagui*, the larger commercial size category (T1) had a low frequency of samples (14 samples, 9.03%), followed by T2 with 21 samples (13.55%), T3 with 60 samples (38.71%), and finally, T4 with 60 samples (38.71%). Almost half (49.03%) of the samples were accurately assigned a commercial species but could not be measured, followed by samples wrongly identified but the species being one of the skate species from this study (23.87%), then by samples correctly identified and measured (20.65%), after that in 5.16% of samples it was not possible to confirm species identification, and all other classifications were under 1%.

For the species undulate ray, *R. undulata*, there were only 3 commercial size categories present in the available samples, the largest, T1 with 41 samples (33.06%), secondly, T2 with 70 samples (56.45%), and T3 with only 13 samples (10.48%). Most of the samples were correctly commercially identified but measurements were not possible (51.61%), followed by samples accurately identified and suitable for measurement (21.77%), and by images that were assigned as system errors (i.e., a mismatch between image and box information, as confirmed in the detailed daily lists of sold boxes from DocaPesca) (19.35%). The lower percentages were attributed to blank images (6.45%) and samples with specimens from other species not included in this study (0.81%).

For the group of skates Raja spp., only the 3 smaller size categories were present, with T2 having 1 sample (2.08%), T3 having most of the share, with 39 samples (81.25%), and T4 with 8 samples (16.67%). Half of the samples were identified correctly but could not be measured, followed by samples accurately identified and suitable for measurement (26.08%), then by duplicated samples (16.67%), and the last two classifications were system error (4.17%) and samples of skate species from this study that were misidentified as other skate species (2.08%).

Table 3.5 – Summary of the samples/images pre-selected for analysis in the FishMetrics platform, per commercial species and commercial size category and classification of the samples, percentage rounded to the hundredth place.

		Classification							
Commercial Species	**Commercial Size Category**	**Measured**	**Measure not possible**	**Wrong ID - Not study ray**	**Wrong ID - Study ray**	**ID not possible**	**Duplicate**	**System Error**	**Blank**
R. brachyura	T1	6 (2.17%)	44 (15.94%)	1 (0.36%)	2 (0.72%)	-	-	-	-
	T2	14 (5.07%)	36 (13.04%)	1 (0.36%)	-	-	1 (0.36%)	2 (0.72%)	-
	T3	15 (5.43%)	39 (14.13%)	3 (1.09%)	12 (4.35%)	2 (0.72%)	1 (0.36%)	2 (0.72%)	-
	T4	19 (6.88%)	31 (11.23%)	1 (0.36%)	31 (11.23%)	3 (1.09%)	5 (1.81%)	5 (1.81%)	-
R. clavata	T1	14 (6.60%)	36 (16.98%)	-	2 (0.94%)	-	-	-	-
	T2	13 (6.13%)	37 (17.45%)	-	-	1 (0.47%)	-	-	-
	T3	7 (3.30%)	44 (20.75%)	1 (0.47%)	1 (0.47%)	1 (0.47%)	1 (0.47%)	-	1 (0.47%)
	T4	10 (4.72%)	41 (19.34%)	1 (0.47%)	-	1 (0.47%)	-	-	-
R. microocellata	T1	2 (1.44%)	5 (3.60%)	-	-	-	-	-	-
	T2	8 (5.76%)	42 (30.22%)	-	-	-	-	-	-
	T3	16 (11.51%)	34 (24.46%)	2 (1.44%)	-	1 (0.72%)	-	-	-
	T4	9 (6.47%)	18 (12.95%)	-	-	-	-	1 (0.72%)	1 (0.72%)
R. montagui	T1	-	-	-	14 (9.03%)	-	-	-	-
	T2	1 (0.65%)	2 (1.29%)	-	17 (10.97%)	1 (0.65%)	-	-	-
	T3	14 (9.03%)	38 (24.52%)	-	5 (3.23%)	3 (1.94%)	-	-	-
	T4	17 (10.97%)	36 (23.23%)	1 (0.65%)	1 (0.65%)	4 (2.58%)	-	-	1 (0.65%)
R. undulata	T1	5 (4.03%)	24 (19.35%)	-	-	-	-	4 (3.23%)	8 (6.45%)
	T2	18 (14.52%)	31 (25.00%)	1 (0.81%)	-	-	-	20 (16.13%)	-
	T3	4 (3.23%)	9 (7.26%)	-	-	-	-	-	-
	T4	-	-	-	-	-	-	-	-
Raja spp.	T1	-	-	-	-	-	-	-	-
	T2	-	1 (2.08%)	-	-	-	-	-	-
	T3	9 (18.75%)	19 (39.58%)	1 (2.08%)	-	-	8 (16.67%)	2 (4.17%)	-
	T4	4 (8.33%)	4 (8.33%)	-	-	-	-	-	-

3.3.2 Morphometric data

For the data analysis of measured individuals in the FishMetrics platform, 226 specimens of skates were sampled, and captured by 33 different vessels of the multi-gear and trawl fleets during a total of 175 fishing trips. Of the 226 specimens, 63 individuals were *R. brachyura*; 43 *R. clavata*; 36 *R. microocellata*; 44 *R. montagui*; 13 *L. naevus*; and 27 *R. undulata*. Total length was measured in all individuals, but not all additional measurements could be taken for all individuals, since some landmarks were not visible or difficult to be identified through imaging, which resulted in a high variability in the numbers of individuals in each relationship tested for each species. The first three species mentioned showed a larger variability in all considered measures (Figure 3.12). *R. montagui* and *L. naevus* presented a smaller variability, and smaller values compared with the preceding species. Unlike the previous similar analysis in the fish market sampling (Section 2.2.2), *R. undulata* was present in these samples, since there was a larger number of specimens available for sampling. The variability of measurements for this species was like the smaller species but with higher values.

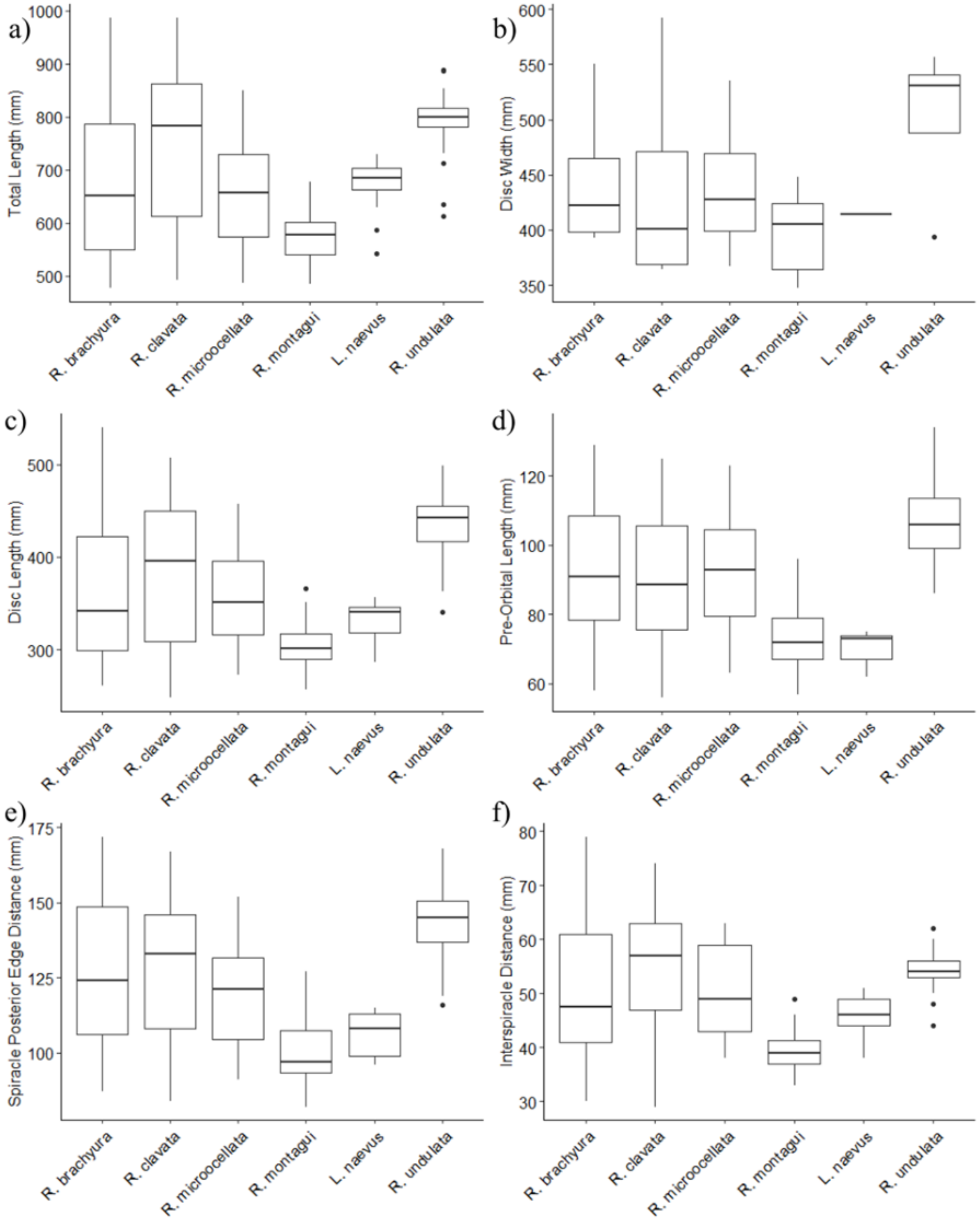

Figure 3.12 – Boxplots showing the variation in the different measurements taken from images acquired at the port of Aveiro and available in the FishMetrics platform: a) Total length; b) Disc width; c) Disc length; d) Pre-orbital length; e) Spiracle posterior edge distance; f) Interspiracle distance; by species. Boxplot statistical entries: minimum, first quartile (25%, Q1), median (Q2), third quartile (75%, Q3), maximum, and the black dots represent possible outliers.

Overall, the linear regressions between total length and the other measures (Table 3.6; Figure 3.13 – Figure 3.18) showed highest coefficients of determination (r^2) for *R. brachyura*, *R. clavata* and *R. microocellata* ($r^2 > 0.82$), while the remaining species showed high values, but only for some of the analyzed relationships. The relationships between total length and disc length showed the highest coefficients of determination in the linear regressions (0.99 – 0.80) for all species of skates studied. On the other hand, the relationships between total length and pre-orbital distance generally showed the lowest r^2 values (0.88 – 0.39), in comparison with the other secondary measures, with the lowest value for *R. undulata*. The remaining measures showed intermediate r^2 values, and all of these were highly significant ($P < 0.001$), apart from TL – POD and TL – SPED for *L. naevus* ($P < 0.01$), and TL – DW for R. montagui ($P < 0.01$) and *R. undulata* ($P < 0.05$). *Leucoraja naevus* did not present value for TL – DW due to the lack of data. Furthermore, the TL – POD relationships had the highest number of sampled individuals, whereas TL – DW had the lowest number of samples, for all species. The various linear regression slopes and intercepts, as well as the data previously summarized, are available in Table 3.6 for each species and each relationship analyzed.

Regarding the adequacy of using secondary measures to infer total length measurements, as executed in the fish market (Section 3.2), we could observe the linear regressions between predicted and observed total length based on the secondary measures taken for all species (Figure 3.19 – Figure 3.24). The coefficients of determination (r^2) of those relationships were identical to their correspondent relationship between secondary measures and total length, for all species, as previously pointed out for the results of the fish market results (Section 3.2). As such, in terms of r^2 values, as well as significance, the same results were obtained (Table 3.7).

