Biomass estimation and trophic analysis of fish and shellfish in Kagoshima Bay, southern Japan

（鹿児島湾産魚介類の現存量の推定とトロフィック解析）

Bernerd Mulwa Fulanda

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Biomass Estimation and Trophic Analysis of Fish and Shellfish in Kagoshima Bay, Southern Japan

Bernerd Mulwa Fulanda

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Approval of Dissertation

This dissertation titled:

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Submitted to:
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in partial fulfilment of the requirements for the award of the degree of

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Fisheries Science

is hereby approved under the recommendation of

…………………..…………………….……

OHTOMI, Jun, PhD.,
Professor, Faculty of Fisheries, Kagoshima University Japan

………………..…………...………

MASUDA, Yasuji, PhD.,
Professor, Faculty of Fisheries,
Kagoshima University, Japan.

………………..…………...………

NISHI, Ryuichiro, PhD.,
Professor, Faculty of Fisheries,
Kagoshima University, Japan.

………………..…………...………

FUWA, Shigeru, PhD.,
Professor, Faculty of Fisheries,
Kagoshima University, Japan.

………………..…………...………

SUGIMOTO, Yasushi, PhD.,
Professor,
The United Graduate School of
Agricultural Sciences,
Kagoshima University, Japan.

Dedication

This Dissertation is dedicated to:
***Firstly, to our second daughter, Abigail Nthenya (kamami)*:**

For the silent sacrifice, and your grand arrival on while I was away in the pursuit of this degree,

***To our first daughter Effie Kalunde (kasusu) and son Brian Fulanda (Papa)*:**

for the love and endurance during the many years I was away, seeking knowledge out and about
“You can never be afraid of the storms once you learn to sail your ship”

***To my loving wife Elizabeth*;**

It’s a 20 since we first met, your love, and your endurance has carried us across milestones,

***To our father Mzee Pius Fulanda wa Mailu (Papa Snr.)*:**

Through sacrifice, and family unity, and calm assurances even when stormy weather was eminent has seen me stand the test of time, molding "me" into "I" this day!

***To our mother, Kalunde (Usua wa kasusu, kapapa and kamami)*:**

For the unrelenting love all along: without the asserting look that made me feel comfortably capable, I would have "sunk the ship" ages ago!

***To my sister Josephine (Sioks)*;** your faith (more than I had!) that I could captain any storm kept me focused, walking higher for I was not prepared to let you stumble behind me.
“May all captain the ship of life safely thro’ oceans, plateaus and mountains alike!”

Lastly and most importantly: to the Fulandas, Mailus and Mukulas ;
I came this far on the shoulders and assurances of family strength - may the Lord keep us together, and bless you all the more!

Quote:

The strength of a family, like the strength of an army, lies in its loyalty to each other,
(Mario Puzo, The Family)
…..for God, surely blesses us in different ways....!

DECLARATION

This is to certify that:

(i) This dissertation comprises only my original research work towards the attainment of the Doctor of Philosophy (PhD.), except where indicated.

(ii) Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Professor Dr. Jun Ohtomi, in The United Graduate School of Agricultural Sciences, Kagoshima University, Japan.

Sign: …………………………………… Date: …………………………

Bernerd Mulwa Fulanda

In my capacity as supervisor of the candidate's dissertation, I certify that the above statements are true to the best of my knowledge.

Sign: …………………………………… Date: …….……………………

Prof. Dr. Jun Ohtomi

Abbreviations and symbols

ANOSIM	Analysis of Similarity
CPUE	Catch per Unit Effort
Compact-CT logger	Compact conductivity - depth logger
Compact-TD logger	Compact temperature - depth logger
EA	Elemental analyzer
EA-Conflo IV	Elemental analyzer Continuous flow series IV
EA-IRMS	Elemental Analyzer - Isotope Ratio Mass Spectrometry
GC	Gas Chromatography
GC-IRMS	Gas Chromatography - Isotope Ratio Mass Spectrometry
GC-MS	Gas Chromatography - Mass Spectrometry
GIS	Geographical Information System
G.S. core type sampler	Grab sampler core type
GPS	Geographical Positioning System
IAEA	International Atomic Energy Agency
kg	Kilogram
km	Kilometer
kg/ km^2	Kilograms per square Kilometer area
MORB	Mid-Ocean Ridge Basalt
MS	Mass Spectroscopy
nM	Nautical Mile
PCA	Principal Component Analysis
PDB	Pee Dee Belemnite
SIMPER	Similarity Percentage analysis
SD	Standard Error
VPDB	Vienna (Crustaceous) Pee Dee Belemnite
Ws	Wingspread (trawl net mouth width)

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Abstract

The present study aimed to conduct biomass estimation and trophic analysis of fish and shellfish in Kagoshima Bay, southern Japan in an effort to link fisheries and ecosystem management. Sampling was conducted during 2003-2011 onboard the *Nansei Maru*, a training vessel of the Faculty of Fisheries, Kagoshima University, at eight pre-established sampling stations Sts. 1-8 in four areas of the bay: bay head, channel area, central basin and bay mouth. Samples were collected using a simple trawl net measuring 23.5 m long, 6.7 m wingspread and 2.5 m mouth opening height with 37.9 mm and 20.2 mm mesh size at body and codend, respectively. The net was attached with compact temperature-depth (Compact-TD) loggers attached on the headrope for monitoring trawl net depth and recording of physico-chemical parameters. Towing durations were set as 10 or 20 min. "presets" and the duration of the preset tows was recorded at the ship's bridge. The times of the trawl net shooting, towing and hauling were estimated using pre-determined lengths of towing warps for various water depths at each of the sampling stations. Thereafter, effective tow durations were determined by plotting the Compact-TD and echo-sounder data against tow time, and compared with the preset tow durations for standardization of the sampling procedures.

Secondly, the effect of tow duration on the estimation of CPUE and abundance of individual species was assessed on the grenadier *Coelorinchus jordani*, one of the most abundant fish species in the bay. During the sampling, all hauls were sorted onboard and chilled in ice, and the total numbers and weights of each species recorded on arrival at the laboratory. Swept areas were calculated using the Saville (1977) method based standardized tow durations determined from the Compact-TD and echo-sounder data. The catch per unit effort (CPUE) was calculated as the catch weight (Cw, kg) divided by area swept by the trawl net during the standardized/effective 10 min. tow duration and fish biomass expressed as the

CPUE (Cw/area) × (catchability, *X*). Strata areas were estimated using latitude-longitude overlay and area calculator in ArcGIS 9.2 (ESRI, US). The fish biomass estimations in the 10 min. swept areas were then extrapolated over each stratum. Further, biomass estimations were conducted for all the fish and shellfish species in Kagoshima Bay and the distribution structure of the species assemblages assessed using ecological matrices including species diversity, evenness, and taxonomic distinctness and ordination techniques to decipher sentinel/indicator species in the areas of the sampling stations. Bathymetric, oceanographic and bottom sediment types are noted for each of the sampling stations to investigate any correlation with species distributions and community structures. Bottom sediments were sampled using a G.S. type core sampler (RIGO, Japan).

Lastly, stable Carbon (C) and Nitrogen (N) isotope analysis were conducted for the fish, shellfish and bottom sediments during 2009-2011 to investigate trophic structures in Kagoshima Bay. The isotopic analyses were conducted using an organic elemental analyzer (EA Conflo IV, Thermo Scientific, Japan) coupled to a gas chromatograph (GC analyzer, Thermo Scientific, Japan) and an isotope ratio mass spectrophotomer (Delta V Advantage, Thermo Scientific, Japan) at the Faculties of Agriculture and Engineering, Miyazaki University, Japan.

Trawl depths ranged from 78 to 233 m in sampling stations of the present study. A total of 172 species of Pisces, 124 species of Crustacea and 41 species of Mollusca were identified during the present study. Trawl analysis showed that the effective tow durations were, on average>50% longer than the preset tow values. Further, the computation of effective tow durations using Compact-TD logger and vessel's onboard instrumentation data presented a simple corrective approach to inadvertent estimations of tow duration, swept area and species abundance. The analysis of abundance showed that estimations based on the preset tow durations were highly biased: -10 to 130% and -5 to 85% bias relative to the effective tow duration estimations in the 10 and 20 min. presets, respectively. The biases were more pronounced in shorter tow durations in the deeper-water trawl hauls. Furthermore, in the analysis of individual species, CPUE and biomass estimations based on preset durations were highly biased compared to the standardized effective values: the abundance estimations for *C. jordani* were influenced by duration of the preset tow: the 10 min. tow duration CPUE and biomass were three times higher than the 20 min. values. The CPUE and biomass for *C. jordani* was correlated with the total catch per haul suggesting that haul size would influence the estimations of abundance for individual species. Therefore, both tow duration and size of haul and other factors associated with multispecies fisheries cannot be ignored in the estimations of abundance in fisheries surveys. Analysis of species distributions showed that species numbers in fish and shellfish assemblages in Kagoshima Bay were stable: sentinel and indicator species were identified as a *Amblychaeturichthys sciistius*, *Plesionika semilaevis* and *Euprymna morsei* community in central basin, a *C. jordani*, *Trachysalambria curvirostris* and *Octopus vulgaris* community in bay head and channel area, and a *Squatina nebulosa* and *Parapenaeus provocatoria owstoni* community bay mouth. The assemblages are closely correlated with bathymetric features in the bay including water depth and bottom sediment type. Therefore, the results of the biomass estimations and species assemblages provide a baseline for future assessment of the dynamics of the fish and shellfish species in Kagoshima Bay.

Isotopic analysis for fish, shellfish and bottom sediments showed varied $\delta^{13}C$ and $\delta^{15}N$ signatures by group: -18.6 to -12.5‰ $\delta^{13}C$ and 4.2 to 14.8‰ $\delta^{15}N$ for fish and -17.3 to -12.9‰ $\delta^{13}C$ and 5.77 to 11.76‰ $\delta^{15}N$ for shellfish. Bottom sediments recorded lower values at -23.7 to -19.3‰ $\delta^{13}C$ and 6.1 to 6.4‰ $\delta^{15}N$. The $\delta^{13}C$ and $\delta^{15}N$ signatures in fish and shellfish varied with body size which was attributed to ontogenic shifts in diets within species as their development through life history stages progresses. Trophic analysis of the $\delta^{13}C$ and

$\delta^{15}N$ signatures for all species revealed 12 niche groups. Allocating the base trophic level T_1 to primary producers with $\delta^{15}N$ of <3.4%), four trophic levels (T_2, T_3, T_3 and T_5) were discernible for fish and three levels (T_2, T_3 and T_4) for shellfish based on the $\delta^{15}N$ signatures: T_2 (3.4‰~ $\delta^{15}N$) grouping sediments and several shellfish species together, T_3 (6.8‰~ $\delta^{15}N$) comprising fish and some shellfish species, T_4 (10.4‰~ $\delta^{15}N$) including both fish and shellfish species, and T_5 (13.6‰~ $\delta^{15}N$) comprising only fish species such as *Uroconger lepturus*, *Argentina kagoshimae* and *Mustelus manazo*. The lower trophic level (T_1) was allocated to primary producers pending the analysis of benthic primary producers and plankton. Therefore this trophic level was not included in analysis of the trophic structures of fish and shellfish in Kagoshima Bay. The results of the trophic analysis of the species in Kagoshima Bay using stable isotope analysis are important in linking fisheries and ecosystem management of the bay and ecosystem for sustainable utilization of the marine and fisheries resources.

Keywords: Biomass and Abundance estimation, Deeper-water, Trawl survey, Swept area, Tow duration, CPUE, Stable isotope, Trophic analysis, Ecosystem management.

CHAPTER 1. BACKGROUND OF THE STUDY

1.1 General Introduction

Fishing and fisheries are economically and socially important activities the world over and more than 90 million tonnes of fish are landed from capture fisheries each year (Maxwell and Pilling, 2008). However, the management of the fisheries resources is faced with a delicate balancing act owing to the continuing demand for marine resources. Further, the sustainability of the fisheries resources is faced with numerous challenges including among other issues, i) the need to maintain healthy fish populations and profitable fishing industries, ii) the conservation of vital habitats and species, and recreational communities. Moreover, the management of many marine and coastal fisheries is often based on abundance indices derived from both experimental and commercial fisheries surveys. The situation is further augmented by the global decline in marine fisheries landings since the late 1990's, with low and continuously declining annual catches of both fish and shellfish with a global estimate of about 80 million tonnes (FAO, 2004). Several researchers have attributed the increase in landings observed in the 1980's and early 1990's to increased fishing effort and changes in type and efficiency of fishing gear and vessels used in the industry. The increased fishing effort resulted in changes in catch composition with serious depletion threats to long-lived species (Gislason, 2001; Blanchard et. al., 2002). Such changes in fishery stocks, from large predatory species to smaller planktivores and invertebrates often leads to a decline in the mean trophic level (Pauly et. al., 1998); a phenomenon referred to as "fishing down the food-chain". However, anthropogenic activities both within the coastal zone and fisheries as well as the overall functioning of natural ecosystems must be taken into account in order to ascertain the cumulative causative effects for the declining fisheries. Therefore, resource management must shift focus to continuous assessment of both the biotic and abiotic interactions within the aquatic ecosystems through trophic analyses and ecosystem modelling. As a result, current research initiatives have shifted from the study and management of fish stocks as single species, to a multi-species cum ecosystem management approach (Pauly et. al., 2000; FAO, 2004). This shift has enhanced the existing knowledge on the inter- and intra-species interactions and effects of various abiotic factors and natural climate processes on multi-species fisheries and entire ecosystems as outlined in the Kyoto protocol (Kyoto declaration, 1997). Therefore, the ecosystem approach to fisheries management helps define the best approaches to sustainable exploitation of multi-species fisheries while incorporating an understanding of ecological responses and the impacts of exploitation on the fishery and ecosystem as a whole.

Numerous efforts have been made towards achieving sustainable fisheries management including a range of tools such quotas, size limits, fishing gear restrictions, open and closed fishing seasons, fishing area closures, and establishment of a variety of marine protected areas (Dugan and Davis, 1993; Agardy, 1994; Botsford et. al., 1997; Lauk et. al., 1998). In this regards, fisheries policies have attempted to balance potentially conflicting management drivers for sustainable marine and fisheries resource use, and maintenance of ecosystem biodiversity, with socio-economic drivers of profit and employment along wide ranges of geographic scales (Constanza, 1997; Maxwell and Pilling, 2008). However, determination of the appropriate policies and management tools for sustainable resource exploitation as well as decisions on the best combinations of tools to accomplish the objective presents additional huddles for sustainable management of marine and fisheries resources. In view of the above huddles, stock assessments present a fast approach to equipping resource managers with the much needed information in order to make the correct decisions. These assessments attempt to establish stock size, growth rates and predictions about how the stock would respond to present and future management options. Therefore, the stock assessments are part of the decision making process and help to estimate present and possible future fishery states and the effects of management decisions on marine and fisheries resource sustainability (Maxwell and Pilling, 2008).

Bottom trawl surveys have been widely used in many demersal fisheries for monitoring demersal stocks especially in fisheries where only an index of abundance is required. Biomass estimations from these surveys are also useful in virgin stocks or in fisheries stocks when little or no data is available on the fishery (FAO, 1998). Therefore, experimental trawl surveys have become a preferred and indispensable adjunct to commercial catch and effort data in the assessment and management of marine and fisheries resources (Godø et. al., 1990; Hilborn and Walters, 1992; Somerton et al., 1999). The surveys provide a unique insight into species distributions and abundance with a wider coverage than commercial fisheries surveys. Experimental surveys are also independent of additional biases and errors of commercial fisheries data including the discarding of low-value bycatch, mis-identification and skewed reporting as well as variations in fishing effort and gear catchability which characterize commercial fisheries operations (Stratoudakis et al., 1998). Moreover, the use of fine mesh nets ensures that small individuals and species, normally absent in commercial fishing gear are caught, thus providing recruitment information on commercial species (FAO, 1998). The surveys are also important for monitoring changes in commercially important species and stocks and for collection of biological data on the more important species to support shore-based sampling and management programs. However, the estimation of total biomass from catch per unit of effort (CPUE) data entails several crucial assumptions which results in rather imprecise estimations of stock abundance. The CPUE calculated as catch per unit of swept area represents an index of stock abundance assuming an even distribution of the species in the area. Consequently, conversion of abundance indices into absolute measure of biomass can be done via holistic methods including the swept area method initially described by Saville (1977).

However, species catchability in bottom trawl fisheries is influenced by numerous factors. Accuracy of the estimated indices is crucial in defining sustainable management regimes especially in deeper semi-enclosed marine ecosystems which are particularly vulnerable to environmental damage and often difficult to fully understand and manage. Moreover, such ecosystems have remained largely under studied. Several studies have reviewed various abundance estimations methods for fisheries stock assessment (Gulland, 1975; Doubleday, 1981; Rivard, 1981; Troadec, 1980; Grosselin and Laurec, 1982). Due to the dependency of effective tow (fishing) durations and consequently, the accuracy of fishing effort and swept area estimations on oceanographic factors including the nature of sea bottom, water depth and ocean currents among other factors, biomass estimations based on mean catch using the Swept-area method often result in enormous bias (Krieger and Sigler, 1996) due to the assumption that the trawl gear sweeps "equal areas" for "equal durations of tow time". Consequently, the capture efficiencies are inadvertedly assumed to be independent of water depth, hydrodynamic conditions and towing velocities and other factors influenced by the nature of the sea bottom as well as water currents. The errors resulting from such assumptions are often more pronounced in fisheries where wide variations in water depth occur.