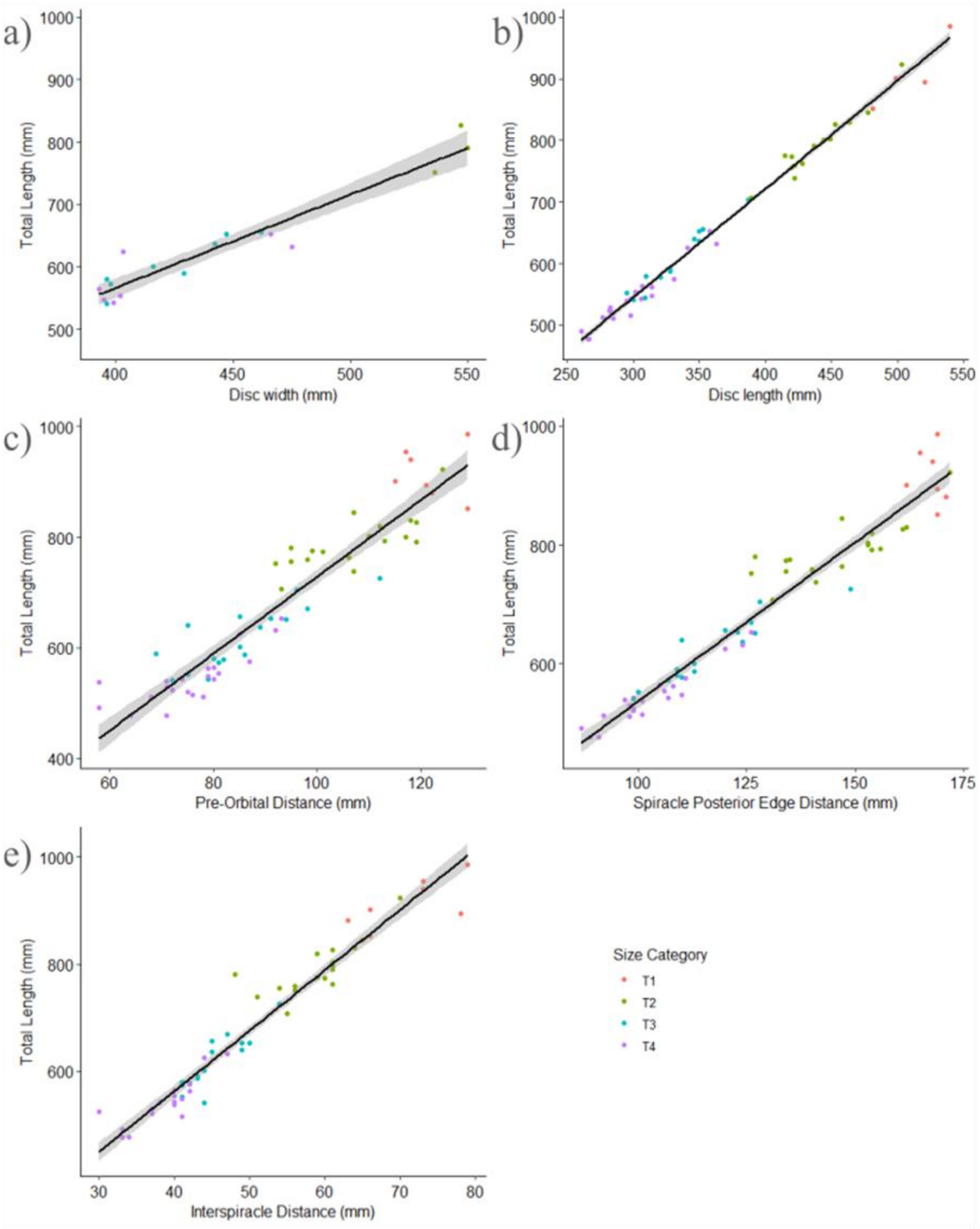

Figure 3.13 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. brachyura* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc width, b) Total length - Disc length, c) Total length - Pre-orbital distance, d) Total length - Spiracle posterior edge distance and e) Total length - Interspiracle distance.

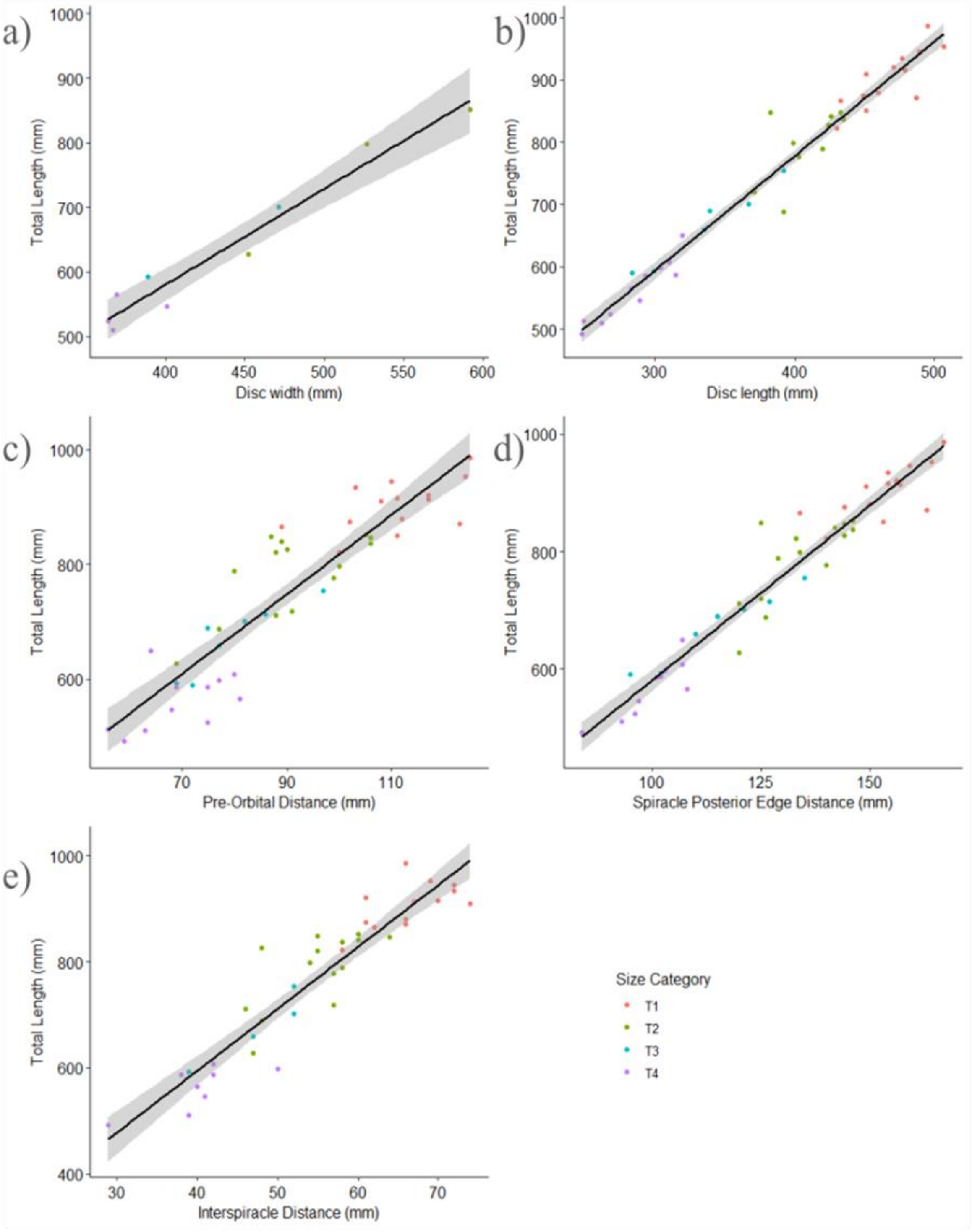

Figure 3.14 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. clavata* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc width, b) Total length - Disc length, c) Total length - Pre-orbital distance, d) Total length - Spiracle posterior edge distance and e) Total length - Interspiracle distance.

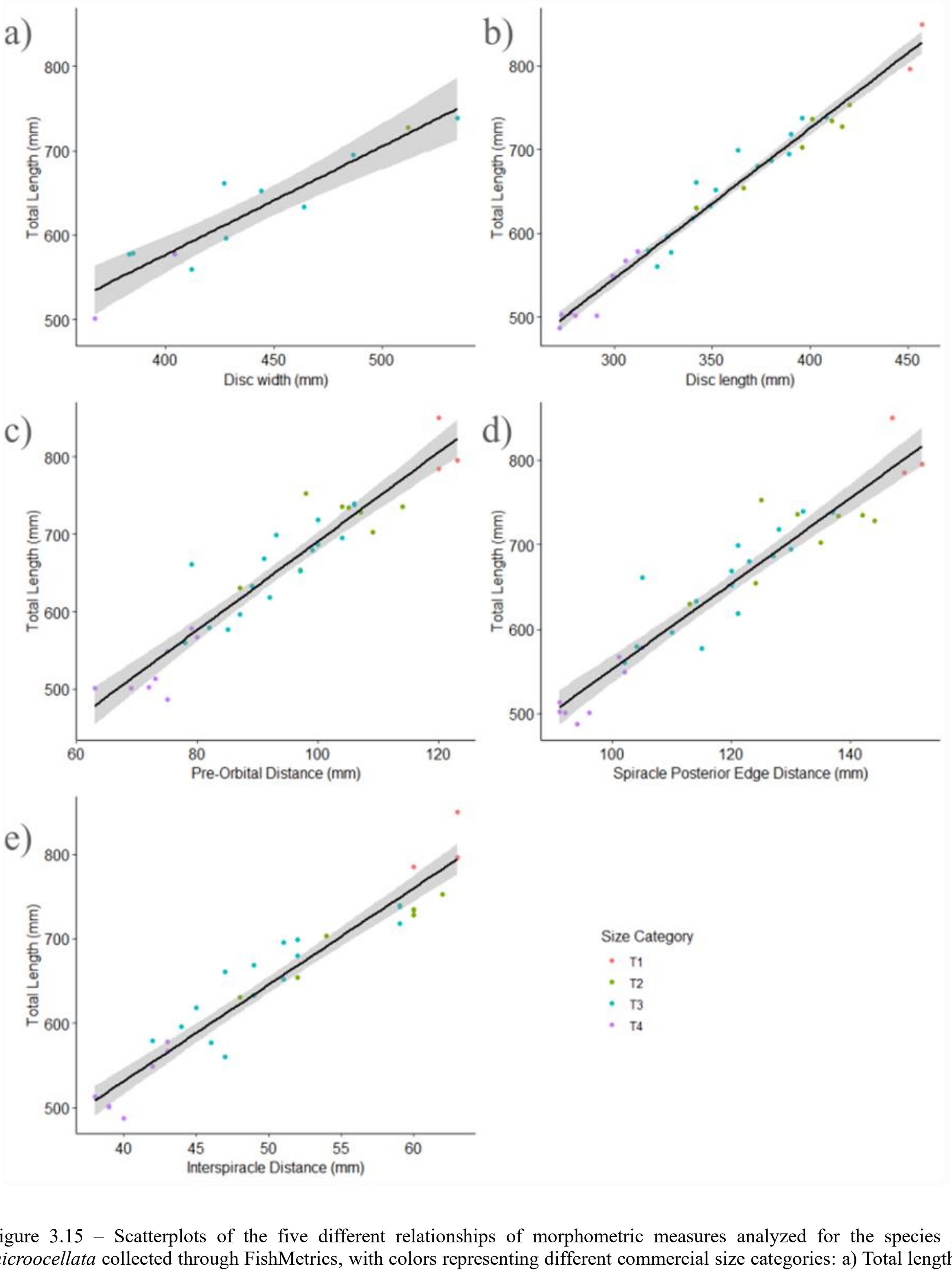

Figure 3.15 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. microocellata* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc width, b) Total length - Disc length, c) Total length - Pre-orbital distance, d) Total length - Spiracle posterior edge distance and e) Total length - Interspiracle distance.

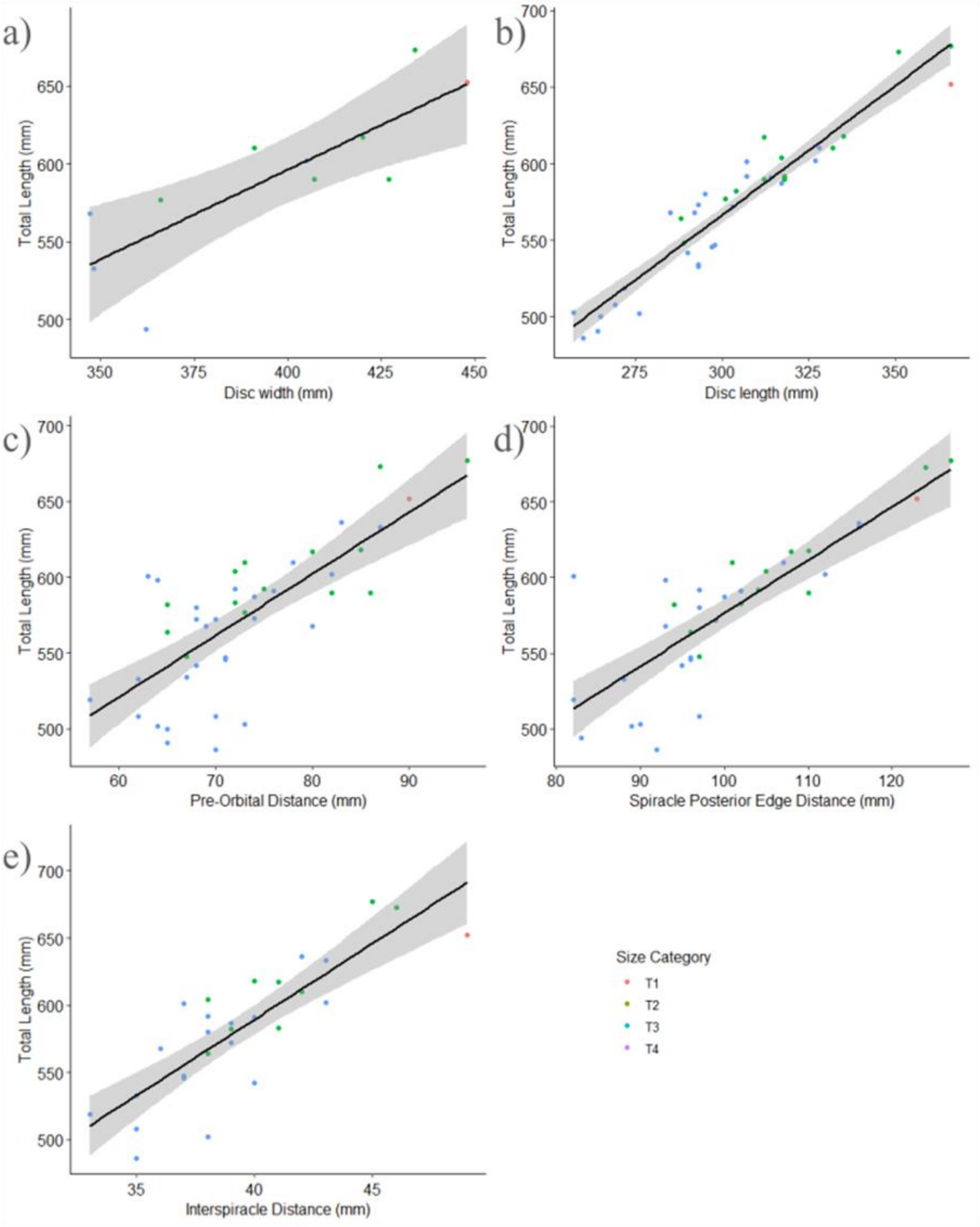

Figure 3.16 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. montagui* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc width, b) Total length - Disc length, c) Total length - Pre-orbital distance, d) Total length - Spiracle posterior edge distance and e) Total length - Interspiracle distance.

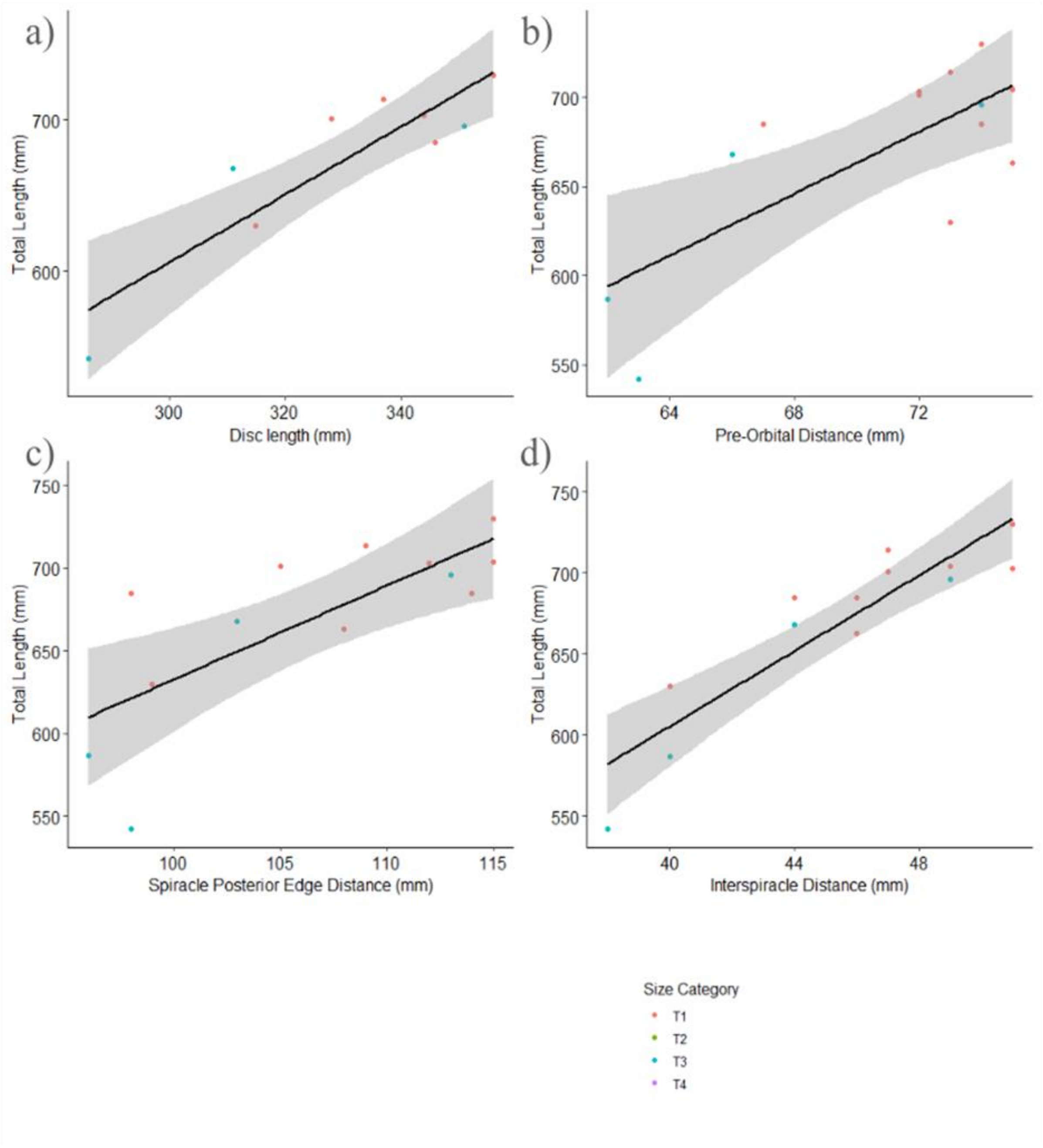

Figure 3.17 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *L. naevus* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc length, b) Total length - Pre-orbital distance, c) Total length - Spiracle posterior edge distance and d) Total length - Interspiracle distance.

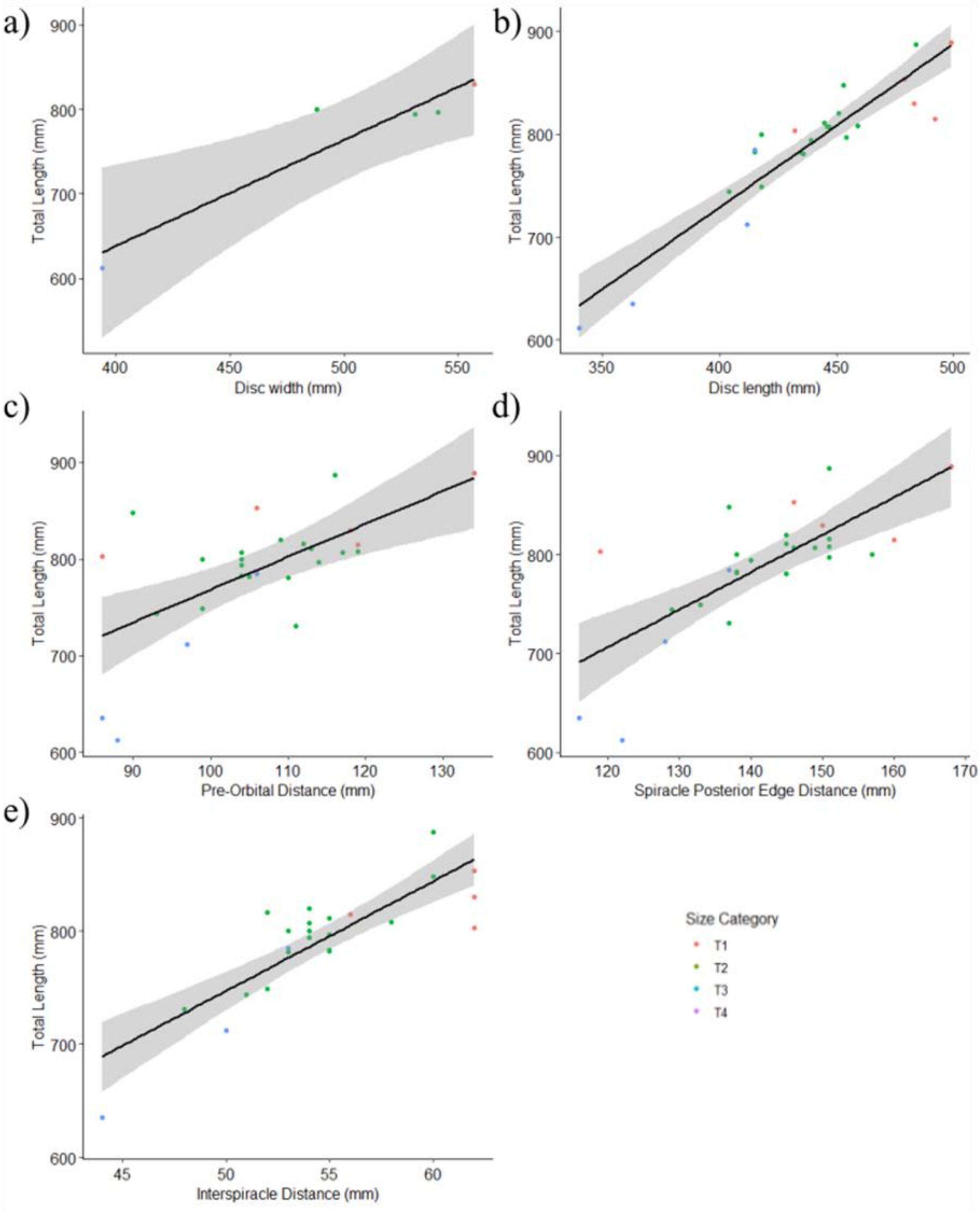

Figure 3.18 – Scatterplots of the five different relationships of morphometric measures analyzed for the species *R. undulata* collected through FishMetrics, with colors representing different commercial size categories: a) Total length - Disc width, b) Total length - Disc length, c) Total length - Pre-orbital distance, d) Total length - Spiracle posterior edge distance and e) Total length - Interspiracle distance.

Table 3.6 – Parameters of the linear models for the pair of points/landmarks distances (TL – DW, TL – DL, TL – POD, TL – SPED and TL – ISD). (TL, total length; DW, disc width; DL, disc length; POD, pre-orbital distance; SPED, spiracle posterior edge distance; ISD, interspiracle distance, *$P < 0.05$; ** $P < 0.01$ and *** $P < 0.001$).