Ecosystem-based approach to management of natural resources is an important complement to existing fisheries management programs and has become an increasingly important concept in the management of marine and fisheries resources (Langton et. al., 1998; Mooney, 1998). Moreover, in face of the worldwide overfishing of marine and fisheries resources, development of ecosystem approaches to fisheries management has recognized as a major challenge in the 21st Century. The approach entails understanding the complex ecological and socioeconomic environments in which fish and fisheries exist, the effects that fishery management has on the ecosystem and the impacts of ecosystem change on fisheries (Mooney, 1998). Therefore, it is an important complement to existing fisheries management. Moreover, there is a growing consensus that sustainable management and fisheries-resource monitoring can only be achieved by shifting to ecosystem-based fisheries management (EBFM) which appreciates the dynamics and inter-relationships in aquatic ecosystems. Additionally, acknowledging the present fishing effort and deleterious practices in many fisheries worldwide has further buttressed the apparent need to modify fisheries management policies for biological and economically sustainable yields of the resources. However, EBFM can only resolve the underlying problems of existing fisheries management regimes if policies to stop overfishing and environmental degradation, and expand research and monitoring of fisheries resources are implemented (Mooney, 1998).

The ecosystem concept of fisheries management combines various components of the fishery including studies on populations, community, flows among components, energy, cycling, predation, resources sustainable management and conservation (Cherret, 1989; Power and Dietrich, 2002). Consequently, mathematical models that describe food webs present a key complement to fishery stock models which typically focus on single target species. Furthermore, traditional fisheries stock models have proved insufficient in guarding against over-exploitation of fishing resources and/or their declination due to habitat degradation (Mace, 2001; FAO, 2003; Hilborn et. al., 2003). Therefore, ecosystem-based fisheries management reverses the order of management priorities to start with the ecosystem rather than the target species aiming for sustainable and healthier aquatic systems (Pikitch et. al., 2004).

The development of models that incorporate energy flow kinetics to represent trophic functioning of marine ecosystems is an obvious key towards implementation of an ecosystem approach to fisheries management (Gascuel et. al., 2008). Moreover, concerted efforts have been put into trophic analysis and ecosystem modelling of marine fisheries to compliment EBFM. Harvesting of fisheries resources and decline in abundance of target and non-target species affects prey-predator equilibriums as well as competition, and via the trophic web, the entire ecological community (Jennings and Kaiser, 1998; Hall, 1999; Jennings and Blanchard, 2004). The impacts of fishing and marine resource exploitation vary with type and intensity of trophic interactions and tropho-dynamic models can be used to analyse, quantify, and forecast the impacts of fishing on target species as well as on other biological components of marine ecosystems (Gascuel et. al., 2008).

Worldwide, marine food resources have traditionally played a more significant role in Japanese diet and the dietary protein comprises over 40% sea food. Therefore, ensuring long-term sustainability of the marine and fisheries resources is one of the most important fishery policy objectives for Japan. Moreover, the country has one of the oldest and most successful marine fishery co-management regimes in the world (Asada et al., 1983; Yamamoto, 1995; Pomeroy, 1995). Like in many other countries, the regimes are based on regulations through licensing, closed seasons and/or closed areas. However, despite the superb co-management structure of Japan's fisheries industry, the country's overall fishing industry output has been declining and production dipped below 7 million tonnes in 1998 (Japan Diplomatic Blue-book, 1988). There is a need to analyse the existing fisheries resources and associated exploitation regimes to safeguard the country's fisheries sustainability and food sufficiency. Therefore, this study focussed on one of the most important bays in Japan, Kagoshima Bay and employed stock assessment tools and trophic analysis using stable isotope techniques to model the trophic structures of fish and shellfish in Kagoshima Bay fishery in an effort to link fisheries to ecosystem management.

Kagoshima Bay (locally known as Kinko-wan) is a deeper semi-enclosed bay with water depths reaching over 230 m (Ohtomi, 2001). The bay faces the East China Sea and the wider Pacific Ocean to the south. A large number of commercially important species of fish and finfish species inhabit the bay and sustain the Kagoshima Bay fishery (Ohtomi, 2001). Dominant species of fish include the grenadier *Coelorinchus jordani* (Macrouridae) and lantern-bellies *Malakichthys griseus* and *M. wakiyae* (Acropomatidae) (Fulanda and Ohtomi, 2009). Mariculture is also active in the bay for species such as Japanese amberjack *Seriola quinqueradiata* and Yellowtail *S. lalandi* (Carangidae). Commercially important decapod crustaceans inhabiting the bay include the deep-water mud shrimp *Solenocera melantho* (Pandalidae) (Ohtomi and Irieda, 1997). Other important decapod crustacean species in the bay include deep water pandalid shrimp *Plesionika semilaevis* and southern rough shrimp *Trachysalambria curvirostris* (Penaeidae) (Ohtomi et. al., 2009). Stomatopod crustaceans including *Squilloides leptosquilla* are also abundant in the bay (Ohtomi et. al., 2004).

Kagoshima Bay and fishery are well studied on many aspects: river discharge, water quality and ocean currents (Tsutsumi et. al., 1999; Sakurai, 1983; Kohno et. al., 2004; Hosotani and Kikukawa, 2005), mariculture (Nakano et. al., 2001), primary productivity (Kobari et. al., 2002; Adachi et. al., 2009), stock enhancement, recreational fisheries and resource management (Ahmed et. al., 2001; Atsuchi and Masuda, 2004; Ohtomi, 2001; Shishido, 2006; Nakashima and Matsuoka, 2006) and biology and population structure (Iwakawa and Ozawa, 1999; Masuda et. al., 2003; Puentes et. al., 2004; Ohtomi and Nagata, 2004; Ohtomi, 2006; Ohtomi and Sakata, 2006). However, very few studies have focused on estimations of biomass from bottom trawl surveys and/or trophic structures and relationships of fish and shellfish species in the bay. Ohtomi et. al. (2004) conducted a preliminary survey for estimating distributions of benthic animals and marine debris in Kagoshima Bay while Ishiguro et. al. (2006) assessed estimation methods of seaweed biomass using spectral images.

Consequently, there is lack of documented studies on standardization of trawl survey protocols, overall catch-effort assessment and trophic analysis of fish and shellfish species in the bay. The present study conducted a standardization of bottom trawl survey protocols and trawl gear operation, determination of tow durations and fishing effort, and biomass estimations for fish and shellfish species in Kagoshima Bay. Further, the study conducted a trophic analysis of fish and shellfish species using stable isotope techniques to avail data for tropho-dynamic modelling of Kagoshima Bay ecosystem and integrate available data and information for design of sustainable management regimes for this important fishery. The overall objectives of the present studies were to: i) assess the status of Kagoshima Bay fishery, ii) investigate spatial-temporal changes in fish and shellfish species, iii) assess the species diversity and community structures in the fishery, and iv) conduct a tropho-dynamic modelling of the bay ecosystem for evaluation of the efficacy of fisheries management policy interventions among other factors. Consolidation of present studies with available data to address the ecosystem and fishery management issues, evaluate impacts of existing management, environmental changes and trophic characteristics of the fishery forms an important step in linking the present research to resource management in Kagoshima Bay.

The study and research components were outlined as follows: -

1. Standardization of experimental trawl survey protocols for ongoing research in Kagoshima Bay, southern Japan. This involved calibration of the sampling gear, tow and effective tow durations, swept areas and standardization of fishing effort and Catch per Unit Effort (CPUE) for abundance estimations of fish and shellfish species in the bay.
2. Investigate the effect of tow durations on biomass and abundance estimations using selected species in Kagoshima Bay and recommend standardized sampling protocols for future experimental trawl surveys and stock assessment studies in the bay.

3. Conduct abundance estimations for fish and shellfish in Kagoshima Bay using experimental bottom trawl surveys and extrapolate estimated abundances to total biomass based on established sampling strata and stations in the bay.
4. Investigate the distribution structure of fish and shellfish assemblages in Kagoshima Bay with regards to species distribution, density and diversity and community structure analysis using community matrices and ordination techniques.
5. Conduct stable isotope analysis for fish and shellfish species in Kagoshima Bay based on $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios.
6. Characterize the trophic structure of the community of fish and shellfish species in the Kagoshima Bay and describe the trophic interactions using stable C and N isotope ratios and changes in $\delta^{13}C$ and $\delta^{15}N$ signatures in demersal species and bottom sediments to link fisheries to ecosystem management for resource sustainability.

1.2 Description of the study site

The present study was conducted in the semi-enclosed deeper Kagoshima Bay, southern Japan (Figure 1-1). The bay straddles latitude 31° 25' 0 N and longitude 130° 37' 60 E in southern Japan (Figure 1-1). The bay measures 80 km long and 25 km wide and is sandwiched between the Hokusatsu area of Kyushu Island, and the sinuate Satsuma and Ōsumi peninsulas to the west and east respectively. The Satsuma Peninsula borders the East China Sea to the west while the eastern coast of the Ōsumi Peninsula is washed by the Pacific Ocean. Sakurajima, one of the most active volcanoes in Japan towers out of the bay at 1110 m high.

Kagoshima Bay is comprised of two basins; a central basin and a bay head connected by a shallow channel area. The central basin represents a basin like topography with maximum water depths reaching about 237 m deep with an average depth of 126 m and opens out to the Pacific Ocean through a narrow bay mouth. The bay head, north of Sakurajima Island, has a semi-circular outline and both its east and the west coastlines are steep extending down to about 140 m. The bay mouth covers about 300 km^2 with average water depths of 80 m and extends about 20 km north-south and 10 km east-west. Two channel topographies are evident: the bay mouth and channel area which connect the open sea and the central basin and, the central basin and bay head, respectively. The bay is influenced by the warm Kuroshio Current from the south (Schmeits and Dijkstra, 2001). Therefore, the sea area around Kagoshima is relatively warm with water temperatures ranging about 15 to 28º C. Water circulation and surface currents within the bay deduced from surface temperature, salinity and transparency data indicate a counter-clockwise current system in the central basin (Sakurai and Maeda, 1980). In this basin, high-salinity open-sea water enters the bay along the east coast of the bay mouth flowing northwards along the Osumi Peninsula coast while low-salinity embayment water flows southward along the Satsuma Peninsula coast (Oki and Hayasaki, 1983; Sakurai, 1983; Sakurai et. al, 1998). During springtide the water currents measure about 50 cm/s in the central basin and are highest around the channel area at 90 cm/s. Current movements in the bay head are generally weak, with 15.4% of the 10 m-depths recording zero velocity (<1.2 cm/s) currents), 57.1% at 40 m, 38.4% at 100 m, and 99.0% at 180 m-depths (Takahashi, 1981; Kikukawa, 1983).

Seven major river systems empty their waters into the bay including the Hasegawa, Yamagawa, Kaminogawa, Kenkougawa, Amorigawa, Amikakegawa and Beppugawa in addition to 12 other smaller rivers. The entire Kagoshima Bay coastline is estimated at about 330 km.

Figure 1-1. A map of Japan with Kyushu (inset) showing the location of the study area in the present study; Kagoshima Bay, southern Japan

The bottom sediment type in the bay strongly rhymes with the hypothesized current flows: muddy and gravel-muddy sediments dominate the eastern edge of bay mouth, central basin, south of Sakurajima volcano and channel area while the western edge and bay head are characterised by gravel sediments (Ohtomi et. al., 2009).

Kagoshima Bay is home to a fishery resource with complex exploitation regimes from fisheries cooperatives, small scale bottom seiners, purse seiners, recreational fisheries and varied maritime activities. The bay has estimated 139 fishing ports with about 7,800 fishing vessels. Marine conservation in the bay is fairly active and two of Japan’s first designated marine protected areas (MPA’s): Sakurajima and Satamisaki which acts as marine refugia for the fishery resources of the bay (http://www.coremoc.go.jp/english/status03/contents_3.html). Therefore, the fishery is rich with target species including large carangids and a diverse speciose of decapod and stomatopod crustaceans. However, a holistic approach incorporating biomass estimations, trophic analysis and ecotrophic modelling is required to support other management tools in defining an ecosystem-based management program for sustainability of Kagoshima Bay and fishery.

1.3 Experimental design and sampling

In the present study, the demarcation of Kagoshima Bay comprises the bay and fishing grounds located within the central part of Kagoshima prefecture in a quadrangle at latitudes 30º 59' N and 32º 11' N and longitudes 130º 06' E to 131º 12' E. The fishing grounds extend from Cape Nagasakibana (31º 10′ N and 130º 32′ E) in on the Satsuma Peninsula, through Kagoshima, Aira, Kirishima, Tarumizu and Kanoya to Cape Sata (31º 00′ N and 130º 38′ E) in Ōsumi Peninsula. The total area of the bay is estimated to cover about 1130 km^2.

Based on oceanographic factors including water circulation, bathymetric characteristics and surface currents deduced from surface temperature, salinity and transparency data, a stratified sampling technique was used to demarcate the bay into four main areas with eight strata and one sampling station each: i) bay head, where water depths average at 140 m, with two strata Sts. 1 and 2, ii) channel area which connects the bay head and the central basin with one stratum St. 3, iii) central basin, south of Sakurajima with four strata, Sts. 4, 5, 6, and 7, and iv) bay mouth, connecting the central basin to the Pacific Ocean with one strata St. 8 as shown in Figure 1-2.

During 2003-2011, experimental trawl surveys were conducted onboard *Nansei Maru*, a 175 t training ship of the Faculty of Fisheries, Kagoshima University. The ship is equipped with an onboard trawling system comprised of a global positioning system (GPS JLR-7700 MK-II Navigator, JRC, Japan), a split-beam quantitative echo-sounder (KFC-3000, KAIJO, Japan), scanning sonar, (KCS-228Z, KAIJO, Japan) and an automatic tension controlled trawl winches system (Kawasaki hydraulics Co., Japan). The GPS navigator system displays the position of the ship while the echo-sounder displays water depth data. A simple trawl net (LC-VI, Nichimo Co., Japan) measuring 23.5 m long and 37.9 and 20.2 mm nominal mesh size at body and codend respectively was used in the present survey (Figure 1-3). The wings of the net are fanned by 1 m^2 canvas kites and the footrope consists of a rubber covered chain without bobbins or similar footrope gear such as often increases fish escapement under the footrope. A set of compact temperature-depth (compact-TD) and temperature-salinity (Compact-CT) loggers (ATD-HR and ACT-HR, JFE Advantech, Japan) were attached on the headrope for measurement of trawl net depth, water temperature and salinity. Data logging on the submersible loggers was set at 1-min. polling frequency and towing was conducted at 2.0 kt velocity.

Monthly sampling was conducted at four of the eight sampling stations in the bay while seasonal sampling was conducted at all stations while maintaining constant sampling procedures throughout the present survey.

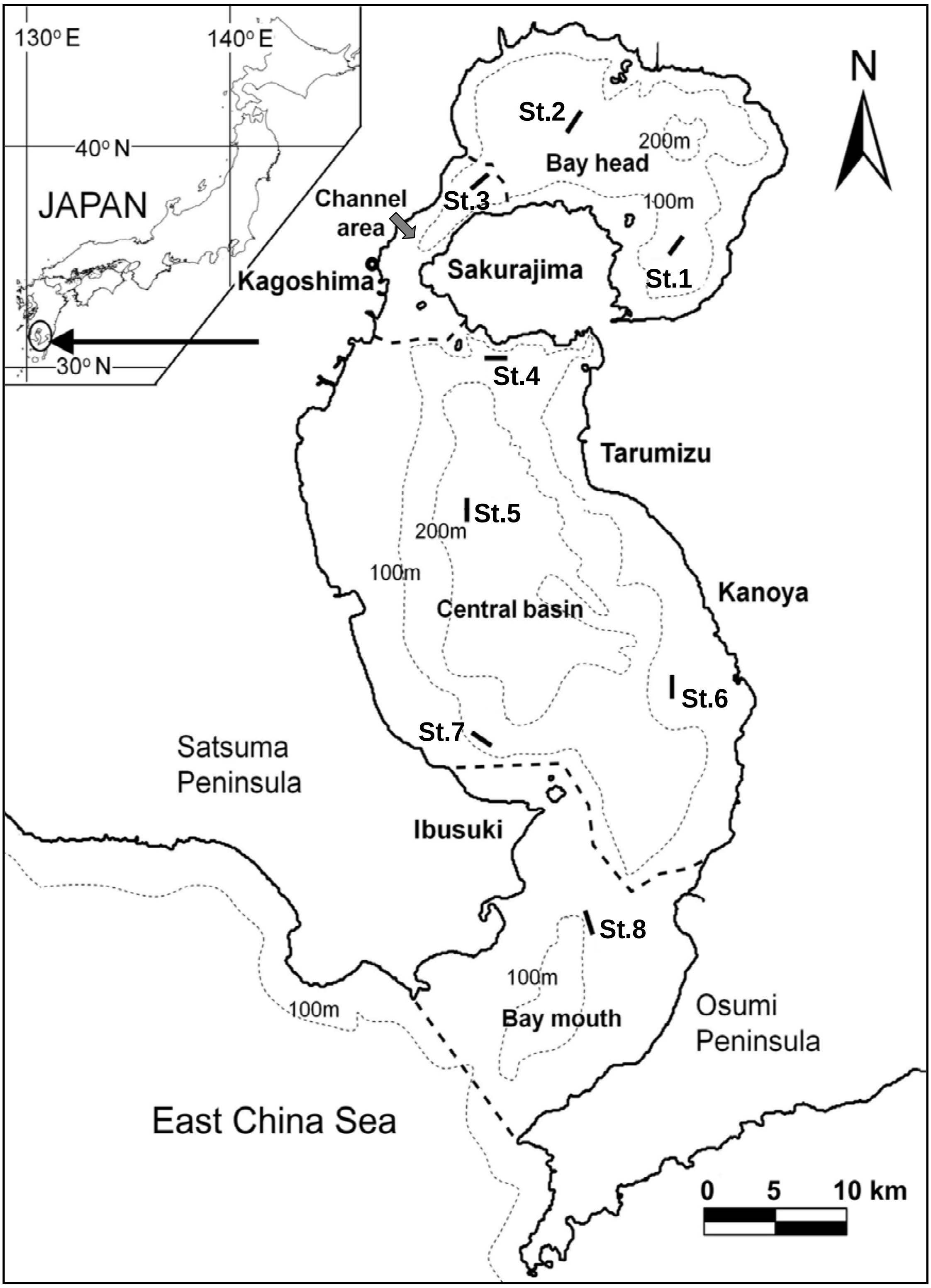

Figure 1-2. A map of the study area: Kagoshima Bay, southern Japan showing demarcation of the study area: bay head, channel area, central basin and bay month (shown by dotted lines) and location of the eight sampling stations (Sts. 1- 8) in the present study

All species of the bottom trawl gear including fish and shellfish were sorted at each haul and identified to species level. The samples were chilled in ice and transferred to the laboratory where total numbers were recorded and mensuration of total weights by species done an electronic weighing balance (Shimadzu BW3200D, Shimadzu, Japan) to 0.1 g precision.