Species	**Parameter**	**TL – DW**	**TL – DL**	**TL – POD**	**TL – SPED**	**TL – ISD**
Raja brachyura	a	-31.3	17.4	32.5	2.13	111
	b	1.49	1.76	6.97	5.35	11.3
	r^2	0.92	0.99	0.88	0.94	0.94
	P	***	***	***	***	***
	n	18	51	63	62	58
Raja clavata	a	-14.5	41.9	123	-17.1	126
	b	1.49	1.84	6.95	5.97	11.7
	r^2	0.95	0.96	0.82	0.93	0.87
	P	***	***	***	***	***
	n	9	40	46	45	39
Raja microocellata	a	65.6	4.99	116	46.9	73.2
	b	1.28	1.8	5.75	5.06	11.4
	r^2	0.88	0.97	0.89	0.89	0.92
	P	***	***	***	***	***
	n	12	32	35	35	33
Raja montagui	a	138	60.5	277	225	137
	b	1.14	1.69	4.07	3.51	11.3
	r^2	0.66	0.90	0.55	0.68	0.69
	P	**	***	***	***	***
	n	11	37	43	35	28
Leucoraja naevus	a	-	-67.4	56.6	63.8	141
	b	-	2.24	8.66	5.69	11.6
	r^2	-	0.80	0.55	0.56	0.82
	P	-	***	**	**	***
	n	1	10	13	13	13
Raja undulata	a	135	93.6	428	251	263
	b	1.26	1.59	3.4	3.79	9.67
	r^2	0.89	0.85	0.39	0.55	0.70
	P	*	***	***	***	***
	n	5	24	27	27	25

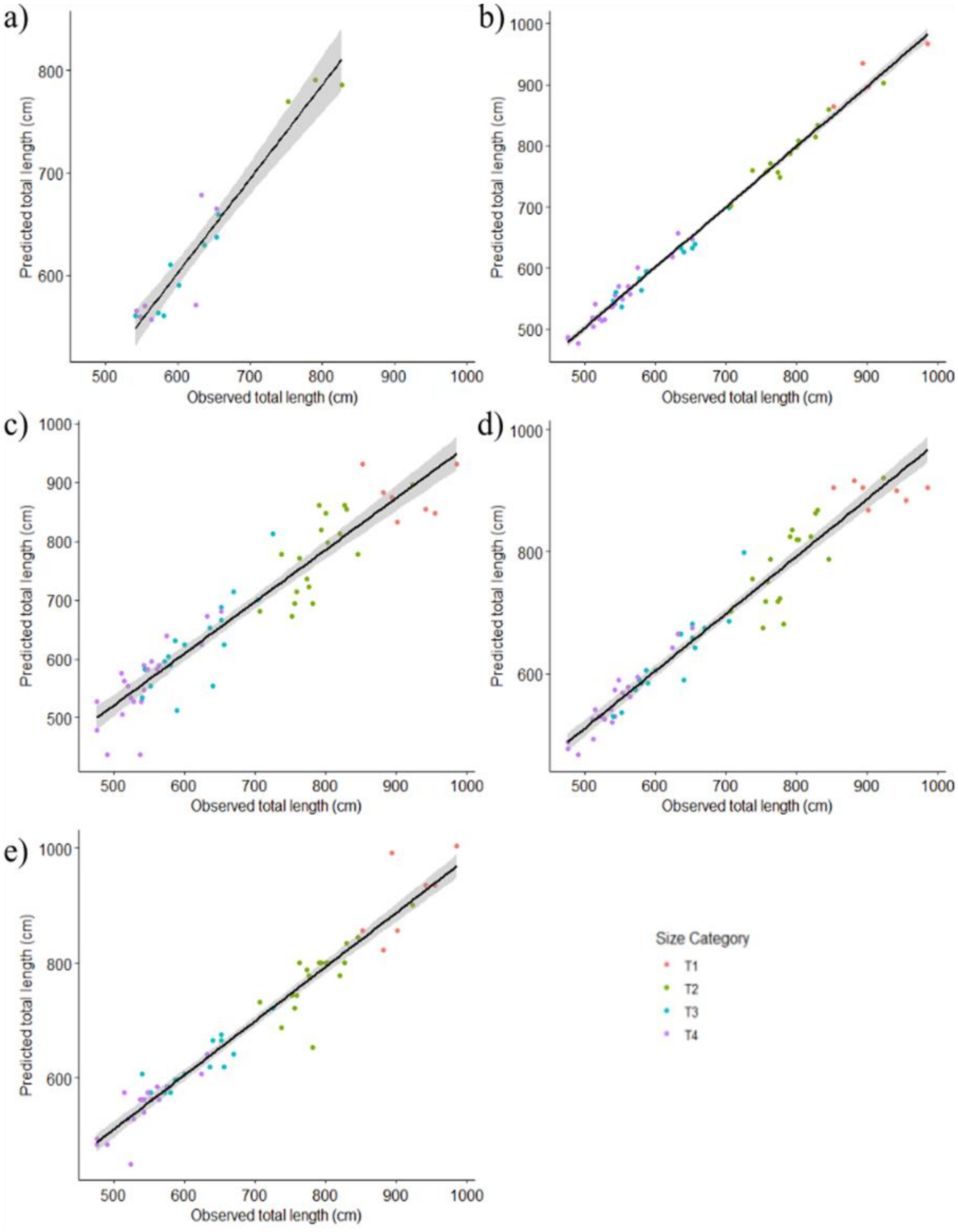

Figure 3.19 – Scatterplots of the relationship between observed and predicted values of total length of *R. brachyura* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

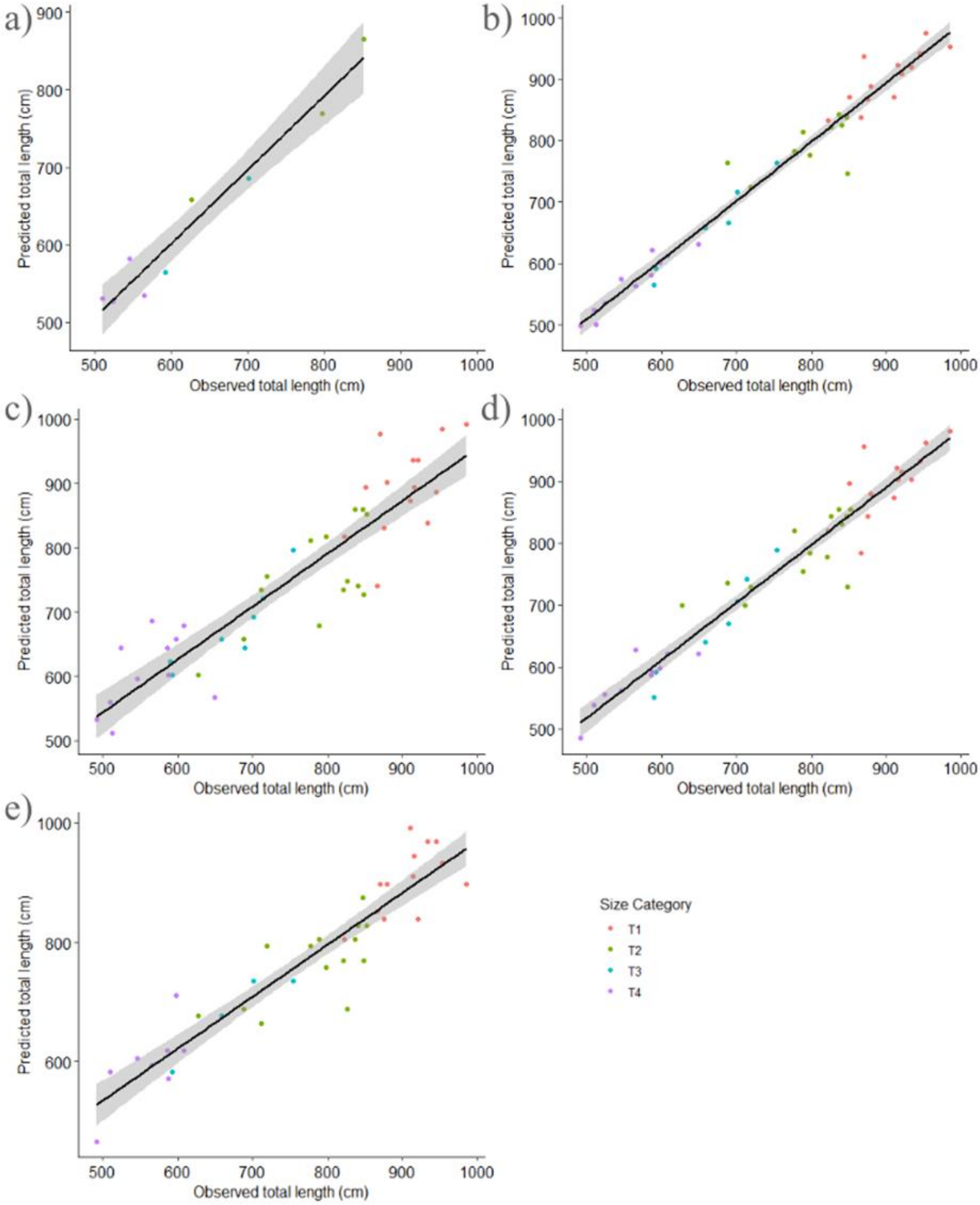

Figure 3.20 – Scatterplots of the relationship between observed and predicted values of total length of *R. clavata* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

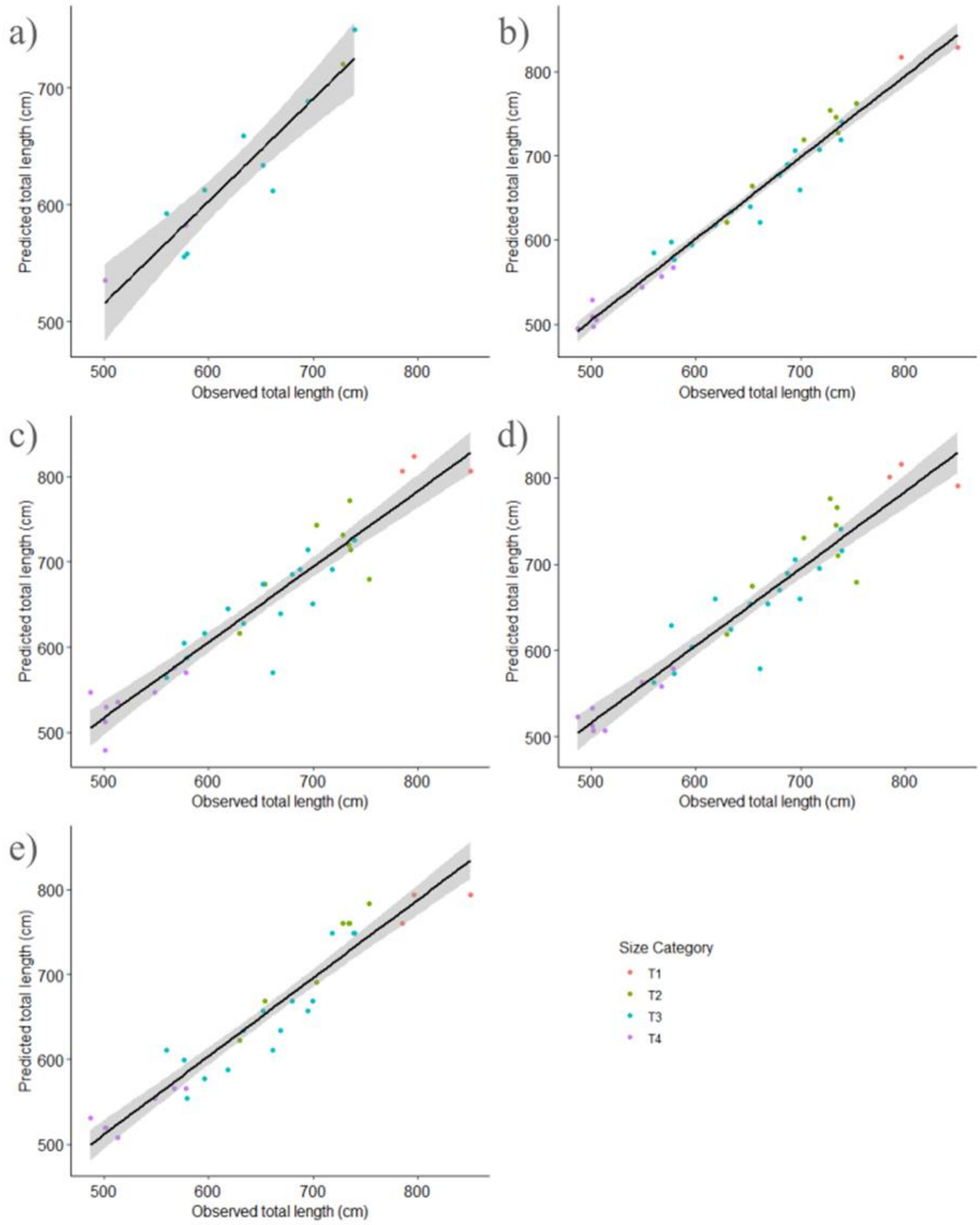

Figure 3.21 – Scatterplots of the relationship between observed and predicted values of total length of *R. microocellata* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