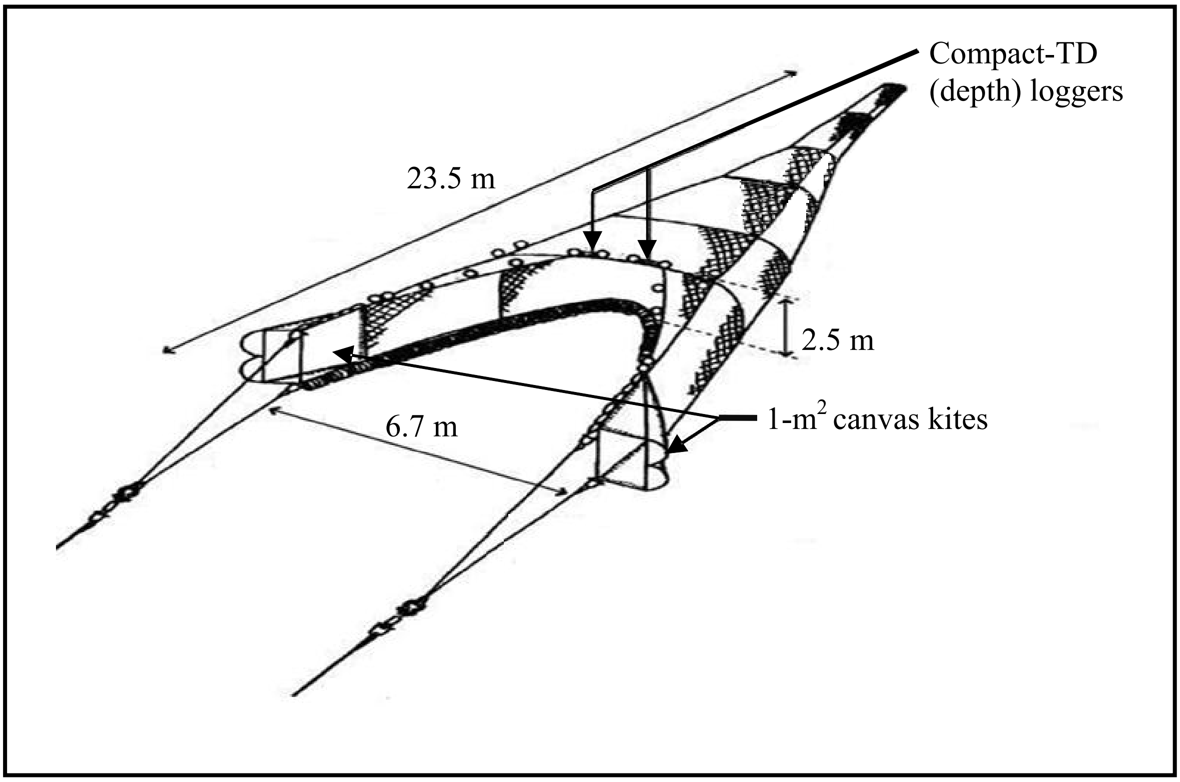

Figure 1-3. A simple trawl net (Nichimo LC-VI) used in the present study showing location of compact temperature-depth (Compact-TD) data loggers. The net measured 17.1 m headrope; 22.1 m footrope and 37.9 mm and 20.2 mm mesh sizes at body and cod end, respectively. The 6.7 and 2.5 m are the established wingspread and mouth opening height, respectively at 2.0 kt tow velocity

CHAPTER 2. STANDARDIZATION OF SURVEY PROTOCOLS FOR ASSESSMENT OF KAGOSHIMA BAY FISHERIES RESOURCES

2.1 Determination of effective tow durations for fish and shellfish abundance estimations in deeper-water trawl surveys

2.1.1 Summary

Experimental trawl surveys were conducted for standardization of stock assessment and survey protocols during 2003-2009 and to determine effective tow durations for estimation of fish and shellfish abundance in deeper-water bottom trawl surveys. A total of 304 hauls were conducted in Kagoshima Bay, southern Japan, for preset tow durations of 10 and 20 min. using a simple trawl net fitted with depth loggers (Figure 1-3). Towing durations were recorded at the ship’s bridge based on shooting, towing and hauling times of the trawl net using warp lengths pre-determined for various water depths based on *in-situ* model simulations and experimental field tows. The established warp lengths represented the optimal warp length to water depth ratio at which the trawl net was in contact with the bottom during towing. Effective tow durations were computed by plotting depth logger and echo-sounder data against tow time, and compared with preset tow durations. Trawled distances and fished areas were computed using euclidean metrics and the Saville (1977) Swept-area method, respectively. Effective tow durations ranged from 9 to 23 and 19 to 37 for the 10 and 20 min. preset tow durations, respectively. Preset tow duration estimations for abundance were highly biased: -10 to 130% and -5 to 85% bias relative to estimations from the effective tow duration values in the 10 and 20 min. presets, respectively. Moreover, the biases were more pronounced in the shorter tow durations in deeper-water trawl tows. Therefore, the

computation of effective tow durations using depth loggers and the ship's onboard instrumentation presents a simple corrective approach to inadvertent estimations of effective tow duration, swept area and abundance indices.

2.1.2 Introduction

Bottom trawl surveys provide important estimates of abundance and relative frequency of various population characteristics including distribution, reproduction and growth of demersal fish and shellfish (Gunderson, 1993; Godo, 1994). Studies show that well designed experimental survey-based assessments provide more accurate prognosis of the stock status than catch-based assessments (Nakken, 1998; Pennington and Stømme, 1998; Korsbrekke et. al., 2001). Moreover, the surveys remain an indispensable adjunct to commercial catch and effort data in the assessment of demersal fish and shellfish, providing unique insight into species distributions and abundance with a wider coverage than commercial surveys (Stratoudakis et. al., 1998). A key advantage of experimental survey-based assessment is that uncertainties associated with the estimations can be studied and quantified. Consequently, survey methodology, and ultimately, the derived abundance estimations can, carefully, be improved. Furthermore, it is easy to standardize fishing gear and sampling procedures in experimental trawl surveys, thus reducing bias in the catch per unit effort (CPUE) estimations which may be attributed to variations in trawl efficiency (Nakken, 1998; Pennington and Stømme, 1998; Korsbrekke et. al., 2001). Assuming even distribution in the sampling strata, CPUE represents an important index of stock abundance. Consequently, conversion of abundance indices into absolute measure of biomass can be done via holistic methods, including the swept-area method (Saville, 1977). Several authors (Gulland, 1975; Doubleday and Rivard, 1981; Troadec, 1980; Grosselin and Laurec, 1982) conducted early reviews of these methods. In comparison to errors associated with variations in trawl gear geometry including mouth opening height and wingspread, variability in towing velocity and effective tow duration (the actual fishing time) are the main sources of uncertainty in swept area estimations for abundance indices.

The speed over-ground measured from the global positioning system (GPS) is a commonly used method for determination of effective tow duration and distance. The precise duration of each haul is recorded manually where start of a tow is established from pre-established definitions of when correct trawl geometry is established at sea bottom, based on data and information from the vessel's onboard instrumentation such as GPS system, bottom depth echo-sounder, trawl monitoring system, scanning sonar, and total warp length and warp tension monitoring system.

Experimental trawl surveys have been conducted in the semi-enclosed deeper-water Kagoshima Bay, southern Japan since 2003 for quantitative and qualitative assessment of the demersal fish and shellfish (Ohtomi, 2001; Ohtomi and Nagata, 2004; Ohtomi and Sakata, 2006). In these surveys, the start of effective trawling is recorded as the time when the trawl net establishes contact with sea bottom based on optimal warp lengths pre-established for various water depths using initial field tows. In the present study, the warp lengths, established from *in-situ* model simulations and field experimental towing were the lengths of trawl warps at which the footrope and headrope opening height reached acceptable values and the trawl net was assumed to have established stable contact with sea bottom. Subsequently, retrieval time was preset after 20 min. of trawling for each haul while ensuring a skilful conducting of the towing and hauling. However, initial survey results showed significant differences between preset tow durations and the computed effective tow durations (Fulanda and Ohtomi, 2009). Moreover, high variations in the size of the hauls were also recorded for similar preset tow durations within the same sampling stations raising further doubts on the precision of preset tow duration measurement. These differences were a clear indication that the sampling procedures influencing effective tow duration during shooting and retrieval of the trawl net varied between different survey periods. During towing, both footrope contact with sea bottom and probable escapement of fish under the footrope were also thought to have important effects on trawl catchability. Secondly, the initial survey results often recorded too large sample sizes on each haul making it difficult to feasibly sort the catch in entirety (Fulanda B and Ohtomi J, unpubl. data, 2010). Consequently, the preset tow durations were scaled down to 10 min. However, changing the preset tow durations from 20 to 10 min. was likely to influence the bias in the estimation of effective tow durations. Moreover, the influence of such bias on the precision of the abundance estimations was an added concern for continuity of the survey time series in the assessment of Kagoshima Bay fishery resources. Therefore, improved instrumentation for more precise determination of the effective tow durations was needed. The present study presents a simple approach for determination of effective tow duration for estimation of fish and shellfish abundance in bottom trawl surveys, using a combination of submersible depth loggers, onboard GPS equipment, bottom depth echo-sounder, and a calibrated warp length and tension monitoring system.

2.1.3 Material and Methods

The present study was conducted in the semi-enclosed deeper-water Kagoshima Bay, southern Japan as described in section 1-2 and Figure 1-2. Experimental trawl surveys were conducted onboard *Nansei Maru*, a 175 t training ship of the Faculty of Fisheries, Kagoshima University. The ship is equipped with an onboard trawling system comprised of a GPS (JLR-7700 MK-II Navigator, WMJ Marine, USA), a split-beam quantitative echo-sounder (KFC-3000, KAIJO, Japan), scanning sonar (KCS-228Z, KAIJO, Japan) and an automatic tension controlled trawl winches system (Kawasaki hydraulics Co., Japan) for standardization of experimental field surveys. The GPS system displays position of the ship while the fishing gear is controlled by use of the onboard echo-sounder, scanning sonar and the automatic trawl winches system. A simple trawl net (LC-VI Nichimo Co., Japan) (Figure 1-3) measuring 23.5 m long, 17.1 m headrope, 22.1 m footrope and 37.9 and 20.2 mm nominal mesh size at body and codend respectively, was used in the study. The wings of the net are fanned by 1m^2 canvas kites and the footrope consists of a rubber covered chain without bobbins. A compact temperature and depth logger (Compact-TD) (ATD-HR, JFE Advantech, Japan) was attached on the headrope for measurement of trawl net depth and data logging set at 1min. polling frequency. A second logger, Compact-CT was also attached on the trawl net for temperature and conductivity measurements, and as a backup for trawl net depth data in the event of failure of the Compact-TD logger.

Standardization of the sampling procedures was conducted as follows. The behaviour of the trawl net and changes in its geometry including mouth opening height and wingspread were established using *in-situ* model simulations and experimental towing in the field from varying tow velocities and hydrodynamic conditions. The *in-situ* simulations are conducted at the Nichimo research and development (R&D) facility, Shimonoseki, Japan. In the simulations, a 1:10 scale model of the simple trawl net was towed in a 100 m x 5 m x 1.5 m tank at different velocities to observe changes in trawl net geometry. Results of the *in-situ* model experiments established the nominal dimensions of the simple trawl net as 2.0 and 8.0 m for mouth opening height and wingspread, respectively at a mean tow velocity of 2.0 kt (Hirayama M, pers. comm., 2010).

Further, experimental tows were conducted onboard the *Nansei Maru* to standardize sampling procedures for assessment of the Kagoshima Bay fisheries resources. Warp lengths were measured using a calibrated in-line counter and tension recorders (accuracy 0.1 m) on the trawling system. On *Nansei Maru*, warp lengths and tension are monitored using the in-line counters and tension recorders in order to maintain trawl net symmetry during towing. Experimental trawl tests conducted by Fuwa et. al. (2010) determined mouth opening height using dual Compact-TD loggers attached to both the headrope and footrope, and the wingspread, by use of a trawl monitoring system (SIMRAD PI-32, Norway: range 1-350 m, accuracy 0.1 m and precision, ± 0.25% FS). Towing was conducted at 2.0 kt velocity. Compared to the *in-situ* model simulations, the field trials showed a satisfactory performance of the simple trawl net and the trawling system on the *Nansei Maru* ship (Fuwa et al., 2010). The determined mouth opening height and wingspread were 2.5 ± 0.3 m (Mean ± SD) and 6.7 m, respectively (Fuwa et al., 2010). Therefore, the present study used the 2.5 and 6.7 m dimensions for mouth opening height and wingspread, respectively. Optimal warp lengths for towing at each of the sampling stations were determined from *in-situ* model simulations and field experimental towing. The optimal lengths are the trawl warps lengths at which the net mouth opening height reach acceptable values and the trawl net footrope establishes stable contact with sea bottom. Thereafter, constant sampling procedures were maintained throughout the study to ensure little variation in the established trawl net geometry as follows. Warp length and tension were controlled using the automatic tension trawl winches system to optimize the configuration of trawl net, and ensure that the trawl net dragged directly behind the ship without significant lateral deflection from a hypothetical straight warp line. The position of the ship was recorded on the onboard GPS equipment with data logging set at 1 sec. intervals. Various parameters influencing trawl net geometry and performance such as warp length and tension, water depth, towing course and velocity were recorded during each haul.

The standard measures of trawl geometry including door spread, wingspread, mouth opening height and headrope height are fairly robust (Weinberg and Somerton, 2006).

However, these measures are easily influenced by warp tension, tow velocity and sea bottom currents as well as differences between the starboard and portside warp lengths (Weinberg and Somerton, 2006; Friedman, 1973; Stauffer, 2004). Therefore, the main factors influencing trawl net geometry including warp length, warp tension and tow velocity were monitored throughout the study to ensure uniformity of the established trawl net geometry. Based on the principle trawling principle, the trawl net drags behind the ship without significant deflection from a straight warp line provided that the warp lengths and tension on both the starboard and portside are symmetrical. The off-bottom distance of the headrope was therefore determined by synchronizing depth data from the Compact-TD loggers attached to the trawl net and the sea bottom depth measured on the echo-sounder. Shooting of the trawl net was conducted while towing at 2.0 kt velocity (approximately 1.03 m/s.). The trawl net shooting was conducted at a warp release speed of 1.0 m/s monitored on the automatic trawl winches system. Prior to setup of the Compact-TD loggers on the trawl net, the logger time was adjusted to the ship's real time settings at bridge. Therefore, at start of shooting, the time on both the Compact-TD loggers and onboard echo-sounder and their latitude-longitude positions readings, are the same. As the trawl net is released, the ship and trawl net positions shift apart along the trawl path, and the trawl starts to drag behind the ship thus increasing the distance between echo-sounder and the trawl net depth position readings. However, the real time settings on both remain unchanged. The duration of net shooting to the established 430-900 m warp lengths for the different sampling stations is approximately 7.2 to 15.0 min. at the 1.0 m/s warp release speed depending on bottom water depth at each station. At the end of trawl net shooting, the ship's position is about 423 to 871 m ahead of the trawl net at the different sampling stations at 2.0 kt towing velocity. Therefore, all echo-sounder depth readings along the ship's path are also recorded by the Compact-TD loggers after time lapses varying between 6.9-14.1 min.; the duration after which the maximum lag distance of the trawl net behind the ship is established at 2.0 kt tow velocity. Consequently, bottom depth values from the echo-sounder and Compact-TD logger could be precisely synchronized using real time settings on the Compact-TD loggers and the onboard GPS system. With an established mouth opening height of 2.5±0.3 m, trawl net contact with sea bottom was assumed when the difference between the depth readings on the echo-sounder bottom depth and the Compact-TD logger reached 2.8 m (Mean±SD). Therefore, the trawl net footrope contact with sea bottom would be assured as long the ≤ 2.8 m difference between readings from the Compact-TD logger and echo-sounder is maintained. Further, all tows were made along the axis of the dominant current direction based on characteristics of water currents and circulation in Kagoshima Bay. Similar sampling procedures have been employed in other fishery surveys with resultant good estimations for abundances (Somerton and Weinberg, 2001; Weinberg et. al., 2002; Stauffer, 2004; Weinberg and Somerton, 2006).