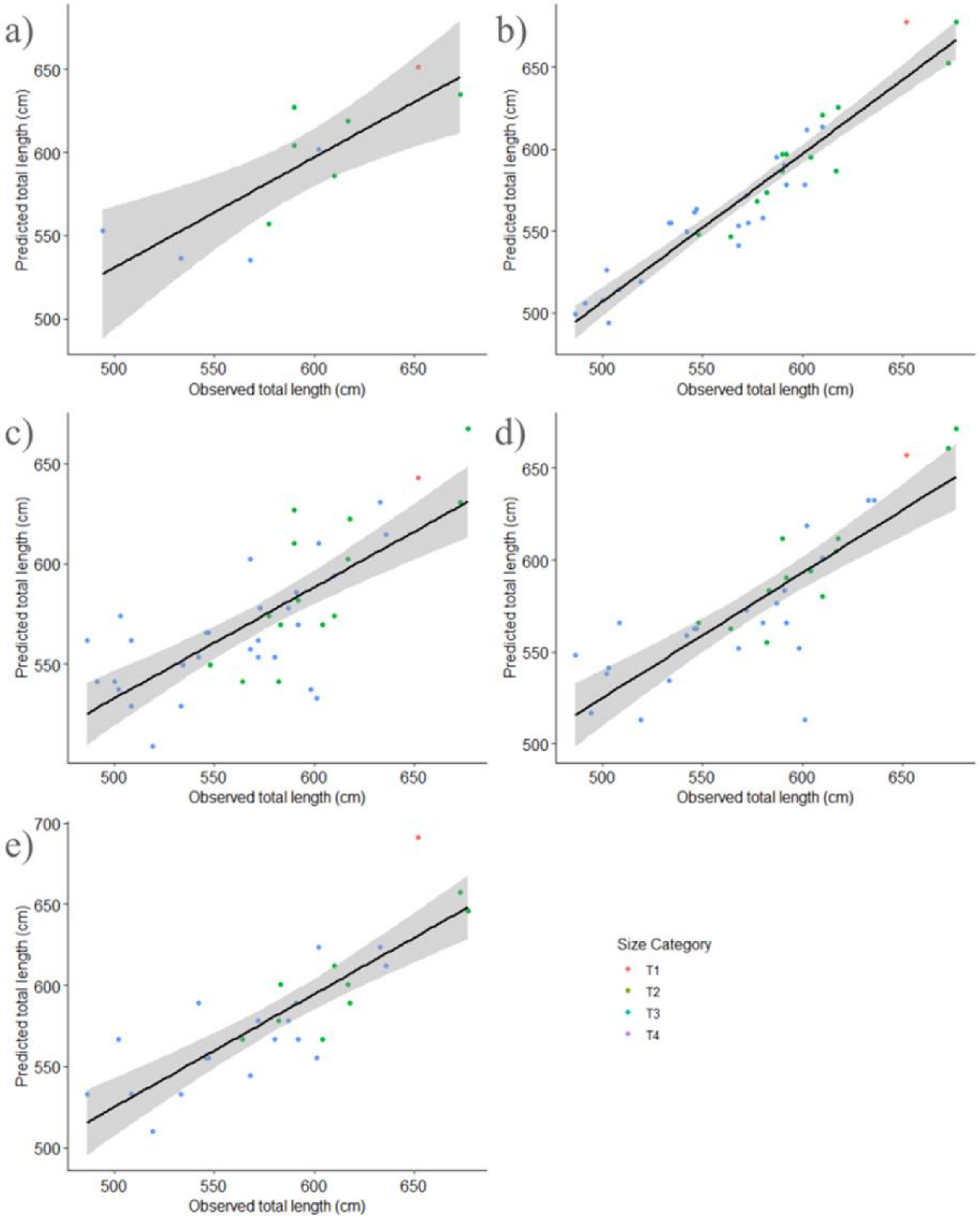

Figure 3.22 – Scatterplots of the relationship between observed and predicted values of total length of *R. montagui* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

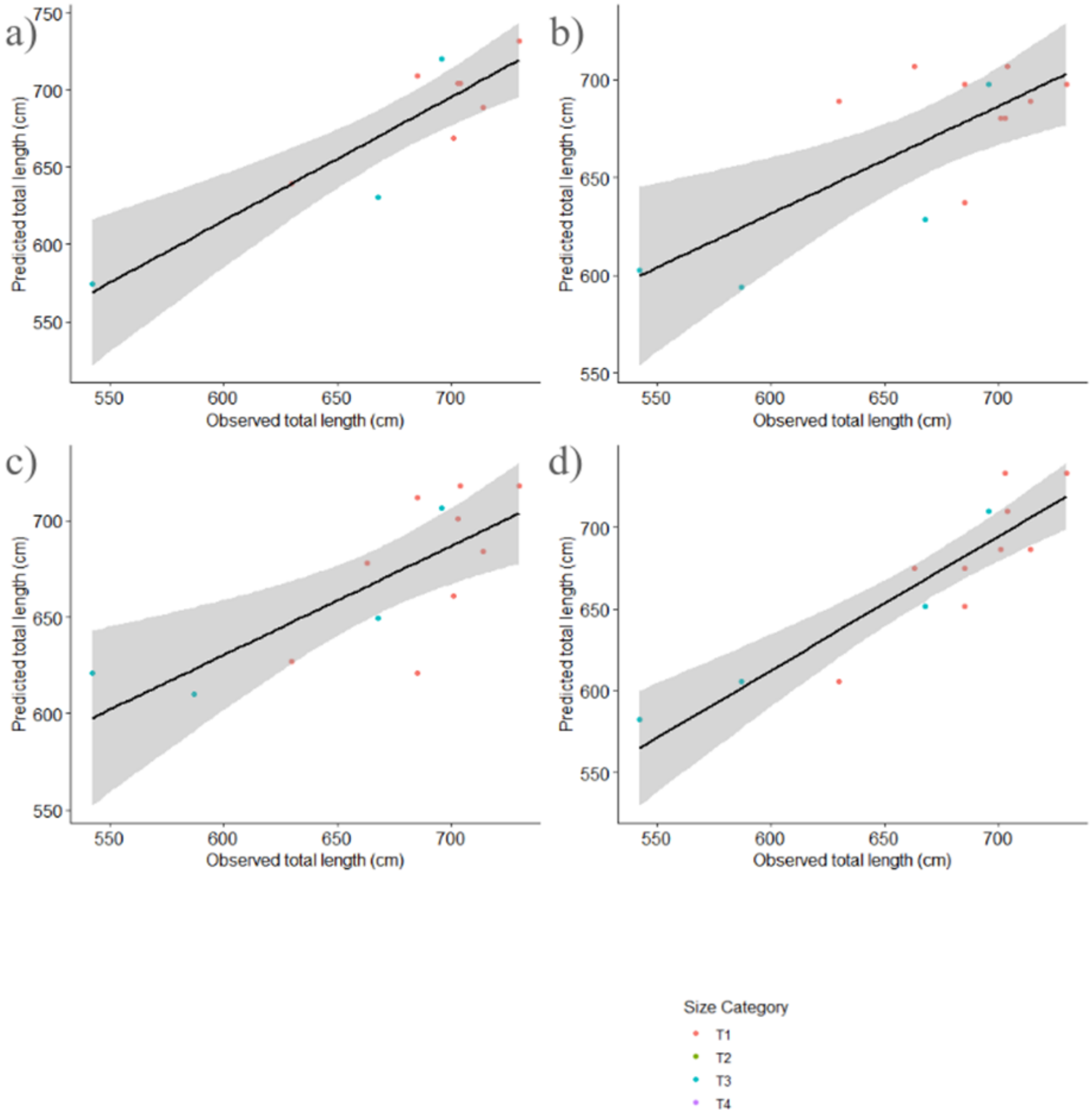

Figure 3.23 – Scatterplots of the relationship between observed and predicted values of total length of *L. naevus* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

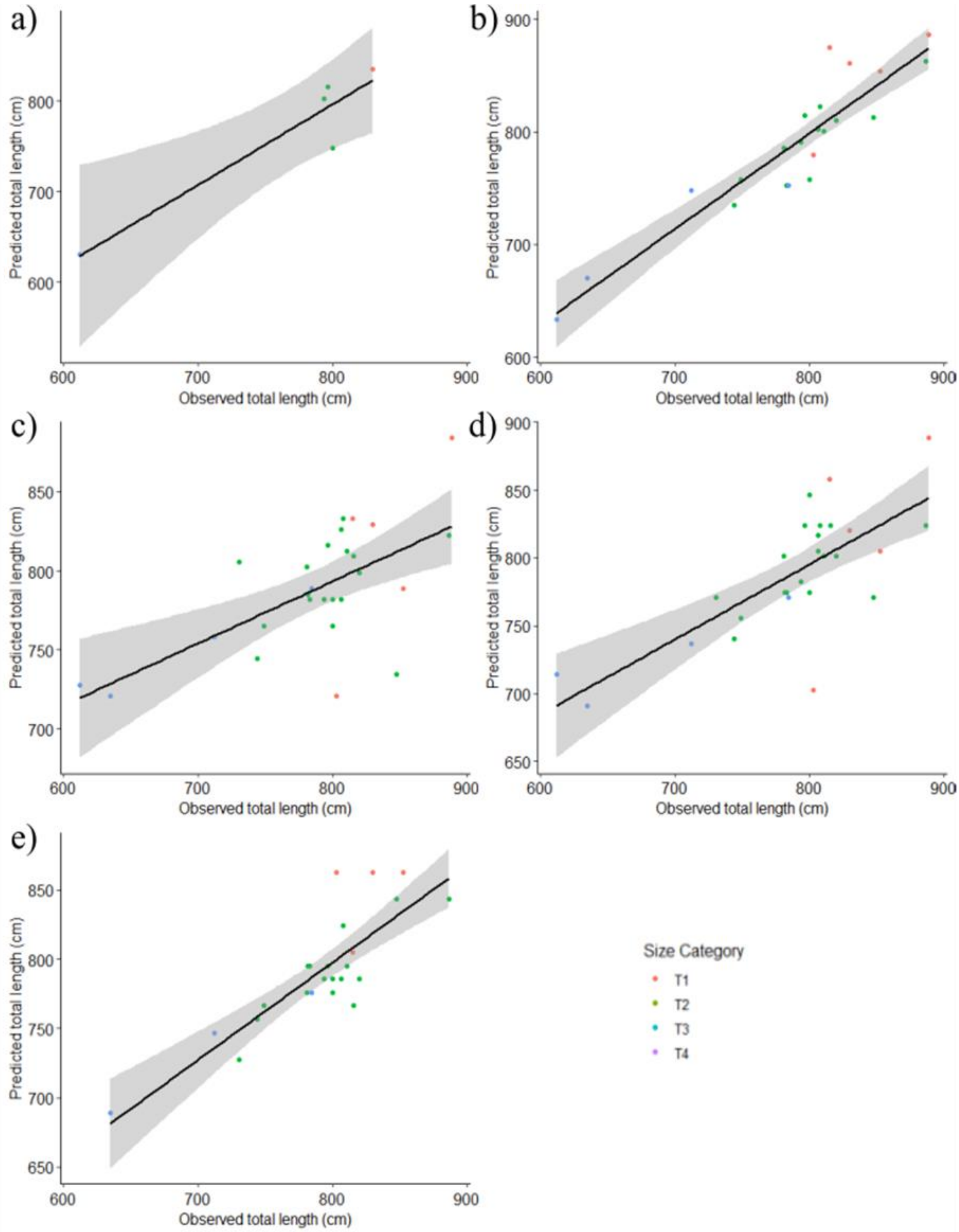

Figure 3.24 – Scatterplots of the relationship between observed and predicted values of total length of *R. undulata* collected through FishMetrics, based on five different secondary measurements: a) disc width, b) disc length, c) pre-orbital distance, d) spiracle posterior edge distance and e) interspiracle distance. Different colors represent the different commercial size categories.

Table 3.7 – Parameters of the linear regression equations between the observed and predicted values of total length using the secondary measures (DW (disc width), DL (disc length), POD (pre-orbital distance), SPED (spiracle posterior edge distance) and ISD (interspiracle distance); * P < 0.05; ** P < 0.01 and *** P < 0.001).

Species	**Parameter**	**TL – DW**	**TL – DL**	**TL – POD**	**TL – SPED**	**TL – ISD**
Raja brachyura	r^2	0.92	0.99	0.88	0.94	0.94
	P	***	***	***	***	***
Raja clavata	r^2	0.95	0.96	0.82	0.93	0.87
	P	***	***	***	***	***
Raja microocellata	r^2	0.88	0.97	0.89	0.89	0.92
	P	***	***	***	***	***
Raja montagui	r^2	0.66	0.90	0.55	0.68	0.69
	P	**	***	***	***	***
Leucoraja naevus	r^2	-	0.80	0.55	0.56	0.82
	P	-	***	**	**	***
Raja undulata	r^2	0.89	0.85	0.39	0.55	0.70
	P	*	***	***	***	***

4 DISCUSSION

This study aimed to contribute to the development of automatization of two processes: i) identification of commercially relevant species landed at the fishing port and ii) measurement of total length of individual specimens, achieved by characterizing the most useful relationships with other morphometric measurements that can be used as a proxy of total length. The study focused on six commercially relevant skate species, commonly landed in mainland Portugal (*Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui*, *Leucoraja naevus* and *Raja undulata*), and was developed in the main fishing port of mainland Portugal (Peniche and Aveiro) in the context of a digital measurement system implemented, developed by FishMetrics. This approach will allow to enhance both the sampling effort and intensity, aiming to increase the quality and quantity of collected biological data, which will facilitate and improve the fisheries assessment of different species. Towards this goal, the accuracy of species identification from the data collected using the FishMetrics platform was assessed. Only a small number of samples were incorrectly identified by the fishing port, primarily involving misidentifications between the smaller specimens of *R. brachyura* and specimens of *R. montagui*, which are very similar, especially to an untrained eye. Following the identification step, morphometric relationships for the six studied skate species were assessed through two instances, one *in situ* at the fish auction in Peniche and another using the FishMetrics platform with data from fish auction in Aveiro. Due to a low number of samples, *R. undulata* was not included in the *in situ* sampling data analysis. Most of the morphometric relationships (total length with disc width, disc length, pre-orbital distance, spiracle posterior edge distance and interspiracle distance) showed a high level of correlation, with the best results obtained using the FishMetrics sampling. Also, in both instances, the best relationship was between total length and disc length, for all species, while the least reliable relationship was generally between total length and pre-orbital distance. Then, the verification of the use of these alternative measures to infer total length measurements was carried out and the results and conclusions obtained were consistent. The set of results obtained in this work has shown a promising future for the use of electronic sampling, especially for the purposes mentioned above. However, it still presents limitations, some of which may be worked on in the future to improve its functionality. There was a similar study that utilized an automatic system that captured images of hake (*Merluccius merluccius*) at landing and used head length (a secondary measure) to estimate fish length, with good results. The study developed a deep neural network to detect and delineate the contour of the objects of interest, the fish's head, and later infer the total length of the fish based on it (Álvarez-Ellacuría et al., 2020).

4.1 *Raja brachyura*

Results from the sampling performed using FishMetrics denoted that for *R. brachyura* there was a substantial number of misidentifications by the fish market among the smaller commercial size categories (T3 and T4), namely difficulty in distinguishing specimens of the referred species and *R. montagui*. This occurred in the smaller commercial size categories of *R. brachyura* since this species achieves a larger maximum total length (125 cm, Froese and Pauly, 2023) than *R. montagui* (102 cm, Froese and Pauly, 2023). The similarity in morphologic characteristics between these two species may cause some erroneous identifications to untrained eyes. Moreover, since their commercial value (for the same size) does not differ much, there is little incentive for fishers to separate individuals of the two species in separate boxes, especially for smaller sizes who are more susceptible to misidentification due to overcrowding, since more boxes represent less space in the fishing vessels and a higher cost of box handling at the fish market.

However, from a fisheries assessment perspective, these misidentifications have implications in statistics and evaluation. Incorrect identification leads to unclear and incorrect species catch attribution, for instance, evidenced by the quantity of catches reported at a higher taxonomic level grouping in fishing statistics. On the one hand, there has been an increase in catch classified at the species level in FAO statistics at the beginning of the XXI century, especially Chondrichthyes (Lleonart *et al.*, 2006). But there are cases of catches reported under incorrect species as shown for several species landed in Portuguese markets, especially for species such as skates (ICES, 2022b), some flatfish species such as *Solea solea*, *Solea senegalensis* and *Pegusa lascaris* (ICES, 2022b), and between *Merlangius merlangus* and *Pollachius pollachius* (ICES, 2022b). This can result from equal or interchanging common names for distinct species (such as between *Merlangius merlangus* and *Pollachius pollachius*) or a remarkably close morphological similarity between species making their distinction hard to the untrained eye (such as for *Solea* spp., and skate species). These types of issues are still present, and according to ICES, this problem extends to all EU ecoregions (ICES, 2016). Erroneous or biased species catch attribution may lead to the necessity of correcting data from countries' official statistics and/or even the implementation of specific monitoring programs. IPMA implemented such a program in 2011, as a part of a three-year pilot study, in Portugal, to improve the knowledge of Rajiformes in the Portuguese fishery data, since fisheries data of landings at species level for this group of species had limitations (incomplete or contained errors) (Figueiredo *et al.*, 2020). Results from this study showed that the number of species of Rajiformes landed is more than those reported in official statistics and that misidentification and/or coding errors still persist in the Portuguese official fishery data. But authors also provide possible measures to diminish misidentification and under-reporting. The proposed measures can also be easily adapted to other situations of limited data on landings in fisheries statistics. Programs alike aim to monitor and correct the status of the mentioned problems since species misidentification in landings data can result in misleading assessments of stock status, as shown for the European common skate (Iglésias *et al.*, 2010). Furthermore, for this and other species, there may be variation in the attribution of the commercial size category during the weighing process, depending on the person assigning the data for the fish auction, meaning the boundaries of each commercial size category are not completely fixed.

Another key variable in fisheries assessment is individual size which allows for studying the status of explored stocks and is also linked to key biological parameters (such as fecundity, growth rate, attainment of sexual maturity, and maximum size). Errors in fish size measurements, with the main measurement being total length, will affect the accuracy of growth rate and growth curve parameters' estimates (Francis, 2006). Alternative common metrics, such as disc width and disc length, are also used, although disc widths for skate species were stated as presenting a higher variability than other measurements and as so not recommended as an alternative measure (Francis, 2006). Various alternative measurements have been employed and shown reliable, repeatable, and affirming tight linear relationships to total length (Downs and Cheng, 2013), and length-length or width-length relationships have been applied in stock assessment (Downs and Cheng, 2013).

Overall, high correlations between secondary measures and total length for all species in the present study showed promising prospects for the usage of EM to increase size measurement data. These measurements performed *in situ* at the market and via FishMetrics for *R. brachyura* presented a high correlation between total length and all secondary measures assessed. Among the secondary measures, disc width presented one of the highest correlations with total length for this species, in agreement with previous studies. In total, nine studies presented also high correlation (r^2>0.98) between total length and disc width, pointing out disc width as a good measure to derive total length (Rogers and Ellis, 2000; Catalano *et al.*, 2007; Porcu *et al.*, 2010; Serra-Pereira *et al.*, 2010; Ellis *et al.*, 2011; McCully *et al.*, 2012; Porcu *et al.*, 2014; Marongiu, 2015; Thys *et al.*, 2022). Disc width also has a high degree of importance for fisheries assessment since it is usually employed as an alternative measurement when is not possible to acquire the total length, which happens mainly when the tail is damaged. A recent study (Thys *et al.*, 2023) found that the disc width is a major divisive measure to distinguish between *R. brachyura* and *R. montagui*, and with further verification might be used as an additional measure to distinguish between specimens of these different species. These findings would enable the use of alternative measures not only to be used on fisheries assessment but also to aid in distinguishing between these different yet morphologically close species.

Additionally, one study evidenced a high correlation ($r^2>0.99$) between total length and disc length (Serra-Pereira *et al.*, 2010). Similar to species-specific features of disc length used to differentiate between skate species, such as *R. brachyura* and *R. montagui* (Serra-Pereira *et al.*, 2010), this may also be possible using other measurements like disc width.

The remaining secondary measures assessed in this study were selected due to their position on the dorsal side, which corresponds to the side that is more often visible at the fishing port, and in the anterior area, since it is an area of easy access for measurement and sampling of skate species, given that skates are horizontally flat chondrichthyans.

In contrast to sampling in FishMetrics, the obvious advantage of sampling specimens *in situ* at the market is that all individuals selected for sampling can be measured and all measurements can be recorded since handling by the observer is possible, allowing to clearly identify all points/landmarks. In the case of *R. brachyura*, in the FishMetrics approach, only around one fourth of all samples correctly identified were measured. Among these, most specimens had only some measures taken in FishMetrics, rarely all, which is due to several reasons, such as specimens overlapping each other, ice used to conserve the fish or slime produced by the skates obscuring or completely hindering the identification of the points/landmarks needed for measurements, resulting in a different number of samples by measure. Despite the mentioned difficulties, the measurements taken in the anterior dorsal region, such as pre-orbital distance and spiracle posterior edge distance, presented the higher number of measures taken, closely followed by interspiracle distance and disc length, for *R. brachyura*.

Although through FishMetrics there was a smaller number of samples from the larger commercial size category (T1) compared with the other categories, both methods showed very similar results, except for pre-orbital distance where, although small, there was a higher difference between methods.

4.2 *Raja clavata*

Sampling with the FishMetrics system revealed that most of the samples classified as *R. clavata* in the fish market were correctly commercially identified, this is mostly due to this species being very distinct and easy to identify, in terms of morphology, compared to other skates landed in Portuguese fishing ports. Nonetheless, and mainly due to the common practices at the Portuguese fishing ports, namely stacking individual specimens and adding ice to the boxes, only around a fifth of *R. clavata* samples (i.e. boxes) could be measured, through FishMetrics. The most sampled secondary measures followed the same trend as the other studied species, using the mentioned method, meaning the difficulties mentioned affected all sampled species, with pre-orbital distance and spiracle posterior edge distance having the greatest number of samples, followed by the remaining measures, and disc width having the lowest number of samples available, for this species. As for the measures taken both at the fish market and through the FishMetrics platform for *R. clavata*, both methods showed a good correlation between total length and all other secondary measures ($r^2 > 0.82$). Among the secondary measures, disc length presented the highest correlation with total length for this species. However, from the analyzed literature on morphometric relationships for this species, studies described a very high degree of correlation between disc width and total length, ranging from 0.88 to 0.99 in coefficients of determination (Nottage and Perkins, 1983; Rogers and Ellis, 2000; Fernández et al., 2001; Demirhan et al., 2005; Krstulović Šifner et al., 2009; Serra-Pereira et al., 2010; McCully et al., 2012; Kadri et al., 2014a; Adda-hanifi et al., 2017; Johanna and Thys, 2022), which is within the range of the results obtained in this study from both sampling methods. Kadri et al. (Kadri *et al.*, 2014a) also presented good relationships between total length and other alternative measurements, including pre-orbital distance. Authors termed this as snout tip to eye (SE), but used the same points/landmarks as those used in the present study, to measure pre-orbital distance and are thus comparable. Results from that study (coefficients of determination 0.92 for males and 0.94 for females) were slightly better than those obtained here, which can be related to differences in the study area (this work using data from the Northeast Atlantic, more concretely from ICES Division 9a and the other in the Central Mediterranean). It can also be because that study separated data by sexes, which could potentially lower variability in the relationships between measures. In the present study, sex was not determined, in part because sex determination through morphological characteristics, the claspers which are on the ventral side, is generally not possible using the FishMetrics platform, especially in smaller individuals and is often further complicated by overlapped individuals and ice-covered specimens.

4.3 *Raja microocellata*

Sampling with FishMetrics revealed that almost all the samples identified as *R. microocellata* in the fish market were correctly identified commercially. This can be explained by the very distinctive morphologic species characteristics of this species, which are very easy to identify, compared to other landed skates in Portuguese fishing ports, as in *R. clavata*. Due to the already mentioned factors of specimens overlapping and ice packing, only around a fourth of the samples identified as *R. microocellata* could be measured through FishMetrics. The number of sampled secondary measures followed a similar trend as observed for the other studied species, with pre-orbital distance and spiracle posterior edge distance having the highest number of available measurements, and disc width the lowest. For this species, fewer samples from the larger commercial size category (T1) were available through FishMetrics and for both methods applied (*in situ* and FishMetrics), a lower number of the smaller commercial size category (T4) was available. The smaller number of samples from the larger sizes may be linked to a smaller maximum length of this species (87 cm, Froese and Pauly, 2023). As for the measures taken both at the fish market and through the FishMetrics platform for *R. microocellata*, both methods showed a good correlation between total length and all other secondary measures, with slightly lower values than the previous two species but still highly significant. Among the secondary measures, disc length presented the highest correlation with total length, a trend observed for almost all studied species. However, the morphometric relationships in scientific literature found for this species were scarce compared to the other studied species, but nonetheless, showed a very high degree of correlation between disc width and total length ($r^2 > 0.92$) (Rogers and Ellis, 2000; Ellis *et al.*, 2011; McCully *et al.*, 2012). Differences in the correlation coefficients among studies may be related to the difference in the study area since the mentioned articles presented data from around the British Isles.