In the present study, a stratified experimental design based on bathymetric features and water currents was used. The bay was sub-divided into four areas: bay head, channel area, central basin and bay mouth. Eight sampling stations (Sts. 1-8) were established, with two stations (Sts. 1 and 2) in the bay head, one station (St. 3) in the channel area, four stations in the central basin (Sts. 4, 5, 6 and 7) and one station (St. 8) in the bay mouth (Figure 1-2). A total of 304 hauls were conducted for estimation of actual fishing time by use of effective tow durations gauged from the times of trawl net footrope contact with sea bottom. A total of 249 and 55 hauls were conducted for 10 and 20 min. preset tow durations, respectively. Trawl net geometry was indirectly monitored from the ship's instrumentation for warp length and tension while sea bottom depths were recorded from the onboard echo-sounder. The latitude-longitude positions were recorded on the GPS at the ship's bridge. The time at net shooting, apparent start and end of netting, and hauling were recorded for each sampling station based on pre-established warp lengths for the different stations and water depths.

Standard procedures were employed throughout the survey and all data and information recorded from the ship's instrumentation at bridge. The mean water depth, warp length, net lag behind ship, and number of hauls at each station are shown in Table 2-1.

Estimation of tow duration was conducted as follows. The time of net contact with water was set as the shooting time. The start and end of towing or netting, registered as the effective tow duration, was estimated from the footrope's initial and final contact with sea bottom based on the synchronization of depth data from the Compact-TD loggers and bottom depth echo-sounder plotted against tow time (Figure 2-1).

The positions of the ship along the cruise path, registered as latitude-longitude degree data on the GPS equipment were used to establish the trawl net position relative to the ship with the hypothesis that: i) the trawl net and ship positions are described by straight warp line without significant bending of the trawl warps, ii) lateral deflection of the trawl warps due to wingspread are insignificant relative to an hypothetical straight warp line, and iii) the trawl net drags directly behind the ship during towing and haul back.

The distance of the swept path was calculated from the footrope's initial and final contact with sea bottom at 1min. intervals, established from the initial latitude (Lat_t) and longitude (Lon_t), and subsequent latitude (Lat_{t+1}) and longitude (Lon_{t+1}) relative positions according to the GPS data, respectively. To reduce errors associated with differential ship velocity and estimated tow time due to hydrographic factors, swept distances can be directly calculated using effective tow duration and speed over-ground.

The spherical nature of the earth implies that elliptic distances are more appropriate since the distances are "great circle" Haversine distances. Elliptic geometry postulates that the perceived Euclidean "flat" planes are actually spheres. However, for the short tow durations used in this study, swept distances were considered too small to be affected by the earth's curvature. Kagoshima Bay lies within 30^{o} N latitude.

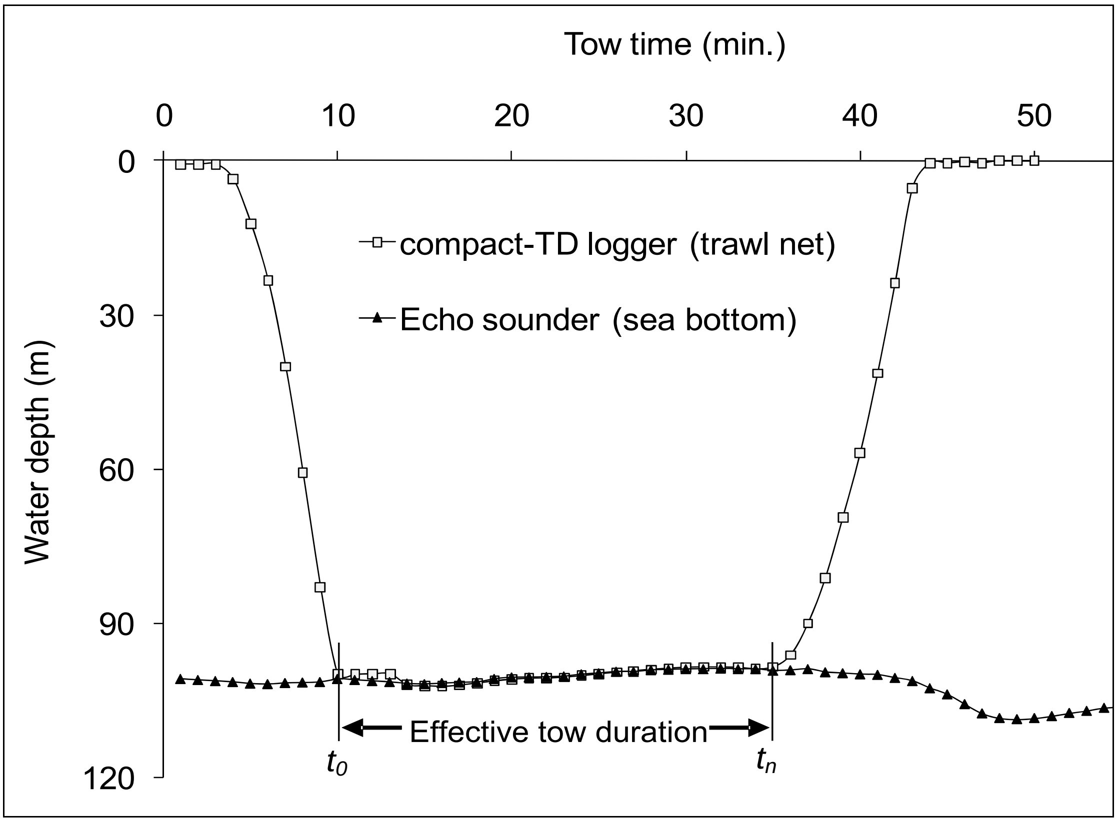

Figure 2-1. A Plot of trawl net depth (Compact-TD logger) data and sea bottom depth (echo-sounder depth) data (St. 8 data) to determine effective tow duration for estimation of swept area and abundance indices in the present study. The t_0 and t_n show the time of the initial and final trawl net contact with sea bottom, respectively

Based on the GPS data, any two points P (Lat_t, Lon_t) and Q (Lat_{t+1}, Lon_{t+1}) are separated by 1min. tow duration at time t and t+1 respectively, along the swept path. Therefore, the distances between the two points were calculated using 110.854 km for 1degree latitude and 96.486 km for 1degree longitude as:

$$D_t^{\mathrm{Lat}} = 110.854 \times (\mathrm{Lat}_{t+1} - \mathrm{Lat}_t) \quad \text{……………………..…} \text{ Eqn. 1-(i)}$$

$$D_t^{\mathrm{Lon}} = 96.486 \times (\mathrm{Lon}_{t+1} - \mathrm{Lon}_t) \quad \text{……………………..…} \text{ Eqn. 1-(ii)}$$

where D_t^{Lat} and D_t^{Lon} are the 1min. latitude and longitude distances respectively.

Consequently, the Euclidean distance between the two points (d_t) is given by:

$$d_t = \sqrt{(D_t^{\mathrm{Lat}})^2 + (D_t^{\mathrm{Lon}})^2}. \quad \text{………………………} \text{ Eqn. 1-(iii)}$$

Table 2-1. Mean water depth, warp length and number of hauls at sampling stations of Kagoshima Bay, southern Japan. The duration for warp release, net lag relative to vessel and duration to establish the maximum net lag was calculated by assuming straight-line warps between trawl net and vessel, and that the trawl net drags directly behind the vessel during towing and haul back

Station	Mean water depth (m)	Warp length (m)	Duration for warp release (min.)	Net lag relative to vessel (m)	Duration to establish net lag (min.)	Number of hauls
1	136	620	10.3	605	9.8	18
2	143	650	10.8	634	10.3	41
3	128	600	10.0	586	9.5	49
4	179	700	11.7	677	11.0	34
5	229	900	15.0	871	14.1	59
6	79	430	7.2	423	6.9	33
7	136	600	10.0	586	9.5	46
8	99	500	8.3	490	7.9	24
Total						304

The effective tow distance along the tow path (D_{eff}) was then calculated as a summation of d_t

$$D_{\mathrm{eff}} = \sum_{t=1}^{n} d_t \qquad \text{.. Eqn. 1-(iv)}$$

where n is the total duration (min.) of the effective tow.

Using the established wingspread (Ws) of 6.7 m for the simple trawl net at 2.0 kt tow velocity in the present study, the area swept by the simple trawl net (A, km^2) was calculated as a product of the effective trawl distance (D_{eff}) and the wingspread as follows:

Swept area, $A = D_{\mathrm{eff}} \times (Ws/1000)$ .... Eqn. 1-(v)

All statistical analyses were conducted in SPSS ver. 15.1. Variation between the preset and effective tow durations and within the effective tow durations computed from the 10 and 20 min. preset tow durations, were examined using Mann-Whitney U-test to compare hauls at each station. The expected survey bias on estimations of abundance indices were then calculated based on differences between the preset and effective tow durations. Further, the influence of water depth and sampling error on effective tow durations was assessed by analysis of the factors influencing tow duration using variance component analysis in SPSS.

2.1.4 Results

Trawl depths ranged from 69 to 233 m in the sampling stations of Kagoshima Bay, southern Japan. The mean water depth, length of towing warps used, duration of warp release, distance of net lag behind the ship, and time taken to establish the net lag distances are shown in Table 2-1. The use of Compact-TD loggers and bottom depth echo-sounder, onboard GPS, and warp length and tension symmetry monitors, proved fully functional for more precise determination of effective tow durations. Variations in depth measurements on the headrope were observed, and were attributed to slight changes in mouth opening height appearing as spikes in the trawl net depth profile when the Compact-TD data was plotted against tow time. The preset and effective tow durations varied widely. The initial procedure of using preset tow durations registered at the ship's bridge generally underestimated the effective tow durations (and consequently the fishing durations) by more than 50% on most of the hauls (Figure 2-2).

On most of the tows, analysis of the trawl net depth and the sea bottom depth profile profiles (as Compact-TD logger and echo-sounder depth data plotted against tow time) showed that bottom contact was established approximately 2-5 min. earlier than the manually registered netting start time of the preset tow durations at the bridge. Further, the trawl net contact with sea bottom extended for several minutes after the netting end time and start of trawl net retrieval recorded at the bridge which was defined as the end of the preset tow duration. Effective tow durations were significantly different ($P<0.05$) among stations and were on average 3-5 minutes longer than the corresponding 10 and 20 min. preset tow durations recorded at the ship's bridge. The median and range for the computed effective tow durations against the corresponding 10 and 20 min. preset tow durations at each station are shown in Table 2-2. Generally, the shorter 10 min. preset tow durations showed higher bias in estimation of the effective tow durations compared to the 20 min. presets. In the 10 min. preset tow durations, the error in determination of the effective tow duration reflected a -10 to 130% bias suggesting cases of both underestimation and overestimation of the abundance indices. In the 20 min. preset tow durations, similar errors in determination of the effective tow durations would result in inadvertent overestimation of the abundance indices by up to 85% bias.

Effective tow durations were significantly correlated with preset tow durations (Spearman's correlation coefficient by rank test, $r_s = 0.662$, $P<0.01$). Mann-Whitney test showed highly significant differences ($P<0.01$) in variations of effective tow durations computed from the 10 and 20 min. preset tow durations.

The bias in the estimations of abundance from preset tow durations compared with the estimations from the corresponding effective tow durations was higher in the shorter tow durations, accounting for 80-90% in most of the 10 min. preset tow durations, compared to about 35-55% in the 20 min. preset tow durations. In the deepest sampling station (St. 5, mean water depth of 229 m), the error in abundance estimations based on the 10 and 20 min. preset tow durations reflected 130 and 85% bias respectively, compared to 90 and 55% bias in the shallower St. 6 (79 m). Analysis of variance components showed that differences in water depth among sampling stations accounted for 76.1% of the variations in effective tow durations while sampling error accounted for 19.6%. Comparison between expected bias in estimations of abundance from the preset and effective tow durations showed that errors in definition of the effective tow duration would have a highly significant influence ($P<0.01$) on abundance indices including CPUE and biomass.

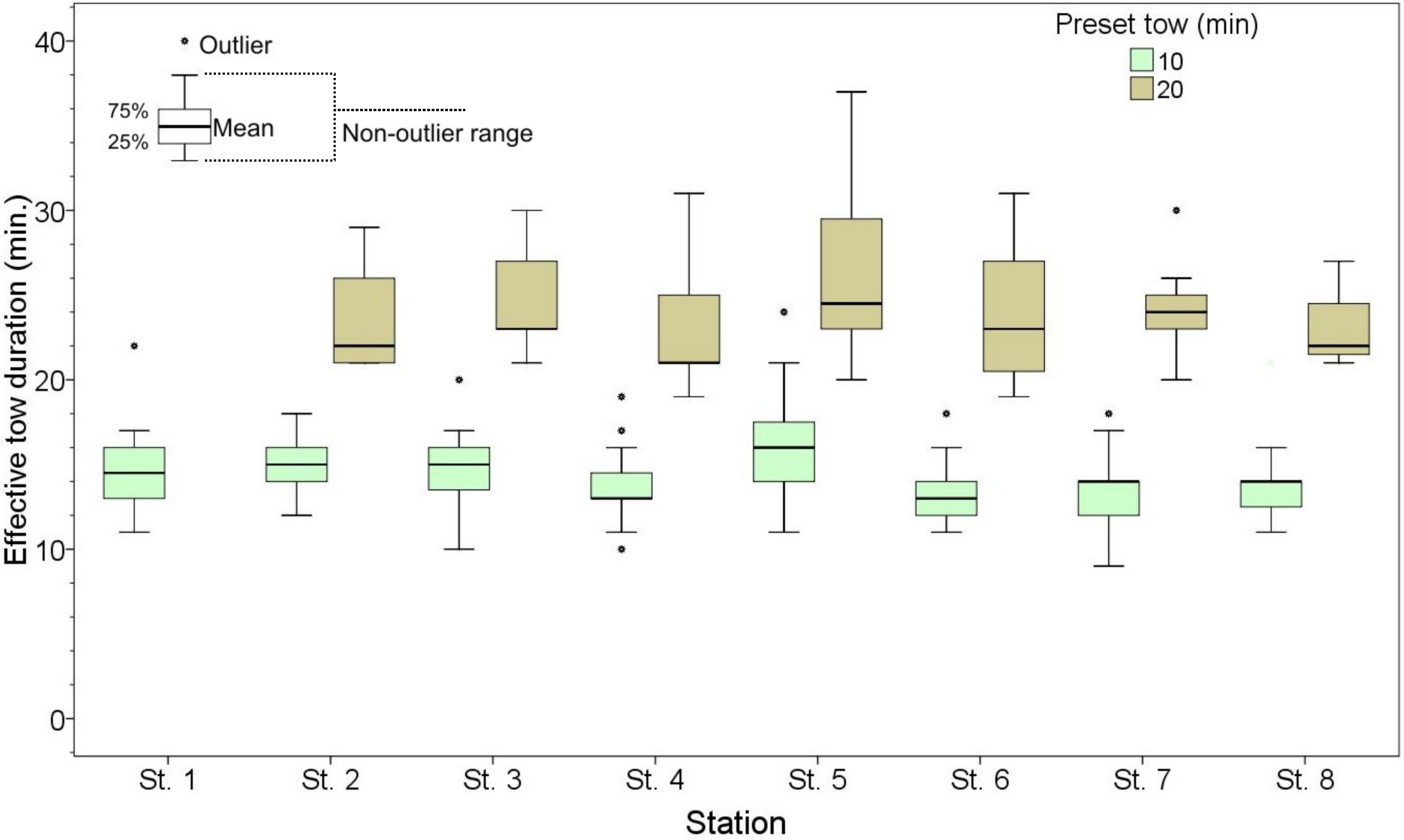

Figure 2-2. Variations between effective tow durations and the corresponding 10 and 20 min. preset tow durations in the present study. The Median, 25-75% percentile range and Maximum and Minimum of the non-outlier range are shown in box plot at each station

Table 2-2. Median and range of effective tow durations computed from compact temperature-depth (Compact-TD) loggers and echo-sounder depth data and the expected % bias in abundance indices estimated from the preset tow durations against the effective tow durations at station

	10 min. preset			20 min. preset		
Station	Number of hauls	Effective tow duration (min.)	% bias	Number of hauls	Effective tow duration (min.)	% bias
1	18	15 (12 - 19)	20 - 90	-	-	-
2	37	15 (12 - 17)	20 - 70	4	22.5 (21 - 29)	5 - 45
3	44	15 (12 - 19)	20 - 90	5	24 (22 - 28)	10 - 40
4	24	13.5 (10 - 19)	0 - 90	10	21 (19 - 31)	(-5) - 55
5	47	19 (15 - 23)	50 - 130	12	29 (24 - 37)	20 - 85
6	22	14 (11 - 19)	10 - 90	11	23 (19 - 31)	(-5) - 55
7	37	13.5 (9 - 18)	(-10) - 80	9	24 (20 - 30)	0 - 50
8	20	14 (10 - 18)	0 - 80	4	22.5 (21 - 27)	5 - 35
Total	249			55		

2.1.5 Discussion

Studies have shown that trawling with very low warp length to water depth ratio results in the trawl gear dragging lightly on the bottom for most of the hauls and increases errors in estimation of the actual fishing duration unless it is detected and corrected. The method defined in this study using Compact-TD depth loggers attached to the headrope and/or footrope presents a simple approach for detecting the non-normal behaviour of the trawl net along the sea bottom. This can be corrected for, by adjustment of the warp length, warp tension and/or tow velocity based on analysis of the trawl net depth profile data. Further, the effective tow durations can be computed more precisely by synchronizing the trawl net depth data from the Compact-TD loggers with bottom depth data from the echo-sounder, while factoring the time lapse between position of the trawl net relative to the ship/vessel based on the depth recordings on the logger and the latitude-longitude readings on the GPS system. The operation of the trawl is easily monitored from the relative positions of the ship and trawl net, warp length and tension, and tow velocity from the onboard instrumentation at the ship's bridge.

In many fisheries such as Kagoshima Bay, experimental trawl surveys provide both quantitative and qualitative assessment of fisheries resources. The surveys are useful for estimation of abundance indices, and consistency in the sampling procedures from one period to the next is important for ensuring continuity of the survey time series in the assessment of the fisheries. Consequently, changes in preset tow durations should be adjusted with respect to the initial definitions of the effective tow duration as well as the method used to compute the tow durations. The present study established a method for monitoring trawl net depth by use of Compact-TD loggers and calibration of the effective tow durations by synchronization with echo-sounder sea bottom depth data for a more precise computation of the effective tow duration. Attachment of dual Compact-TD loggers on both the footrope and headrope presents an option for more precise measurement of the mouth opening height throughout the towing duration and sampling period. However, due to the risk of damage and/or loss of loggers attached at the footrope, no Compact-TD loggers were attached on the footrope during the present study. Consequently, established trawl net mouth geometry was maintained by careful application of the defined standard sampling procedures including monitoring warp symmetry and the ship's course and velocity from the onboard instrumentation. The method is incorporated as part of standard procedures in the ongoing experimental trawl surveys in Kagoshima Bay, and can be applied to similar fisheries where use of sophisticated trawl net monitoring equipment is practically untenable. However, the use of Compact-TD loggers attached on both headrope and footrope as well as bottom contact recorders (Somerton and Weinberg, 2001; Weinberg et. al., 2002; Honda et. al., 2003) would be more useful especially in fisheries where the bottom topography is highly rugged. Consequently, data and information from the surveys should be analysed continuously to account for any variations in abundance estimations from the computed effective tow durations. Further, continuous monitoring of the trawl net wingspread would detect any variations likely to influence the width of the swept path. Generally, the trawl net will continue to fish as long as footrope is in contact with the sea bottom which can be determined by comparing the Compact-TD data and echo-sounder bottom depth. Based on the observed spikes on the trawl net depth profile, shorter tow durations were variably more affected by the tardiness of the trawl operation, especially at the start and end of towing. These spikes were partly attributed to variations in mouth opening height. Further, the bias is more likely amplified in deeper waters as observed among sampling stations in the present study. Engaas et. al. (1997) suggested the use of opening and closing devices on cod end as the only alternative to solving the variations in trawl operations attributed increased spikes in short tows. However, in the present study, the wingspread and mouth opening height of the simple trawl net are maintained uniform by canvas kites carried at the wings of the net, and by use of constant tow velocity and symmetrical warp length and tension which are controlled using the automatic trawling system on the *Nansei Maru* ship. Therefore, the Compact-TD loggers are fairly effective in determining establishment of sea bottom contact for most demersal trawls. Further, the loggers would equally be effective in pelagic trawls working close to the sea bottom as well as Danish seines commonly used in many fisheries including Kagoshima Bay. The use of dual sets of Compact-TD loggers mounted simultaneously on different positions of the footrope and headrope can ensure more refined monitoring of trawl net morphometry in experimental surveys for species abundance estimations.

2.1.6 Conclusions

The computation of effective tow duration using the Compact-TD loggers attached to the trawl net in combination with bottom depth echo-sounder and other onboard instrumentation provides a more precise method for estimation of abundance indices in bottom trawl surveys. Observed differences between preset and effective tow durations were significant and were partly explained by lag in recording of the shooting, trawling and hauling times defined in the preset tow durations at the ship’s bridge. The use of preset tow durations results in highly biased estimations of species abundance. Subsequently, use of the estimated abundance indices in defining resource exploitation strategies is likely to augment the poor state of management in many fisheries worldwide. Wallace and West (2006) mainly attributed variation between the preset and effective tow durations to hauling lag or delays in retrieval of the fishing gear after the trawl winches were engaged, resulting in extended towing time. Further, variations in oceanographic factors including water depth and the nature of the sea bottom may also influence the duration of trawl net retrieval. This increases the variability of the estimated effective tow durations against the corresponding preset tow durations, especially in deeper-water trawling grounds with highly variable sea bottom terrain. Consequently, oceanographic factors, seasonal and annual variations as well as between strata variations should be taken into account when analyzing for variations in abundance indices estimated using the effective tow durations. Increased warp tension and trawl net speed along the bottom during hauling may also influence clearance of the footrope off the sea bottom (Somerton and Weinberg, 2001; Wallace and West, 2006). The latter is an important factor especially for species slightly above the bottom and which are still vulnerable to the trawl net during the hauling period. The higher bias in estimated abundance indices would further increase uncertainties in fisheries management.

Systematic variation in trawl catchability with time due to changes in trawl geometry has been shown to influence average catchability with changes in tow duration (Godo et. al., 1990; Walsh, 1991). Other factors such as escapement under the footrope due to spiking of the footrope attributed to rough terrain have also been shown to influence catchability, and abundance estimations (Godo et. al., 1990; Walsh, 1991). However, since escapement is a strongly size selective process (Godo et. al., 1990; Walsh, 1991; Somerton and Otto, 1999), future surveys for abundance estimations should incorporate studies on species' length-frequency distribution by tow in order to assess the escapement factor and its influence on the estimation of abundance indices for different species.

The present method derived from monitoring of the performance of the trawl net using depth profiles from the Compact-TD loggers and synchronized with data for echo-sounder bottom depth was evaluated on 304 hauls in Kagoshima Bay, southern Japan. The Compact-TD logger recorded consistent performance on the simple trawl net used onboard the *Nansei Maru* ship. Effective tow durations were more accurately computed by calibration of the times of trawl net contact with sea bottom as well as hauling times, when compared with the conventional method of recording preset tow duration at the ship’s bridge based on assumed contact with sea bottom for pre-established warp lengths. Spikes in the trawl gear contact with sea bottom were easily recorded and analyzed from the trawl net depth profile along the sea bottom. The establishment of sea bottom contact and hauling of the trawl net was precisely determined from synchronization of trawl net and echo-sounder bottom depth data, thus improving precision for the estimation of abundance indices. Computed effective tow durations were significantly longer than the preset tow durations traditionally registered at the ship’s bridge during previous procedures. The use of preset tow durations in estimating abundance indices would result in higher bias during shorter durations, and is more pronounced in deeper water as noted during the present study where the deepest station recorded up to 130% bias. Therefore, the established method provides for more precise estimation of effective tow duration (and actual fishing time) and can be easily adapted for use in bottom trawl surveys for abundance estimations in different fisheries including deeper-water fishing grounds.

2.2 Effect of tow duration on CPUE and Biomass estimation

2.2.1 Summary

The effects of tow duration on the estimation of catch per unit of swept area (CPUE) and the abundance of the grenadier *Coelorinchus jordani* were investigated in Kagoshima Bay, southern Japan. A total of 304 tows were completed using a trawl net with mesh sizes of 37.9 mm and 20.2 mm at the body and cod-end, respectively. Towing was conducted at pre-determined warp lengths for each station and for preset tow durations of 10 or 20 min. Effective tow durations (actual fishing times) were computed from the trawl depth profiles derived from Compact-TD loggers that were attached to the net. All hauls were sorted by species, and the total numbers and weights of the catches were recorded. Estimations of CPUE and biomass were conducted for *C. jordani,* one of the most dominant fish species in Kagoshima Bay. Effective tow durations varied; on average, they were >50% longer than the preset times. CPUE and biomass estimations for *C. jordani* were significantly influenced by the tow duration. Estimations from 10 min. preset tow durations were approximately three times higher than estimates from 20 min. values. The total catch per haul and log-transformed 10:20 min. preset CPUE ratios were positively correlated, indicating that haul size influenced CPUE for *C. jordani*. Consequently, the influence of other species on CPUE and biomass estimations for a particular species in multi-species fisheries cannot be ignored. Coefficients of variations for CPUE and biomass estimations from both preset and effective tow durations were not significantly different. However, abundance estimations that were based on effective tow durations showed slightly lower coefficients of variations (*CV*s) and the calibrated 10 and 20 min. effective tow durations were equally efficient for estimating the CPUE and abundance of *C. jordani*.

2.2.2 Introduction

Research trawl surveys have become an indispensable addition to commercial catch and effort data in the assessment of marine and fishery resources (Godø et. al., 1990; Hilborn and Walters, 1992; Somerton and Otto, 1999). These surveys provide unique insight into species distributions and abundance because they have wider coverage than commercial fisheries. Moreover, they are independent of certain biases and errors of commercial fisheries, including the practice of discarding low value bycatch. These surveys assume that catch rates are independent of the tow duration. Therefore, the mean catch per unit swept area (CPUE) represents an index of stock abundance, assuming an even distribution and proportionality of abundance in the survey area. Any deviations from a linear relationship between catch and effort have significant implications for CPUE and abundance estimates and increases biases in bottom trawl surveys (Wassenberg et. al., 1998; Quinn-II and Deriso, 1999). Krieger and Sigler (1996) observed that in bottom trawl fisheries, abundance estimations based on mean catch often resulted in enormous biases which were more pronounced in fisheries with wide water depth variations.

The tow durations of commercial trawls are often long with some lasting for several hours (Godø et. al., 1990; Hilborn and Walters, 1992; Quinn-II and Deriso, 1999). However, operating costs coupled with the need for large numbers of replicates required to maintain statistical validity often limits the number of tows in research trawl surveys to standard durations of approximately 10 to 60 min. at selected stations (Wassenberg et. al., 1998; Quinn-II and Deriso, 1999; Somerton and Otto, 1999; Can and Demirci, 2004; Fulanda and Ohtomi, 2009). However, the duration of time that fish swim in the mouth of the trawl net without entering the cod-end can vary depending on the size of the fish, with larger fish swimming for longer periods than smaller fish (Godø et. al., 1990). Consequently, different towing durations often result in varied catch rates and size compositions, although the mean size and maximum length of a particular species might remain the same (Wieland and Storr-Paulsen, 2006). Some studies have postulated a "catch-by-surprise" theory, where fish swimming toward the centerline of the trawl net are herded and accumulate in front of the footrope as the towing progresses (Godø et. al., 1990; Somerton et. al., 2002). Therefore, over longer tow durations, the accumulated fish would sweep into the cod-end because of exhaustion. Consequently, the herded fish are essentially caught outside the estimated swept area and this phenomenon further influences the precision of estimated abundance indices.

The grenadier *Coelorinchus jordani* belongs to family Macrouridae. The family is distributed at great depths from the Arctic to the Antarctic Oceans and members of this family are among the most abundant deep-sea fishes (Brandt et. al., 2007). The species of this family account for up to 15% of the deep-sea fish population and frequently comprise more than half of the fishes recorded from trawls taken at depths greater than 1,000 m (Marshall and Iwamoto, 1973; Brandt et. al., 2007; Clark et. al., 2010). *Coelorinchus* is a genus composed of more than 100 benthopelagic species (Iwamoto and Graham, 2008). Members of this genus occur worldwide in tropical to temperate seas, generally at water depths of 150 to 800 m (Cohen et. al., 1990). *Coelorinchus jordani* is a relatively small species. Adults reach a total length of 26 cm and are characterized by a short snout (Nakabo, 2002). The species is found in relatively shallow (140-380 m depth) habitats off the Pacific coast of southern Japan to the East China Sea (Nakabo, 2002). In Kagoshima Bay, southern Japan, *C. jordani* is one of the most abundant species in the bottom trawl and seine fisheries, occurring mainly at 115-237 m (Ohtomi, 2006). However, locally known as *Kyushu-hige*, its commercial exploitation is low compared with other species, such as *Coelorinchus japonicus* (*Toujin* in Japanese), which is commercially exploited in the Pacific waters of Japan (Okamura, 1970). The abundance of *C. jordani* in the bottom trawl fisheries of Kagoshima Bay presents a potential for its commercial exploitation and utilization. Moreover, its abundance poses serious economic consequences for the bottom trawl and seine fisheries that target shrimp and other high-value catches due to the costs associated with sorting and handling this low-value bycatch species. This study investigated the influence of tow duration on estimations of CPUE and biomass of *C. jordani* in a Kagoshima Bay, southern Japan, taking into account the influence of catches of other species as well as the sizes of the hauls. The study presents the first evaluation of the effect of tow duration on CPUE and biomass estimation for *C. jordani* in a multi-species fishery including Kagoshima Bay.

2.2.3 Materials and Methods

The present study was conducted during April 2003 through March 2009 in the semi-enclosed deeper Kagoshima Bay, southern Japan (Figure 1-1). As described in section 1-2, the bay straddles 31° 25' N and 130° 38' E, with water depths reaching over 230 m. It faces the East China Sea to the west and the Pacific Ocean to the south and is influenced by the warm Kuroshio Current from the Pacific Ocean (Ekman, 1953; Kawai, 1972).

Water circulation and surface currents in the bay suggest a counterclockwise current system in the central basin (Mizuno and White, 1983; Joyce and Schmitz, 1988; Sakurai et. al., 1998). The water currents during the springtide period reach 0.5 m/s in the central basin and are highest around the channel area, at 0.9 m/s (Takahashi, 1981). In the bay head, the currents are generally weak, recorded at less than 0.01 m/s at depths greater than 100 m (Takahashi, 1981; Kikukawa, 1983). Bottom sediments in the sampling areas are characterized by mud and gravel-mud sediments in the eastern edge of bay mouth, channel area, and central basin south of Sakurajima. The Satsuma coast sampling areas and bay head are characterized by gravel sediments (Ohtomi et. al., 2009). On the basis of oceanographic and bathymetric characteristics, a stratified sampling technique was used to demarcate the bay into: bay head, channel area, central basin and bay mouth. Eight sampling stations were established as: Sts. 1 and 2 in the bay head, St. 3 in the channel area connecting bay head and central basin, Sts. 4, 5, 6 and 7 in central basin, and St. 8 in the bay mouth opening to the East China Sea (Figure 1-2). A total of 304 trawls were conducted onboard *Nansei Maru*, a 175-t training vessel of the Faculty of Fisheries, Kagoshima University, Japan. The vessel is equipped with an onboard split-beam quantitative echo-sounder (KFC-3000, KAIJO, Japan) and global positioning system (GPS) (JLR-7700 MK-II Navigator, WMJ Marine, USA) for navigation. The GPS was set at a 1sec. data polling frequency, and the bottom depth was recorded from the echo-sounder at 1min. intervals. The vessel's latitude-longitude positions were established from the GPS recordings and the trawl net relative position gauged from the GPS data based on the trawl net warp lengths and estimated trawl lag behind the vessel.