4.4 *Raja montagui*

Sampling remotely using FishMetrics showed that *R. montagui* was frequently commercially misidentified at the fish market particularly for the larger commercial size categories (T1, T2 and a smaller number of T3), because of the difficulty in distinguishing specimens of this species and *R. brachyura*. The maximum length of *R. montagui* is smaller than *R. brachyura* and the misidentification issue occurs in the smaller commercial sizes of *R. brachyura*. Nevertheless, 30% of the samples correctly identified as *R. montagui* could be measured. The number of measurements taken for each measure followed the same trend as all other studied species, with pre-orbital distance having the most measurements and disc width the fewest. Correlations between total length and some of the secondary measures were very high using both sampling methods and similarly to the species mentioned so far, with disc length obtaining the best correlation, also through both methods. However, for this species, the correlations using the secondary measures arising from the anterior dorsal area (pre-orbital distance, spiracle posterior edge distance and interspiracle distance) were lower ($r^2 < 0.56$), except for interspiracle distance from FishMetrics data (r^2 0.82). This could be due to the lower dispersion of specimen sizes and the smaller sample size. Future analysis of the same correlations but using a larger sample size could shed some insight into the subject. From the perspective of the analyzed literature, they found a very good relation between disc width and total length ($r^2 > 0.94$; Rogers and Ellis, 2000; Fernández et al., 2001; Serra-Pereira et al., 2010; McCully et al., 2012), and a good relation between disc width and disc length (r^2 0.93; Serra-Pereira et al., 2010).

4.5 *Leucoraja naevus*

One of the most particular cases of this study was *L. naevus*, because, through both methods, only a very low number of samples was obtained: 29 samples at the fish market from the smaller commercial size category (T4) and 13 from FishMetrics, from the two smaller commercial size categories (T3 and T4). The data available through remote sampling (FishMetrics), presented no samples classified as *L. naevus*, but a more generalized classification (skates – Raja spp.). Of all samples classified in this way, the majority of them were *L. naevus* samples, and out of all samples correctly assigned to this species, about 35% of them could be measured, the highest percentage of measured samples out of all analyzed species. This species did not follow the same trend in results as the other studied species regarding the number of samples per measure using the FishMetrics platform, as all anterior dorsal measures could be recorded in all available samples (13), and disc length was closely behind measured in 10 samples, whereas disc width could only be recorded in one sample. Results regarding both methods were somewhat similar to the results obtained for *R. montagui*, with some very high relationships (disc length in both methods and disc width through manual sampling at the fish market) and some others not as high, with pre-orbital distance being the worst measure in both methods. In contrast, a very low relationship was obtained for pre-orbital distance sampled at the fish market, but this result was not in agreement with the same output using the FishMetrics method (0.55). This disparity in results for the same measure is most likely due to a sampling error in the *in situ* method, made even more noticeable due to the low number of samples. This highlights a practical contrast between the two methods, since the FishMetrics method allows for errors to be checked whereas the *in situ* method only allows for errors to be checked if detected during the sampling period. In the present study, for this species, the highest correlation between total length and secondary measures was found with disc with through fish market sampling and interspiracle distance through FishMetrics. Similarly to the present work, studies from the literature concerning this species and morphometric relationships arrived at a high correlation between disc width and total length ($r^2 > 0.93$), and one of those studies also found a high correlation between disc length and total length. Although it did not present any obstacles for this study, this species might have some problems in terms of misidentification. This species and *Leucoraja circularis* have the same common name in Portugal, "Raia de São Pedro", but they can easily be distinguishable to the trained eye, as the latter has 4-6 creamy spots on each wing and *L. naevus* has one large roundish black eyespot in the middle of each pectoral fin (Froese and Pauly, 2023). In the present work, the objective was to have samples dispersed across all possible commercial size categories, but in practice, larger size samples could not be sampled, which is justified by the small maximum length of this species (81 cm) which is close to the minimum size permitted for captured (60 cm) in Portugal (Government of Portugal, 2022). Also, the volume of landings for this species is low compared with, for example, *R. brachyura* (ICES, 2022b).

4.6 *Raja undulata*

Due to insufficient data in previous years, *R. undulata* is under special legislation in Portugal, that has been updated several times. The legislation has established special measures of management for this species and the conditions for collection of information as described in section 1.5.6. Because of these limitations concerning landed specimens of this skate species in Portugal, and the time frame for sampling at the fish market defined for this study, it was not possible to provide sufficient data from the *in situ* method to analyze the relationships between total length and alternative measures. Meanwhile, using data collected through FishMetrics, it was possible to achieve results that denote the contrast of the two methods in terms of the flexibility of covering different time periods in a study. Around 30% of the samples identified as *R. undulata* through the FishMetrics platform were measured, this was one of the most measurable species present in this study (same as *R. montagui*). The difficulties already mentioned for other species about specimens overlapped in boxes and covered with ice were also present but there was no misidentification with other skate species involved in this work, mainly because this species is quite distinct from other species of skates and because there are known legal restrictions to its landings. Similarly to the other studied species, the anterior dorsal measures had a higher number of samples, and the measure with the lower number of samples was disc width. All secondary measures had high relationships with total length (especially disc width despite having the lowest number of samples), except for pre-orbital distance and spiracle posterior edge distance (0.49 and 0.55 respectively). The results obtained in this study are in agreement with the analyzed scientific literature for this species, namely reporting a high correlation with disc width (0.98 or 0.97) (Coelho and Erzini, 2002; Ellis et al., 2011; McCully et al., 2012) and one article reporting high correlation with disc length (Serra-Pereira *et al.*, 2010). That same study reported a high relationship between caudal length and total length (0.98) and between disc width and disc length (0.96). These last two relationships presented in the scientific literature were not addressed here in the present work because caudal length is expected to present some restraints to the possibility of achieving measurements even if possibly not as limited as total length. Moreover, the present study aimed to analyze relationships between secondary measures and total length, therefore relationships between secondary measures were not analyzed.

5 FINAL REMARKS

This study investigated morphometric relationships between total length (the main variable used in numerous biological studies and especially in the context of fisheries management) and alternative measures, and results highlight the value of several of these alternative measures as proxies of total length, for both *in situ* sampling and using electronic monitoring systems.

The similarity between the results relating to the secondary measures and total length, with the results relating to observed total length and total length predicted using the secondary measures is because these two analyses use the same set of data for their results. Although they give the same coefficients of determination and statistical significance, the equations for the calculated relationships are different. In future work, the adequacy of using the secondary measures to infer total length values could be further verified with a test data set to evaluate if these alternate measures are truly good predictors of total length. Additionally, most secondary measures used here, such as pre-orbital distance, spiracle posterior edge and interspiracle distance, have had limited employment in morphometric studies (Kadri *et al.*, 2014a). The results obtained in the present study support further investigation, especially for interspiracle distance.

The variability in the coefficients of determination comparing the methods used in the present study (*in situ* and FishMetrics) may be explained by user error and by the heterogeneous distribution of samples through the different commercial size categories. Also, the lower number of samples used compared with other studies involving morphometric relationships in the species of this work may explain the slightly lower values of those correlations, since a larger data pool available could reduce variability in the data. In what concerns the results from the present study alone, lower values were obtained in species and measurements with less data available (this was observed for disc width, through FishMetrics). In future work, a larger sample set of specimens more homogeneously distributed among commercial size categories will be of added value, allowing an even more robust detection of relationships. The present study included the main fishing port of the studied species in Portugal (in terms of landings), Peniche, and further work could benefit from a greater spatial coverage of sampled individuals. Furthermore, future studies should be performed over larger time windows to account for possible seasonal changes in species and length composition of landed skates.

Only the *in situ* method allowed sex determination of each specimen through external visualization during the handling of individuals at the landing port. However, using the FishMetrics method, sex determination is not possible when the specimens have the dorsal side up which is the side that allows for identification of the species. Therefore, the present study was defined to not take into consideration the effects of sex of the specimen. However, previous studies have shown that some skate species present dimorphic disc shapes (Francis, 2006; Orlov and Cotton, 2011). Among the studies analyzed in the literature review focusing on relationships between total length and alternative measurements, several studies took sex into consideration. Several studies reported results separately by sex and some found statistical significance in disc width and total length relationships between males and females, in particular for *R. brachyura* (Catalano *et al.*, 2007; Porcu *et al.*, 2010; Porcu *et al.*, 2014; Marongiu, 2015) and *R. clavata* (Kadri *et al.*, 2014b).

This study showed the potential value of using an electronic monitoring system to aid and expand the data collection of fish landed at the fishing port, with the aim of improving data collection for fisheries assessment. Over the last few years, electronic monitoring systems have gained traction, with more trial studies and innovative applications to aid fisheries assessment (van Helmond *et al.*, 2020). These electronic monitoring systems can be used at the different stages of fisheries (Shibata *et al.*, 2024), although most of the focus has been at the catch level, i.e., data collected onboard vessels when the specimens are caught (van Helmond *et al.*, 2020; Lekunberri *et al.*, 2022; Ovalle *et al.*, 2022), and with fewer applications at the landings level at market (Álvarez-Ellacuría *et al.*, 2020; Palmer *et al.*, 2022; Shibata *et al.*, 2024). The present work was focused on the latter, i.e. on the data collected when the fish is landed at the fish market before auctioning. Monitoring of biological data onboard fishing vessels can provide more information than onshore since the fish landed at the fishing port represent only a part of the catch, not providing information on incidental bycatch and discards, and neither on fishing effort. Such additional information is important for stock assessment and fisheries management but cannot be accurately assessed at the fishing ports. With this in mind, the next step for electronic monitoring in Portugal could be the testing of these systems on board national fishing fleet vessels or onboard scientific research vessels.

The electronic monitoring method applied in this study permits the possibility of collecting data remotely, with the advantage of dismissing the need for travel, presence and intervention *in situ* and manual handling of boxes and fish by scientific observers. Additional potential advantages are the increase of the amount of data available, in terms of the number of sampled fishing trips, but this potential depends on the rate of measurable individuals per box. One limitation of the current mode of implementation of FishMetrics, due to the way the fish market in Portugal works, is that specimens of skates are sometimes landed ventral side up, making it impossible to ascertain their correct identification. Regarding misidentifications, is it also important to further inform and train both fishers and fishing port employees, to minimize incorrect identifications, before and during the weighing process of landed fish. Another limitation of the FishMetrics approach is that in smaller commercial size categories, one box of fish landed contains many overlapping specimens, because of the space that boxes occupy onboard vessels and in the fishing port and because in Portugal there is a cost associated with the handling of each box at the fishing port. This makes it challenging or impossible to ascertain measures or the correct identification for all the specimens in the box, with the FishMetrics approach. Identification and measurement with the FishMetrics system are more frequently possible in larger commercial size categories because, for larger individuals, due to their weight and size, they are usually landed in separate boxes, or at least with fewer specimens per box. A smaller number of non-overlapping individuals per box would be ideal for the FishMetrics system, but this would incur additional space, handling time and handling cost. The potential of the FishMetrics approach could potentially benefit from a lower handling cost for these species, which could incentivize fishers to include a lower number of individuals per box, increasing the quality and quantity of data available for measuring. However, the most suitable approach would need to be discussed and evaluated with all stakeholders involved in the process (i.e. fishers, fishing port/auction, and FishMetrics developers and users) to minimize or avoid negative impact on fish auctions.