Sampling was conducted using a simple trawl net (LC-VI, Nichimo Co., Ltd) which measures 23.5 m in length with a 17.1 m headrope, 22.1 m footrope and 37.9 mm and 20.2 mm mesh sizes at the body and cod-end, respectively (Figure 1-3). The nominal mouth opening height and wingspread of the trawl net were 2.0 m and 8.0 m, respectively. The net is fanned by canvas kites at the wings. The trawl net footrope consists of rubber-covered chain without bobbins or similar footrope accessories that would increase fish escape under the footrope. The trawl net was fitted with compact temperature-depth loggers (Compact-TD; ATD-HR, JFE Advantech, Japan) on the headrope to record the trawl depth profile during each haul. The Compact-TD loggers were set at a 1 min. data polling frequency for synchronization with the towing progression data that were recorded at the vessel's bridge at similar intervals. Towing was conducted during the daytime for preset durations of 10 and 20 min. at a velocity of 2.0 kt (equivalent to 3.704 km/h). The preset durations were based on towing for 10 or 20 min. using pre-established warp lengths and tension for various water depths. Effective tow durations were determined from the initial and final times of net contact with the sea bottom, deduced from the trawl depth profiles from the Compact-TD loggers (Fulanda and Ohtomi, 2011). Warp lengths were measured to 0.1 m accuracy using a calibrated in-line counter and tension recorder on the vessel. Both warp length and tension were monitored using in-line tension recorders to maintain trawl net symmetry during towing. The mouth opening height of the trawl net was determined during experimental field tows using dual Compact-TD loggers attached to both the headrope and footrope. The wingspread (*Ws*) was measured using a trawl monitoring system (SIMRAD PI-32, Norway: range, 1-350 m; accuracy, 0.1 m; precision, ±0.25% FS) (Fuwa et al., 2010). The mouth opening height and wingspread were estimated at 2.5 ± 0.3 m (mean ± SD) and 6.7 m, respectively (Fuwa et al., 2010). Therefore, in the present study, trawl net dimensions were set at 2.5 m and 6.7 m for the mouth opening height and wingspread, respectively. Optimal warp lengths were then determined using ratios between the water depth and warp length for each of the established sampling station in Kagoshima Bay (Table 2-1). Thereafter, sampling procedures were maintained throughout the study to ensure minimal variation in the established trawl net geometry (Fulanda and Ohtomi, 2011). However, because of variations in the trawl net shooting and retrieval process and the influence of oceanographic and bathymetric factors, preset tow durations that were recorded at the vessel's bridge often varied from the actual tow duration; the actual duration which the trawl net was in contact with sea bottom. Therefore, the actual (effective) tow durations were computed from the trawl depth profiles derived from the Compact-TD loggers that were attached to the net. Precise estimations of the effective tow durations were achieved by plotting the trawl depth profiles and echo-sounder depth data against the tow time to determine the actual duration of time that the trawl net was in contact with the sea bottom, according to Fulanda and Ohtomi (2011). The effective tow duration, i.e., the actual duration that the net was in contact with the sea bottom, was computed in the following manner. The initial and final times of net contact with the sea bottom were registered as the start and end of netting, i.e., when the trawl net was assumed to be fishing. Trawl net depth profiles, echo-sounder bottom depth recordings, and GPS data were used to establish the footrope's initial latitude (Lat_t) and longitude (Lon_t) and final latitude (Lat_{t+1}) and longitude (Lon_{t+1}). The effective tow durations were then estimated by synchronizing the trawl depth profiles with bottom depth data, according to Fulanda and Ohtomi (2011). The corresponding tow distances and swept areas were then calculated directly using the Euclidean distance method. On the basis of onboard GPS data and the derived relative positions of the trawl net, any two points P (Lat_t, Lon_t) and Q (Lat_{t+1}, Lon_{t+1}) are separated by a 1-min tow duration along the swept path at times t and $t+1$, respectively. The distances between the two points can be calculated using a distance of 110.854 km for 1 degree of latitude and 96.486 km for 1 degree of longitude for Kagoshima Bay, which lies at 30° N latitude. The effective tow distance (D_{eff}) along the tow path is given by:

$$\boldsymbol{D}_{\text{eff}}\ (\text{km}) = \sum_{\boldsymbol{t}=1}^{\boldsymbol{n}} \sqrt{\{110.854(\text{Lat}_{\boldsymbol{t}+1} - \text{Lat}_{\boldsymbol{t}})\}^2 + \{96.486(\text{Lon}_{\boldsymbol{t}+1} - \text{Lon}_{\boldsymbol{t}})\}^2} \quad \ldots\text{Eqn. 2-(i)}$$

where t is the 1st to nth minute of tow, and n is the total duration (min) of the effective tow.

Using a wingspread, Ws = 6.7 m for the trawl net at a 2.0-kt tow velocity in the present study, the area fished (swept area) by the trawl net (A, km^2) was calculated as a product of the effective trawl distance (D_{eff}) and wingspread:

$$A = D_{\text{eff}} \times (Ws/1000) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn. 2-(ii)}$$

Variations between the preset and effective tow durations were analyzed by grouping the effective tow durations according to the corresponding preset tow durations. For example, effective tow duration of 19 min. that resulted from a 10 min. preset tow was grouped as "10 min. tow", whereas a similar 19-min. effective tow duration that resulted from a 20 min. preset tow was grouped as "20 min. tow".

All sampling and catch record procedures were conducted according to Sparre and Venema (1998). Sorting of the catches at the species level was performed for each haul, and total number of individuals of each species were recorded. The total weight for each species per haul was measured on an electronic balance (Shimadzu BW3200D, Shimadzu, Japan) and the haul weight computed by summing the total weights of all species. The swept area method was used to estimate CPUE and biomass for *C. jordani*. Because no information was available on the vulnerability of *C. jordani* to the trawl net used in this study, a catchability coefficient, given by $X = 1$, was used. The CPUE (kg/km^2) for each haul was calculated as follows:

$\text{CPUE} = Cw/A$ …………………………………………..…… Eqn. 2-(iii)

where Cw is the catch weight (kg), and A is the swept area (km^2).

The fish biomass (kg/km^2) in the swept area was calculated using the CPUE and catchability:

$\text{Fish biomass} = \text{CPUE}/X$ ……………………………….…… Eqn. 2-(iv)

Coefficients of variation (*CVs*) were used to assess the variability in abundance estimations from the 10 and 20 min. tow durations. The impact of effective tow durations on precision of CPUE and biomass estimations for *C. jordani* were investigated by comparing the 10 and 20 min. hauls at each station using the Mann-Whitney U-test in the SPSS v. 15.1 software program. Variations in the haul size (as catch, kg) that were attributable to the effect of the tow duration were assessed by an analysis of variance (ANOVA) for haul sizes at each station. The CPUE estimations from the effective tow durations were then analyzed as follows. First, the CPUE data in the 10- and 20-min hauls were log-transformed to reduce skewness and followed by analysis for variations between the CPUE ratios: $\ln(\text{CPUE}_{10})$ and $\ln(\text{CPUE}_{20})$. For the present analyses, the log-transformed CPUE ratios between the 10 and 20 min. hauls; $\ln(\text{CPUE}_{10}/\text{CPUE}_{20})$ at each station, were simply referred to as the variable X_W. The variations in X_{W} (= $X_{ik\,(\mathrm{W})}$) were examined using an ANOVA and were modeled according to the method adapted from Somerton et al. (2002):

$$X_{ik\,(\mathrm{W})} = \mu_{\mathrm{W}} + \varepsilon_{ik} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2-(v)}$$

where μ_{W} is the overall true mean values of X_{W}, ε_{ik} is the normal random error, and i and k denote the tow duration and tow number, respectively.

An analysis of the variations in the estimated CPUE and biomass that are attributable to the influence of tow duration was conducted using the following test: $X_{\mathrm{W}} = 1$ with null hypothesis that the overall mean value of X_{W}; $\mu_{\mathrm{W}} = 0$. Variations in capture efficiency with respect to haul size were examined by analyzing the correlation between X_{W} and the catch size by weight for each haul and between the variations in $X_{ik\,(\mathrm{W})}$ and the total weights. On the basis of these analyses, an increase in X_{W} with haul size would suggest an inverse relationship between CPUE and tow duration, indicating that catchability would likely decrease as catch size increased. Therefore, catchability coefficients would be lower for longer tow durations.

Lastly, CPUE and abundance estimations from 10 and 20 min. tows were converted using a method adapted from the Somerton et. al. (2002) model: mean CPUE ratio = $\exp[\bar{X} + 0.5\,\mathrm{var}(\bar{X})]$ to estimate the precise ratios between abundance indices from different preset tow durations. The CPUE ratios were compared with the analysis of effective tow durations, swept areas, and the CPUE and biomass estimations between 10 and 20 min. hauls to evaluate the precision in the conversion of abundance indices from different preset tow durations to their expected values, which are equivalent to the effective tow durations.

2.2.4 Results

Water depth and number of hauls, effective tow durations and swept areas in both 10 and 20 min. tow durations at each sampling station are shown in Table 2-3. Trawl depths ranged from 69 m to 233 m. Effective tow durations ranged from 9 min. to 23 min. and from 19 min. to 37 min. for 10 and 20 min. presets, respectively. The Mann-Whitney test showed significantly higher ($p < 0.01$) variations in effective tow durations in 20 min. tows compared with 10 min. values at each station.

In the present study, 172 species of finfish, 124 species of crustaceans and 41 species of mollusks were identified in Kagoshima Bay. The overall mean CPUE ranged from less than 1 kg/km^2 to 127 kg/km^2 with the CPUE for *Coelorinchus jordani* ranging <1-6.5 kg/km^2 for the present estimations in this study. An analysis of abundance estimations for this species showed higher CPUE and biomass in the channel area of St. 3 and bay head area of Sts. 1 and 2, followed by Sts. 5, 7 and 4 in the central basin. The eastern edge of the central basin area, St. 6, recorded the lowest abundances for *C. jordani*. All tows at the bay mouth St. 8 recorded zero-catch for this species. Therefore, St. 8 was excluded from the analysis of variations among different hauls and stations because the zero-catch hauls from this station would artificially increase the coefficients of variations (*CVs*) among stations. Similar studies and analysis with omissions of zero-catch hauls has been reported previously (Somerton et. al., 2002).

The mean CPUE and biomass estimations for *C. jordani* decreased with the change in the preset tow duration from 10 min. to 20 min. CPUE and biomass estimations from effective tow durations at each station were not significantly different within the 10 min. and 20 min. hauls. Therefore, variations in tow duration within the preset limits appear to have no effect on the abundance estimations of *C. jordani*. However, CPUE and biomass estimations that were based on effective tow durations showed wide and highly significant variations in a majority of stations ($p<0.05$). Therefore, changes in the preset tow duration appeared to significantly affect the precision of the swept-area abundance estimations for *C. jordani*. The results of the ANOVA for log-transformed mean ln($CPUE_{10}/CPUE_{20}$) ratios, $\bar{X}_W$, are shown in Table 2-4.

Tests of the hypothesis H_0: $\mu_W = 0$, that changes in tow duration have no effect on CPUE and biomass estimations, only showed a significant deviation for St. 4 in the central basin ($p<0.05$). The back-transformed $CPUE_{10}/CPUE_{20}$ ratios were approximately 1:2.8 suggesting that CPUEs in the 10 min. preset tow durations were on average 2.8 times higher than the 20 min. values. An analysis of CPUE and biomass estimations comparing the preset ($CPUE_{Preset}$) and effective tow durations ($CPUE_{Effective}$) showed significant differences for all stations in the 10 min. tow durations, with the exception of St. 6 in the central basin. This station also recorded the lowest catch rates for *C. jordani*.

On the other hand, the analysis of the 20 min. tow durations showed similar variations for all stations except for St. 4 which, together with St. 6, recorded relatively low catch rates compared with the other sampling stations (Table 2-5). Furthermore, a significant correlation ($r_s = -0.10$, $p<0.05$) was calculated between the effective tow durations and the pooled CPUE and biomass estimations. An analysis of the sampling stations by the preset tow durations showed significant positive correlations between CPUE and tow durations at Sts. 1 and 4 (r_s = 0.57; 0.52, $p<0.05$, respectively), suggesting a likely increase in the CPUE with increases in the tow durations at the two stations. On the other hand, St. 7 in the central basin recorded a negative but insignificant correlation ($r_s = -0.04$, $p = 0.84$) between CPUE and tow duration, while the other stations recorded positive but weak correlations. There was a significant correlation between log-transformed CPUE ratios (X_W) and total haul catch weights (r_s = 0.893, $p<0.05$). Furthermore, abundance estimations that were based on effective tow durations showed lower *CV*s in CPUE and estimated biomass for *C. jordani*, although *CV*s for preset and effective tow durations were not significantly different (p=0.44).

Table 2-3. Water depth, number of hauls, and the effective tow durations and swept areas (Median, range) in the 10 and 20 min. preset tow durations at each station in the study area, Kagoshima Bay, southern Japan

		10 min. preset			20 min. preset		
Station	Trawl depth d ± SD (m)	Number of hauls	Effective tow duration (min.)	Swept area (x 100 m^2)	Number of hauls	Effective tow duration (min.)	Swept area (x 100 m^2)
1	136 ± 1	18	15 (12-19)	62 (50-79)	1	19 *	79 *
2	143 ± 1	37	15 (12-17)	62 (50-70)	4	22.5 (21-29)	93 (87-120)
3	129 ± 2	44	15 (12-19)	62 (50-79)	5	24 (22-28)	99 (91-116)
4	179 ± 2	24	13.5 (10-19)	56 (41-79)	10	21 (19-31)	87 (79-128)
5	229 ± 3	47	19 (15-23)	79 (62-95)	12	29 (24-37)	120 (99-153)
6	79 ± 4	22	14 (11-19)	58 (46-79)	11	23 (19-31)	95 (79-128)
7	136 ± 2	37	13.5 (9-18)	56 (37-75)	9	24 (20-30)	99 (83-124)
8	99 ± 2	20	14 (10-18)	58 (41-75)	4	22.5 (21-27)	93 (87-112)

* Only one tow (haul) was conducted at St. 1 during the 20 min. tow duration presets.

Table 2-4. Results of analysis of variance of catch per swept area (CPUE) ratios for *C. jordani*: $\ln(\mathrm{CPUE}_{10}/\mathrm{CPUE}_{20})$, X_W and catch per unit of swept area (CPUE). The model estimated CPUE ratio is the corrected, back-transformed estimate of $\mathrm{CPUE}_{10}/\mathrm{CPUE}_{20}$ ratio. The significance levels (p) associated with the test that true mean of X_W, $\mu_{XW} = 0$, that tow duration has no effect on CPUE are shown. $\bar{X}_W$ is the mean CPUE ratio for the estimations from the 10 and 20 min. presets

Station	$\ln(\mathrm{CPUE}_{10}/\mathrm{CPUE}_{20})$ ratio ($\bar{X}_W$)	$p\ (H_0: \mu_{XW} = 0)$	Var ($\bar{X}_W$)	Model estimated $\mathrm{CPUE}_{10}/\mathrm{CPUE}_{20}$ ratio
1	1.12	0.085	0.007	2.753
2	1.23	0.163	0.026	2.838
3	1.36	0.255	0.065	3.082
4	1.05	0.035 [a]	0.001	2.610
5	1.34	0.240	0.058	3.101
6	1.43	0.304	0.092	2.049
7	1.28	0.198	0.039	2.946
8	*	*	*	*

[a] denotes significance deviation from H_0: $\mu_{XW} = 0$.

* Due to zero-catch hauls for the target *C. jordani* specimens at St. 8, the station was excluded from the analysis of variance in this study.

Table 2-5. Variations between estimations of catch per unit of swept area (CPUE) (median values and range) for *C. jordani* based on preset and effective tow durations. The probability $p(H_0)$ shows significance values associated with tests for H_0 hypothesis that CPUE and biomass estimations from preset ($CPUE_{Preset}$) and effective tow durations($CPUE_{Effective}$) were not significantly different

	10 min. tow duration			20 min. tow duration		
Station	$CPUE_{Preset}$ (kg/km^2)	$CPUE_{Effective}$ (kg/km^2)	$p(H_0)$ duration effect	$CPUE_{Preset}$ (kg/km^2)	$CPUE_{Effective}$ (kg/km^2)	$p(H_0)$ duration effect
1	198 (15-795)	147 (14-468)	0.001 [a]	88.7 [b]	84.3 [b]	0.025 [a]
2	199 (1-1209)	132 (1-711)	0.000 [a]	59 (47-99)	53 (32-95)	0.068
3	280 (1-1219)	188 (1-937)	0.000 [a]	71 (9-160)	47 (7-139)	0.043 [a]
4	79 (3-325)	59 (3-239)	0.000 [a]	58 (11-256)	48 (7-244)	0.05
5	177 (16-548)	114 (12-368)	0.000 [a]	43 (6-149)	34 (5-99)	0.003 [a]
6	4 (0-9)	3 (0-6)	0.068	2 (2-3)	2 (2-3)	0.042 [a]
7	111 (13-635)	85 (9-397)	0.000 [a]	37 (14-98)	32 (13-82)	0.018 [a]
8	*	*	*	*	*	*

[a] denotes significance deviation from the null hypothesis that there was no significant difference between the CPUE estimations from the preset and effective tow durations i.e. H_0: $CPUE_{Preset} = CPUE_{Effective.}$ [b] Only one haul (tow) was conducted at St. 1 during the 20 min. tow duration presets.

* St. 8 recorded zero-catch hauls for *C. jordani* in most of the hauls and is therefore excluded from this analysis.

2.2.5 Discussion

Preset or nominal tow durations are often deduced from presumed trawl net contact with the sea bottom, on the basis of pre-established warp lengths and warp tensions for different water depths. However, effective tow durations are better estimated from precise determinations of the duration of trawl net contact with the sea bottom using various trawl net mensuration sensors. Therefore, effective tow durations would generally be longer than the corresponding preset durations because of various factors, including fast settling of the net to establish sea bottom contact before the preset tow duration is recorded at the bridge. Moreover, because of a lag in net hauling, there may be continued contact of the trawl net with the sea bottom, especially in deeper-water trawl surveys, thus influencing the precision of the estimated abundance indices from the surveys.

Swept area estimations for abundance indices depend on numerous factors. The assumption that the swept area and catch are proportional inadvertedly suggests that capture efficiency might be independent of tow duration and might ignore variations in the spatial distributions of species, resulting in inadvertent estimations of abundance indices (Krieger and Sigler, 1996). During trawling, it is assumed that fish fall back into the trawl because of exhaustion from swimming in the mouth of the net at a velocity equal to the towing velocity and are therefore caught by "exhaustion" (Godø et. al., 1990). On the basis of this theory and assuming that swimming capacity increases with fish size, CPUE for larger fish should increase over time if the towing durations are increased since fast swimming larger fish would finally succumb to the herding effect of the trawl gear. However, several studies have shown that the mean sizes of a variety of finfish and shellfish species remain nearly constant; therefore, CPUE decreases with increases in the tow duration (Godø et. al., 1990; Wassenberg et. al., 1998; Somerton et. al., 2002). This paradox is attributed to various factors, including a potential underestimation of the swept area, "catch-by-surprise" and/or escape under the footrope. However, none of these factors appears to clearly identify the causal mechanisms that result in the decrease in CPUE with an increase in the tow duration. Further studies are needed to assess the behavior of the trawl net geometry by using net mensuration sensors to determine its optimal performance with respect to the mouth opening height, wingspread and mesh sizes at the body and cod-ends. An analysis of fish size composition in each haul would also provide information on the effect of tow duration on the species and size composition and behavior of *C. jordani*.

In the present study, CPUE and biomass estimations were significantly (p<0.05) correlated with the effective tow duration. However, the coefficients of variation (*CV*) of the abundance indices, estimated from the preset and effective tow durations, were not significantly different. This finding suggests that there were additional factors influencing the precision of CPUE and biomass estimations. Between-strata variations might partly explain the lack of significant differences between *CV*s of abundance estimations from the preset and effective tow durations. Therefore, future studies should conduct a detailed analysis of the spatial distribution of *C. jordani* in Kagoshima Bay to ascertain whether the *CV*s in abundance estimations from different tow durations are influenced by a patchy distribution of this species. Comparisons of the CPUE and abundance indices from 10 and 20 min. tow durations were conducted after conversion using the model of Somerton et. al. (2002). The results showed that the effect of changes in tow duration could partly be minimized by converting abundance indices to their expected values, which are equivalent to the effective tow duration estimations in the present study.

Analysis of within-preset variations showed no significant differences in CPUE or biomass estimation for *C. jordani* from 10 and 20 min. tow durations despite variations in effective tow durations at each station. Moreover, analyses of individual stations only showed an inverse correlation between CPUE and tow duration within preset tow durations at one station. These results are not consistent with previous studies and can be partly attributed to the short preset tow durations used in this study compared with the tow durations of more than 30 min. that were used in other studies. Spatial temporal distributions of species within the bay recorded slightly lower mean catch per haul values and thus relatively lower trawl saturations at St. 4 and 6. This finding might explain the increase in catchability with increases in tow duration within the 10 and 20 min. tow durations at these two stations, in contrast to observations at other stations. However, pooled data by station for the 10 and 20 min. preset hauls showed that estimated CPUE and biomass decreased with a change in preset tow duration from 10 to 20 min. as shown by the $\ln CPUE_{10}/\ln CPUE_{20}$ ratios which ranged between 1.05 and 1.43. These results are consistent with the general theory of trawl catching that was observed previously (Godø et. al., 1990; Wassenberg et. al., 1998; Somerton et. al., 2002). In these studies, the unexpected decrease in CPUE and biomass with an increase in tow duration was attributed to errors in the measurement of the effective trawl path. Likewise, in the present study, advanced instrumentation for measuring wingspread was not used to continuously monitor the wingspread and variations in the trawl path. However, a high positive correlation between tow duration and the swept area in the present study excludes the probability of extreme inaccuracy in measuring the effective trawl path because standard sampling procedures were used throughout the present study.

Wassenberg et. al. (1998) provided a possible explanation for the unexpected behavior of the bottom trawl, wherein CPUE and biomass estimations declined with an increase in the tow duration. Studies on the behavior of the bottom trawl have shown that the net and footrope may bounce and skip over the ground because of snagging of the footrope behind obstacles (Weinberg and Kotwicki, 2008). Fulanda and Ohtomi (2011) observed similar jumps in the ground rope, registered as spikes in the depth profile of the trawl net during towing, and attributed the anomaly to variations in the sea bottom topography. Consequently, longer tow durations are likely to encounter more obstacles and register higher frequencies of spikes in the trawl net mouth opening height, thus increasing the variations in the bias of CPUE and biomass estimations for longer tow durations. Godø et. al. (1990) suggested that the nature of the bottom terrain and sudden changes in the trawl geometry are likely to disturb fish schooling in front of the net, adding to the bias in the swept area estimations of abundance. These factors may explain the variations in CPUE and biomass estimations for *C. jordani* with the systematic change in the preset tow duration from 10 to 20 min. in the present study.

Trawling theory postulates that the net fills as towing progresses, which may result in clogging of the net mesh during extended towing durations. Thus, the influence of clogging on species catchability would likely be higher during longer tow durations. These postulations are in agreement with the results of the present study, and catchability in *C. jordani* appears to be influenced by the tow duration. Previous studies have shown that changes in the trawl geometry, including rounding of the cod-end as the net fills, may result in small fish escaping through the mesh. Furthermore, longer tow durations were also more likely to encounter net mesh clogging than shorter ones, significantly influencing the differential catchability of individual species. Although clogging of the trawl net mesh was not actively monitored during towing in the present study, visual inspection during hauling showed that debris and mud often caused clogging on several hauls. Therefore, the significantly lower catch rates that were observed in the 20 min. tow durations might be partly attributed to net clogging. Clogging would be relatively less severe for the shorter 10 min. tow durations. Correlation coefficients between the CPUE ratios, X_W, and the total haul catch were significantly different from zero in the majority of stations, as determined from the test for the hypothesis that H_0: $\mu_W=0$, that changes in the tow duration have no effect on CPUE or biomass estimations for *C.*

jordani. These finding indicate that the observed differences in CPUE and biomass estimations for 10 and 20 min. tow durations might be partly attributed to the influence of catches of other species and haul sizes. Moreover, filling of the net and relatively higher saturation during longer tows implies that at higher densities, fish would accumulate in front of the trawl net, and individuals arriving later would start to overflow and escape out of the trawl path, reducing overall catchability. Godø et. al. (1990) observed that if fish accumulation in the trawl mouth increased with increasing tow duration, then the catch rate would decrease over time, and this effect would likely be stronger in multi-species fisheries. In the present study, the trawl hauls contained over 300 species of fish, crustaceans and mollusks. This variety of species could have contributed significantly to the relative saturation of the trawl net at different hauls, resulting in dramatic decreases in CPUE and biomass estimations of *C. jordani* with an increase in the tow duration.

2.2.6 Conclusions

Decreases in CPUE and biomass estimations for longer tow durations, suggesting possible saturation of the trawl net by the total haul of all species and probable skipping of the ground rope over the sea bottom, may be factors influencing the catchability and abundance estimations for *C. jordani*. Consequently, the bias in estimated abundance indices is likely to be higher for longer tow durations, especially in multispecies fisheries. Future studies using trawl monitoring systems that include bottom contact sensors and trawl catch sonars are needed to establish footrope bottom tending and catch saturation under different preset tow durations. Continuous monitoring of the trawl net mouth opening height and wingspread should also be conducted using dual Compact-TD loggers and trawl sonars, respectively, to establish the behavior of the simple trawl net. Variations in estimated abundance indices were higher between the 10 min. preset and effective tow durations compared with the 20 min. values. However, based solely on effective tow durations, the 10 min. tow durations were at least as efficient as the longer 20 min. durations for estimating the CPUE and biomass of *C. jordani*. Nevertheless, additional studies are needed to shed light on the effects of extended tow durations on the mean catch size, size composition and abundance estimations of *C. jordani* and other species in deeper-water bottom trawl fisheries.

CHAPTER 3. ABUNDANCE ESTIMATIONS AND DEMERSAL FISH AND SHELLFISH ASSEMBLAGES IN KAGOSHIMA BAY, SOUTHERN JAPAN

3.1 Estimation of fish and shellfish biomass from experimental trawl surveys

3.1.1 Summary

Experimental trawl surveys are important for fishery-independent estimates of abundance of fish and shellfish species and form a cornerstone of many demersal and pelagic fishery stock assessments. They provide valuable measures of relative abundance, population dynamics, and length-weight data with size-sex composition for a wide range of species.

The Kagoshima Bay fishery is a resource with complex exploitation regimes, ranging from fisheries cooperatives, small bottom trawlers, purse seiners, recreational fisheries and shipping. A large number of commercially important species of fish and shellfishes inhabit the bay and are target species of the small scale seine fishery. Since 2003, experimental trawl surveys have provided biological and other related data on the Kagoshima Bay fishery. However, documented studies on biomass estimations, overall catch-effort analyses and stock status of fish and shellfish species of the bottom trawl fishery have clearly been lacking. Therefore, the present study was conducted to assess biomass estimations of the fish and shellfish species using monthly experimental trawl surveys in the pre-established strata and sampling stations of Kagoshima Bay. The area of the each stratum was estimated from latitude-longitude overlay on Google Earth and area calculator in ArcGIS 9.2 (ESRI, US). Sampling was conducted monthly on board the *Nansei Maru* training vessel using the simple trawl net (LC-VI, Nichimo Co., Japan) fitted with submersible loggers for depth, salinity and

temperature measurements. Tow durations were preset at 10 and 20 min. All samples was sorted to species level on each haul and then counted and weighed in the laboratory.

Swept areas were calculated by the Saville (1977) method using standardised tow durations determination from echo-sounder and submersible logger data plots according to Fulanda and Ohtomi (2011). The catch per unit effort CPUE (kg/km^2) for each haul was calculated as catch weight /swept area and biomass (kg/km^2) expressed as the CPUE/catchability as described in standardization of survey protocols section 2.2.3. Stratum biomass was then extrapolated from estimated swept area biomass and summed up for the entire bay for each species.

The estimated areas of the strata Sts. 1 to 8 were 121.4, 73.9, 74.2, 69.8, 211.1, 160.8, 143.9 and 275.6 km^2, respectively totalling 1130.7 km^2 for the whole Bay. A total of 172 fish species belonging to 72 families were recorded in the bay during the present trawl surveys, with 34 species accounting for over 95% of the total biomass. Species biomass varied among the sampling strata. Higher biomass was recorded in the central basin Sts. 5 and 7 radiating out towards the bay head and bay mouth. The most dominant families were Gobiidae, Congridae, Trachichthyidae, Macrouridae, Gymnuridae, Acropomatidae, Serranidae, Ophiididae, Torpedinidae, and Moridae while *Caelorinchus jordani* (Macrouridae), *Amblychaeturichthys sciistius* (Gobiidae), *Benthosema pterotum* (Myctopidae) and *Malakichthys griseus* (Acropomatidae) were the most dominant species. Species diversity was highest in the central basin St. 6 and 7 and decreased towards the bay head and bay head. Mean biomass estimations for the demersal species in Kagoshima Bay ranged 363.4±12.6 to 650.3±20.4 kg/km^2 for Pisces, 270.9±12.6 to 369.4±22.9 kg/km^2 for Crustacea and 29.0±10.0 to 70.8±20.0 kg/km^2 for Mollusca during 2006-2011.

3.1.2 Introduction

Trawl surveys are an integral part of marine fisheries resource assessment process. Data and information gathered from these surveys provide unique insights into species distributions and abundance (Troadec, 1980; Somerton et. al., 1999). Experimental trawl surveys are important for fishery-independent estimates of abundance of fish and shellfish species and form a cornerstone of many demersal and pelagic fishery stock assessments. The measures of stock abundance obtained from experimental trawl surveys are independent of the biases and errors of commercial fisheries operations. Moreover, the data and information are less subject to unknown and often confounding factors that complicate the interpretation of fishery-dependent indices of stock status including discarding, mis-identification and mis-reporting and changes in fishing effort among other factors. The numerous advantages of the survey derived abundance indices are well described by several researchers (Doubleday and Rivard 1981; Smith, 1990; Hilborn and Walters, 1992; Gunderson, 1993).

Bottom trawl surveys have been widely used the world over for stock assessment of demersal stocks. There surveys are particularly useful where only indices of abundance are required or in virgin stocks and stocks lacking historical data (Isarankura, 1971; FAO, 1998). However, the estimation of total biomass from the catch per unit of effort (CPUE) entails several crucial assumptions, resulting in imprecise estimations of both biomass and yield (Somerton and Weinberg, 2001; Somerton, 2003). The trawl gears are typically conical net bags with wide mouths fitted with weights on the ground-rope and floats on the head-rope. During towing, the net is kept open by two otter boards, wooden or iron structures. More recently, the use of canvas kites as the mouth opening structures such as in the simple trawl net used in this study is being embraced in view of the negative impact of the heavy wooden or steel structures used in older trawls. In the canvas kite type trawl nets, the gear are towed by warps attached forward of the centre of the canvas kites ensuring divergence to keep the net mouth open. The mouth opening boards (or canvas kites) are connected to the net by bridles reaching over 200 m long and sweep the sea bed over a wide area, often herding demersal species towards the advancing net thus increasing its effectiveness (Somerton et. al., 1999). Typically, net shape varies depending on the target species and types of bottom to be trawled. Most of the size selection takes place in the cod end or tail end of the gear and therefore a relatively small mesh size is required in order to obtain a representative sample for the entire size range of the species under investigation.

In the trawl surveys, the mean catch per unit of effort (or area) typically represents an index of stock abundance, assuming proportionality to the abundance (Somerton et. al., 1999). Consequently, this assumption withholding, conversion of the abundance index into absolute measure of biomass can be achieved via holistic methods, such as the "swept area method" (Saville, 1977). Several authors have reviewed these holistic approaches to biomass estimations (Gulland, 1975; Saville, 1977; Troadec, 1980; Doubleday, 1980; and Grosselin and Laurec, 1982). Consequently, the precision of the CPUE and swept-area biomass estimations are dependent on numerous factors including the water depth, the nature of the sea bottom, ocean currents and tow velocity among others (Somerton et. al., 1999; Krieger and Sigler, 1996; Somerton and Weinberg, 2001; Somerton, 2003).

The Kagoshima Bay and fishery has been well studied by numerous authors (Oki and Hayasaka, 1978; Hayasaka, 1987; Oki 1989; Masaki et. al., 1998; Kang et. al., 2000; Kohno et. al., 2004; Phuong et. al., 2005; Hosotani and Kikukawa, 2005; Nakano et. al., 2001; Kobari et. al., 2002; Masuda, 1992; Atsuchi and Masuda, 2004; Shishido, 2006; Nakashima and Matsuoka, 2006; Shishidou and Kitada, 2007; Iwakawa and Ozawa, 1999; Masuda et. al., 2003; Puentes et. al., 2004 and Ohtomi et. al., 2004; 2006). However, few or no studies have focused on estimations of biomass from bottom trawl surveys for the fish and shellfish species of the fishery to avail data and information for analysis of fishery trends for sustainable fishery management. Moreover, this data and information would supplement the numerous studies on the bay and fishery including primary productivity, species biology, oceanography and environmental issues among others.

The present study aimed to assess fish and shellfish biomass in Kagoshima Bay and infer on the inter-annual variations in abundance to provide data and information for sustainable management of Kagoshima Bay fishery. Further, the results would be important in modelling of the fishery for design of resource exploitation strategies for sustainable management of the Kagoshima Bay fisheries resources.

3.1.3 Materials and Methods

Biomass estimations were conducted for in eight pre-established sampling stations and strata Sts.1-8 in four area of the Kagoshima Bay: bay head, channel area, central basin and bay mouth taking into consideration oceanographic and bathymetric features, and water circulation (Sakurai et. al., 1998). The central basin of the bay covers the widest area and represents a basin like topography. The bay head has a semi circular outline with both its east and the west coastlines formed by steep sea cliffs extending down to about 140 m deep. The northern area of the bay head has a narrow submarine coastline lying about 10 m below sea level followed by a steep slope descending to 140 m depth. The western half of the bay head has flat bottom topography while the north-eastern part has a 200 m depression with a submarine bank ascending to 70 m above sea level (a.s.l). The bay mouth represents channel topography connecting the central basin to the open sea and the area experiences strong currents and water waves due to the direct link to the Pacific Ocean.

The area of each stratum was estimated from latitude-longitude overlay and area calculator in ArcGIS 9.2 (ESRI, US) and the total area of bay determined by summation of the strata areas. The effective tow duration and path swept by the trawl were defined, and the swept area calculated as described in study 2.1. The swept area was estimated as the product of the swept distance and the 6.7 m wing spread of the Nichimo LC-VI used as shown in Eqn. 1-(v). All estimations of abundance were based on the calibrated effective tow duration as described in section 2.1 on standardization of survey protocols. Since no data was available for the vulnerability of the fish and shellfish species to the simple trawl net used, catchability was assumed unit for all species analysed in this study.