Results of the present study showed that difficulty in species identification and measurement of individuals also arises from the ice used to preserve the freshness of fish during their transportation or at the fishing port while in wait for the auctioning, and the slime produced by skates that mixes and dilutes with the ice on skates' boxes, both substances have a white to translucid appearance hindering high-quality image acquisition due to light reflection. One possible solution to avoid issues with the ice could be addressed by changing the time of placement of ice in the box, changing it to after the auction, which could be feasible if the fish market environment where at an appropriate temperature (e.g. as seen in some other fish markets internationally). Implementing these potential changes would however result in additional expenses with the investment required to modify the existing infrastructure and to install refrigeration equipment and with the increased operating costs of a more energy-demanding infrastructure. It is important to note that not all Portuguese fishing ports may be suitable for these changes due to their differing capacities and daily volume of activities. Any potential implementations or modifications would need to be carefully studied. Additionally, these changes would need to be thoroughly discussed and assessed with all relevant stakeholders, similar to the previous proposal.

An additional step to further increase sampling data acquisition is to develop and employ automated or semi-automated systems for species counting and measuring using artificial intelligence and deep learning models. Several studies have developed such systems (Palmer et al., 2022; Álvarez-Ellacuría et al., 2020; Ovalle et al., 2022; Shibata et al., 2024; Lekunberri et al., 2022) which allow to further reduce the human resources needed whilst increasing the amount of data collected. Furthermore, these types of systems can be extended to include additional parameters that allow species identification (e.g. Gholam Hosseini et al., 2008, Banan et al., 2020 and Chen et al., 2021).

In summary, this study shows the potential of electronic monitoring systems in the fisheries sector, especially for collecting biological data on skate species during landing in fishing ports in Portugal. By comparing traditional manual sampling methods with modern technological approaches, this research highlights the efficiency and accuracy of electronic systems in capturing important morphometric data. The findings suggest that implementing such systems could be used to contribute to fisheries management by providing reliable data with minimal human intervention. However, challenges remain, such as species misidentification and logistical constraints in image collection. Addressing these issues through further research and collaboration among stakeholders, including fishers and regulatory bodies, is crucial for optimizing the use of these systems. Overall, this work contributes to the growing knowledge of sustainable fisheries management and lays the groundwork for future advancements in electronic monitoring technologies.

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7 ANNEXES

Annex 1 – Summary table for morphometric relationships for skate species relevant to this study in the Northeast Atlantic and Mediterranean Sea area from earlier studies.

Species scientific name	**Species common name**	**FAO alpha code**	**Reference**	**Region**	**Study area**	**Sex**	**Number of individuals (n) or N**	**Morphometric Relationship**				**Measurement Units**	**DOI**
								Equation	**a**	**b**	**R^2**		
Raja brachyura	Blonde ray	RJH	(Thys *et al.*, 2023)	North Atlantic Ocean	Southern North Sea (IVc) and Eastern English Channel (VIId)	Mixed/ All	59	DW ≈ a x TL + b	0.72262	-9.38127	0,99	mm	10.1016/j.fishres.2023.106679
			(Serra-Pereira *et al.*, 2010)		Northeast Atlantic	Mixed/ All	262	TL ≈ a x DW + b	-17.78	1.43	0.98	mm	10.1093/icesjms/fsq056
								TL ≈ a x DL + b	32.62	1.73	0.99		
			(Ellis *et al.*, 2011)		Western English Channel	Mixed/ All	142	DW = a x TL + b	0.6989	-0.1806	0.99	cm	10.1017/S0025315410001906
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	401	DW = a x TL + b	0.7125	-0.3288	0.99	cm	10.1093/icesjms/fss150
			(Rogers and Ellis, 2000)		Northwest Irish Sea, Western English Channel and Southern North Sea	Mixed/ All	89	DW = a x TL + b	0.735	-1.079	0.99	cm	10.1006/jmsc.2000.0574

Annex 1 Continued

Species scientific name	Species common name	FAO alpha code	Reference	Region	Study area	Sex	Number of individuals (n) or N	Morphometric Relationship				Measurement Units	DOI
								Equation	a	b	R^2		
Raja brachyura	Blonde ray	RJH	(Porcu *et al.*, 2014)	Mediterranean Sea	Central-Western Mediterranean Sea	M	930	DW = a x TL + b	0.7104	-0.5726	0.99	cm	10.12681/mms.898
						F	862		0.7216	-0.8588	0.99		
			(Catalano *et al.*, 2007)		Western Mediterranean Sea	M	123	DW = a x TL + b	0.7534	-4.239	0.99	mm	10.1080/11250000600831600
						F	102		0.7332	-14.388	0.99		
			(Porcu *et al.*, 2010)		Sardinian Sea	M	431	DW = a x TL + b	0.7406	-21.847	0.98	mm	N.A.
						F	408		0.7332	-16.372	0.99		
			(Marongiu, 2015)		Sardinian Sea	M	930	DW = a x TL^{b}	0.7216	-0.8588	0.99	cm	N.A.
						F	862		0.7104	-0.5726	0.99		
Raja clavata	Thornback ray	RJC	(Serra-Pereira *et al.*, 2010)	North Atlantic Ocean	Northeast Atlantic	Mixed/ All	570	TL ≈ a x DW + b	45.69	1.83	0.97	mm	10.1093/icesjms/fsq056
								DW ≈ a x TL + b	10.12	1.36	0.96		
			(Thys *et al.*, 2023)		Southern North Sea (IVc) and Eastern English Channel (VIId)	Mixed/ All	93	DW ≈ a x TL + b	0.66559	6.99057	0.96	mm	10.1016/j.fishres.2023.106679
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	1962	DW = a x TL + b	0.6572	0.9095	0.98	cm	10.1093/icesjms/fss150

Annex 1 Continued

Species scientific name	**Species common name**	**FAO alpha code**	**Reference**	**Region**	**Study area**	**Sex**	**Number of individuals (n) or N**	**Morphometric Relationship**				**Measurement Units**	**DOI**
								Equation	**a**	**b**	**R²**		
Raja clavata	Thornback ray	RJC	(van Steenbergen, 1994)	North Atlantic Ocean	North Sea	M	20	TL = a + b x DW	-7.108	1.654	N.A.	mm	N.A.
						F	27		2.254	1.331	N.A.		
			(Fernández-Lamas *et al.*, 2001)		ICES Subdivision VIIIc	Mixed/ All	443	DW = a x TL + b	0.7004	0.0773	0.9761	cm	N.A.
			(Rogers and Ellis, 2000)		Northwest Irish Sea, Western English Channel and Southern North Sea	Mixed/ All	168	DW = a x TL + b	0.694	-1.610	0.99	cm	10.1006/jmsc.2000.0574
			(Nottage and Perkins, 1983)		Irish Sea	M	N.A.	DW = a x TL + b	2.53	0.65	0.9801	cm	10.1111/j.1095-8649.1983.tb02880.x
						F	N.A.		0.82	0.70	0.9216		
			(Adda-hanifi *et al.*, 2017)	Mediterranean Sea	South-Western Mediterranean	M	226	DW = a x TL + b	0.64	2.22	0.99	cm	N.A.
						F	337		0.62	0.40	0.97		
						Mixed/ All	563		0.66	1.13	0.98		
			(Kadri *et al.*, 2014a)		Southern/ Central Mediterranean	M	530	DW = a x TL^b	0.5374	1.0588	0.9904	cm	N.A.
						F	750		0.5773	1.0412	0.9912		
						M	530	SE = a x TL^b	0.1209	0.9856	0.9242		
						F	750		0.1375	0.9524	0.9431		

Annex 1 Continued

Species scientific name	**Species common name**	**FAO alpha code**	**Reference**	**Region**	**Study area**	**Sex**	**Number of individuals (n) or N**	**Morphometric Relationship**				**Measurement Units**	**DOI**
								Equation	**a**	**b**	**R²**		
Raja clavata	Thornback ray	RJC	(Krstulović Šifner *et al.*, 2009)	Mediterranean Sea	Northern and Central Adriatic	Mixed/ All	364	DW = a x TL + b	0.6961	-1.6934	0.9870	cm	10.1111/j.1439-0426.2008.01204.x
						M	183		0.6864	-1.5375	0.9855		
						F	181		0.7069	-1.8793	0.9897		
			(Demirhan *et al.*, 2005)		Southern Black Sea	Mixed/ All	52	DW = a x TL + b	0.65	-2.47	0.88	cm	N.A.
						M	N.A.		0.56	-7.59	0.87		
						F	N.A.		0.72	-1.52	0.94		
Raja microocellata	Small-eyed ray	RJE	(Ellis *et al.*, 2011)	North Atlantic Ocean	Western English Channel	Mixed/ All	387	DW = a x TL + b	0.6478	4.0377	0.92	cm	10.1017/S0025315410001906
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	477	DW = a x TL + b	0.7193	-0.9008	0.99	cm	10.1093/icesjms/fss150
			(Rogers and Ellis, 2000)		Northwest Irish Sea, Western English Channel and Southern North Sea	Mixed/ All	308	DW = a x TL + b	0.739	-14.585	0.99	cm	10.1006/jmsc.2000.0574

Annex 1 Continued

Species scientific name	**Species common name**	**FAO alpha code**	**Reference**	**Region**	**Study area**	**Sex**	**Number of individuals (n) or N**	**Morphometric Relationship**				**Measurement Units**	**DOI**
								Equation	**a**	**b**	**R^2**		
Raja montagui	Spotted ray	RJM	(Serra-Pereira *et al.*, 2010)	North Atlantic Ocean	Northeast Atlantic	Mixed/ All	376	TL ≈ a x DL + b	54.50	1.72	0.94	mm	10.1093/icesjms/fsq056
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	1141	DW = a x TL + b	0.6605	0.2841	0.99	cm	10.1093/icesjms/fss150
			(van Steenbergen, 1994)		North Sea	M	55	TL = a + b x DW	-7.441	1.717	N.A.	mm	N.A.
						F	54		-2.620	1.522	N.A.		
			(Fernández-Lamas *et al.*, 2001)		ICES Subdivision VIIIc	Mixed/ All	464	DW = a x TL + b	0.6491	1.4817	0.9495	cm	N.A.
			(Rogers and Ellis, 2000)		Northwest Irish Sea, Western English Channel and Southern North Sea	Mixed/ All	648	DW = a x TL + b	0.666	0.172	0.98	cm	10.1006/jmsc.2000.0574
Leucoraja naevus	Cuckoo ray	RJN	(Serra-Pereira *et al.*, 2010)	North Atlantic Ocean	Northeast Atlantic	Mixed/ All	354	TL ≈ a x DW + b	51.89	1.57	0.93	mm	10.1093/icesjms/fsq056
								TL ≈ a x DL + b	66.37	1.78	0.91		
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	596	DW = a x TL + b	0.5840	-1.0050	0.99	cm	10.1093/icesjms/fss150

Annex 1 Continued

Species scientific name	Species common name	FAO alpha code	Reference	Region	Study area	Sex	Number of individuals (n) or N	Morphometric Relationship				Measurement Units	DOI
								Equation	**a**	**b**	**R^2**		
Leucoraja naevus	Cuckoo ray	RJN	(van Steenbergen, 1994)	North Atlantic Ocean	North Sea	M	30	TL = a + b x DW	1.460	1.688	N.A.	mm	N.A.
						F	45		3.211	1.630	N.A.		
			(Fernández-Lamas *et al.*, 2001)		ICES Subdivision VIIIc	Mixed/ All	556	DW = a x TL + b	0.5734	-0.4038	0.9674	cm	N.A.
			(Rogers and Ellis, 2000)		Northwest Irish Sea, Western English Channel and Southern North Sea	Mixed/ All	386	DW = a x TL + b	0.586	-1.103	0.99	cm	10.1006/jmsc.2000.0574
Raja undulata	Undulate ray	RJU	(Serra-Pereira *et al.*, 2010)	North Atlantic Ocean	Northeast Atlantic	Mixed/ All	228	TL ~ a x DL + b	2.23	1.84	0.96	mm	10.1093/icesjms/fsq056
			(Coelho and Erzini, 2002)		Algarve Coast	Mixed/ All	187	TL = a x DW + b	1.61	-3.03	0.98	cm	10.1017/S0025315402006495
						M	94		1.66	-4.45	0.98		
						F	93		1.58	-2.27	0.99		
			(Ellis *et al.*, 2011)		Western English Channel	Mixed/ All	97	DW = a x TL + b	0.597	2.4013	0.97	cm	10.1017/S0025315410001906
			(McCully *et al.*, 2012)		North Sea, English Channel, Irish Sea, Bristol Channel and Celtic Sea	Mixed/ All	331	DW = a x TL + b	0.5648	4.7130	0.97	cm	10.1093/icesjms/fss150