Fish and shellfish biomass estimations were conducted as described in study 2.2 where the CPUE was calculated as the catch weight (of fish and shellfish) divided by the swept area as shown in Eqn 2-(ii). For the purpose of abundance estimations in this study, the method assumed an arbitrary catchability coefficient X=1 since data and information on the catchability coefficient of individual species analysed in this study was lacking. The catchability may also be compensated for by the herding effects of the canvas kites, sweeps and bridles, although catchability of different species may vary due to various factors including vulnerability to herding under varying tow durations. The biomass in the swept area was then calculated using the CPUE and the assumed catchability (X=1) as shown in Eqn. 2-(iii). The stratum biomass (B_S) for each species was then calculated by extrapolating the mean swept area biomasses into the whole stratum. Therefore, the stratum biomass for species (i) was estimated as follows.

$$B_{S(i)}\ (\text{kg}) = \sum [(\text{CPUE}_{(i)} / X_{(i)})/N] \times S_A \text{……..........................} \quad \text{Eqn. 3-(i)}$$

Where: $\sum [(\text{CPUE}_{(i)} / X_{(i)})/N]$ is mean biomass of species (i) in swept area, kg/km^2, N is total number of tows and S_A is the area of the stratum (km^2)

Consequently, the biomass for the species *i* ($B_{(i)}$) in the study area; Kagoshima Bay, southern Japan was calculated as the sum of the biomasses of all the eight strata sampled as shown:

$$B_{(i)}\,(\mathrm{kg}) = \sum_{i=\mathrm{St.1}}^{\mathrm{St.8}} B_{S(i)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 3-(ii)}$$

To ensure a higher precision for the biomass estimations, we conducted numerous tows during the 2003 through 2011. However, CPUE and biomass estimations were only considered for the 2006-2011 period when the standardization of the sampling procedures had been completed and preset tow durations scaled to 10 min. Further, stratification of Kagoshima Bay based on oceanographic and bathymetric characteristics including water depth and sediments type was conducted, noting that the distribution of various species is dependent on water depth and bottom type. Moreover, bottom type is greatly influenced by hydrodynamic conditions including water currents.

3.1.4 Results

The areas of sampling strata St. 1-8 in Kagoshima Bay, southern Japan were determined as 121.4, 73.9, 74.2, 69.8, 211.1, 160.8, 143.9 and 275.6 km^2 respectively and the area of the entire bay was estimated at 1130.7 km^2. The coordinates of the strata St. 1-8, water depths, length of the coastlines and the area of each stratum are shown in Table 3-1. In the present study, 172 species of fish and 165 species of shellfish comprising 124 crustacean and 41 mollusc species were identified in Kagoshima Bay. The species composition by family from the experimental trawl surveys for the 2006-2011 period are listed in Table 3-2: Pisces, Table 3-3: Crustacea and Table 3-4: Mollusca indicating the relative abundance of each species, from rare, sporadic, common, dominant and highly dominant species.

Table 3-1. Sampling station coordinates; mean trawl depth, the length of the coastline and estimated strata area in Kagoshima Bay, southern Japan during the present study from 2003 through 2011

Strata / Station	Latitude (deg.min)	Longitude (deg.min)	Mean depth (m)	Coastline length (km)	Stratum area (km^2)
St. 1	31° 36.0′	130° 45.0′	136.2	36.3	121.4
St. 2	31° 40.2′	130° 41.4′	143.4	18.3	73.9
St. 3	31° 37.8′	130° 37.2′	127.9	42.6	74.2
St. 4	31° 31.8′	130° 39.0′	179.2	24.6	69.8
St. 5	31° 27.0′	130° 37.2′	228.5	N/A	211.1
St. 6	31° 20.4′	130° 45.0′	78.9	29.4	160.8
St. 7	31° 18.6′	130° 39.0′	135.7	39.6	143.9
St. 8	31° 12.6′	130° 43.2′	99.1	51.9	275.6

NB: St. 5 is located at the centre of the central basin and therefore has no coastline.

The most dominant fish families were Gobiidae, Congridae, Trachichthyidae, Macrouridae, Gymnuridae and Acropomatidae (Table 3-2). Species-wise, *Coelorinchus jordani* (Macrouridae), *Amblychaeturichthys sciistius* (Gobiidae), *Benthosema pterotum* (Myctopidae) and *Malakichthys griseus* (Acropomatidae) dominated the trawl catch throughout 2006-2011. In crustaceans, Pandalidae was the most dominant followed by Penaeidae, Solenoceridae, and Crangonidae, Scyllaridae and Portunidae (Table 3-3). At species level, *Plesionika semilaevis* (Pandalidae), *Solenocera melantho* (Solenoceridae), *Trachysalambria curvirostris* (Penaeidae), *Parapenaeus fissuroides fissuroides* (Penaeidae), *Charybdis bimaculata* (Portunidae), *Metapenaeopsis* species (Penaeidae) and *Plesionika izumiae* (Pandalidae), *Ibacus ciliatus* (Scyllaridae) were the most dominant. In molluscs, the dominant families were Sepiidae, Octopodidae, Mactridae, Sepiolidae, Enoploteuthidae and Nuculidae while *Sepia (Platysepia) madokai* (Sepiidae), *Octopus vulgaris* (Octopodidae), *Sepia lycidas* (Sepiidae) *Raetellops puchellus* (Mactridae), *Acla (divaricata) divaricata*

(Nuculidae) and *Abralia (Heterabralia) andamanica* (Enoploteuthidae) were the most dominant species (Table 3-4).

The mean biomass for fish and shellfish species in Kagoshima Bay during 2006-2011 ranged from 363.4±12.6 to 650.3±20.4 kg/km^2 for Pisces, 270.9±12.6 to 369.4±22.9 kg/km^2 for Crustacea and 29.0±10.0 to 70.8±20.0 kg/km^2 for Mollusca. During the present survey period, some strata occasionally recorded exceptionally high biomass estimations during some years due sporadic occurrence of bigger-sized fish species such as sharks, rays and octopus. Moreover, the central bay recorded relatively higher biomass for both Pisces and Crustacea especially at Sts. 4, 5 and 7. Mollusca biomass was highest in the bay head St. 2 and the Osumi peninsula coast at St. 6. These distributions of biomass indicate a general pattern in species distribution which is characteristic of the water currents and circulation patterns within the bay and the bottom sediment type preference by the various groups of fish and shellfish species assessed in this study. Generally, the bay mouth St.8 recorded lower biomass (<400 kg/km^2) compared to the rest of the sampling strata except in some years e.g. 2006 when the sporadic occurrence of large sized *Squatica japonica* sharks were recorded. Similarly, the bay head St.1 also recorded low biomass (<700 kg/km^2) but the increasing abundance of the *M. griseus* species during 2009 resulted in higher estimated biomass of >1500 kg/km^2 in this strata. The results of biomass estimations (Mean±SD) for Pisces, Crustacea and Mollusca in Kagoshima Bay during 2006-2011 are shown in Tables 3-5, 3-6 and 3-7, respectively.

Table 3-2. Pisces composition from experimental trawl surveys in Kagoshima Bay, southern Japan during 2006-2011 onboard the *Nansei Maru* ship showing the relative abundance by species and family

Family	Species	2006	2007	2008	2009	2010	2011
Myxinidae	*Eptatretus burgeri*	+	++	+	+	+	+
Scyliorhinidae	*Cephaloscyllium umbratile*	*		+	+	+	+
Proscylliidae	*Proscyllium habereri*	*	*	+	+	+	+
Triakidae	*Mustelus griseus*		+	+	+	+	+
	Mustelus manazo		+++	+++	+++	+++	+++
Squatinidae	*Squatina japonica*	+++	++	+	+	+	+
	Squatina nebulosa	++++	+	++	++	++	++
Rhinobatidae	*Rhinobatos schlegelii*		+	*	*	*	
Torpedinidae	*Narke japonica*	++	+++	++++	++++	++++	++++
Rajidae	*Okamejei acutispina*	*		+	+	+	+
	Okamejei kenojei		+	+	+	+	+
	Raja kenojei	++	*	++	++	++	++
Urolophidae	*Urolophus aurantiacus*	++	++	+	+	+	+
Dasyatidae	*Dasyatis akajei*		++	+++	+++	+++	+++
	Dasyatis bennetti	++		+	+	+	+
	Dasyatis kuhlii	++	*		+	+	+
Gymnuridae	*Gymnura japonica*	+++	+++	+++	+++	+++	+++
Myliobatidae	*Myliobatis tobijei*	+++	++	++	++	++	++
Synaphobranchidae	*Dysomma anguillare*	+					
	Meadia abyssalis	+		*		*	
Congridae	*Bathycongrus baranesi*	++	++	+	+	+	+
	Conger japonicus			+	+	+	+
	Conger myriaster	++	+++	+++	+++	+++	+++
	Uroconger lepturus	+++	+++	+++	++++	++++	+++
Muraenesocidae	*Muraenesox cinereus*		*		*		
Engraulidae	*Engraulis japonica*	*		*	*	*	*
Argentinidae	*Glossanodon kagoshimae*	+	+	+	+	+	+
Sternoptychidae	*Maurolicus japonicus*	*	*	*	*	*	*
Phosichthyidae	*Pollichthys mauli*	*	*	+	+	+	+
Synodontidae	*Saurida wanieso*	+		+	+	+	+
	Synodus lobeli	+	*	*	*	*	
	Synodus macrops	+	+	+	+	+	+
	Trachinocephalus myops	*		*	*	*	*
Paralepididae	*Lestrolepis japonica*	+	+	+	+	+	+
Neoscopelidae	*Neoscopelus microchir*		+	*	*	*	*
Moridae	*Physiculus chigodarana*	++	++	++	++	++	++
Bregmacerotidae	*Bregmaceros sp.*	+	+	+	+	+	+
Macrouridae	*Caelorinchus jordani*	++++	++++	++++	++++	++++	++++

Table 3-2. *continued*

Family	Species	2006	2007	2008	2009	2010	2011
Ophidiidae	*Hoplobrotula armata*	++	++	+++	+++	+++	+++
	Neobythites sivicola	++	++	+++	+++	+++	+++
Lophiidae	*Lophius litulon*	+	++	++	++	++	++
	Lophius setigerus	++	++	++	++	++	++
Ogcocephalidae	*Halieutaea stellata*		+	+	+	+	+
	Malthopsis annulifera		*		*	*	
Trachichthyidae	*Hoplostethus crassispinus*	+++	++++	++++	++++	++++	++++
Monocentridae	*Monocentris japonica*			*	*	*	*
	Stephanolepis cirrhifer		*		*	*	
Zeidae	*Zeus faber*	++	++	+	+	+	+
Fistulariidae	*Fistularia commersonii*		*		*	*	
	Fistularia petimba		+		*	*	
Macroramphosidae	*Macroramphosus scolopax*		*	*	*	*	*
Scorpaenidae	*Pterois lunulata*	+		*	*		
	Scorpaena miostoma	++	++	++	++	++	++
	Scorpaena neglecta	+		*	*	*	*
	Scorpaena onaria	+	*	*	*	*	*
	Sebastiscus marmoratus	++	++	+	+	+	+
	Sebastiscus tertius	++	++	+++	+++	+++	+++
Synanceiidae	*Erosa erosa*		*		*	*	
	Minous pusillus	*	*	+	+	+	+
	Minous quincarinatus		*		*	*	
Tetrarogidae	*Ocosia fasciata*	*		*	*	*	*
Aploactinidae	*Erisphex pottii*	*		*	*	*	*
Triglidae	*Chelidonichthys spinosus*	+		*	*		
	Lepidotrigla abyssalis	++	++	++	++	++	++
	Lepidotrigla alata						
	Lepidotrigla guentheri	+	++	++	++	++	++
	Lepidotrigla hime		*	*	*	*	*
	Lepidotrigla japonica	*		*	*	*	*
	Lepidotrigla kanagashira	*	+	*	*	*	*
	Lepidotrigla microptena		+	+	+	+	+
Myctopidae	*Bembras japonicus*	+	+	+	+	+	+
	Benthosema pterotum	+	+	++++	+++	++	++
Platycephalidae	*Cociella crocodila*	+	+	+	+	+	+
	Inegocia guttata	*		+	+	+	+
	Onigocia macrolepis	++		+	+	+	+
	Suggrundus meerdervoorti	+	+	+	+	+	+
	Thysanophrys celebica	+	+	+	+	+	+

Table 3-2. *continued*

Family	Species	2006	2007	2008	2009	2010	2011
Hoplichcthyidae	*Hoplichthys langsdorfii*	+	+	+	+	+	+
Acropomatidae	*Acropoma japonicum*	++	++	++	++	++	++
	Doederleinia berycoides	+	++	+++	+++	+++	+++
	Malakichthys wakiyae	++	++	++	++	++	++
	Malakichthys griseus	+++	+++	+++	+++	+++	+++
	Synagrops japonicus	+	+	+	+	+	+
	Synagrops philippinensis	++	++	+	+	+	+
Serranidae	*Chelidoperca hirundinacea*	+++	++	+++	+++	+++	+++
	Chelidoperca pleurospila	+		*		*	
	Plectranthias japonicus	++	++	+++	+++	+++	+++
Apogonidae	*Apogon carinatus*	+	*	*	*	*	*
	Apogon kiensis	++	+	++	++	++	++
	Apogon semilineatus	+		+	+	+	+
Branchiostegidae	*Branchiostegus auratus*	+		++	++	++	++
	Branchiostegus japonicus	++		+	*	*	
Scombropidae	*Scombrops boops*		+	++	++	++	++
Carangidae	*Decapterus akaadsi*			*	*	*	*
	Kaiwarinus equula	+	+	+	+	+	+
	Seriola dumerili	*		*	*	*	*
	Trachurus japonicus	+	++	++	++	++	++
Leiognathidae	*Leiognathus rivulatus*		*		*		
Haemulidae	*Hapalogenys kishinouyei*	+	*	*	*	*	*
Nemipteridae	*Nemipterus bathybius*	++	++	+++	+++	+++	+++
	Nemipterus virgatus		+	*	*	*	
	Parascolopsis inermis	+	+	*	*	*	*
Sparidae	*Dentex tumifrons*	+	++	+	+	+	+
	Evynnis japonica			*	*	*	*
	Pagrus major	++		++	++	++	++
Sillaginidae	*Sillago japonica*		*	*	*	*	*
Mullidae	*Upeneus japonicus*	++	++	++	++	++	++
Microcanthidae	*Microcanthus strigatus*	+	+	+	+	+	+
Centrolophidae	*Hyperoglyphe japonica*		*	*			
	Psenopsis anomala	+	*	+	+	+	+
Nomeidae	*Cubiceps squamiceps*	++	++	+++	+++	+++	+++
Labridae	*Pseudolabrus sieboldi*	+		*	*	*	
Pinguipedidae	*Parapercis multifasciata*	++	++	++	++	++	++
	Parapercis sexfasciata	++	++	++	++	++	++

Table 3-2. *continued*

Family	Species	2006	2007	2008	2009	2010	2011
Champsodontidae	*Champsodon snyderi*	++	++	+++	+++	+++	+++
Percophidae	*Chrionema furunoi*	++	++	+++	+++	+++	+++
Uranoscopidae	*Uranoscopus chinensis*	++	++	+++	+++	+++	+++
	Xenocephalus elongatus	++	++	+	+	+	+
Callionymidae	*Callionymus japonicus*			*	*	*	*
	Repomucenus lunatus			++	++	++	++
	Repomucenus huguenini	*		+	+	+	+
	Repomucenus virgis	*	*	+	+	+	+
Gobiidae	*Amblychaeturichthys sciistius*	++++	++	++++	++++	++++	++++
	Lubricogobius exiguus	*	*		*	*	
Sphyraenidae	*Sphyraena pinguis*	+	*	+	*	+	
Gempylidae	*Rexea prometheoides*	++	++	++	++	++	++
Trichiuridae	*Trichiurus lepturus*	++	++	++	++	++	++
Paralichthyidae	*Paralichthys olivaceus*	+	++	++	++	++	++
	Pseudorhombus oligodon	*		*	*	*	
	Pseudorhombus pentophthalmus	*	*	*	*	*	*
Bothidae	*Arnoglossus polyspilus*		*	*		*	
	Chascanopsetta micrognathus	*	+	+	+	+	+
	Japonolaeops dentatus	++	+	+	+	+	+
	Laeops kitaharae	++	++	+++	+++	+++	+++
Pleuronectidae	*Dexistes rikuzenius*	*		+	+	+	+
	Pleuronichthys cornutus	++	++	++	++	++	++
	Tanakius kitaharae	*		*	*		
Soleidae	*Aseraggodes kobensis*	+	+	*	*	*	*
	Heteromycteris japonica	+	+	*	+		*
	Soleichthys heterorhinos		+	+	+	+	+
	Zebrias japonica	+	+	+	+	+	+
	Zebrias zebra		*		+		
Cynoglossidae	*Cynoglossus imterruptus*	++	++	++	++	++	++
Tetraodontidae	*Takifugu porphyreus*	+		*	*	*	*

NB:

Key	Abundance	Classification
*	[<5 inds. /tow]	rare species
+	[10- inds. /tow]	sporadic species
++	[50- inds. /tow]	common species
+++	[100- inds. /tow]	dominant species
++++	[200+ inds. /tow]	highly dominant species

Table 3-3. Crustacea species composition from experimental trawl surveys in Kagoshima Bay, southern Japan during 2006-2011 onboard the *Nansei Maru* ship showing relative abundance by species and family

Family	Species	2006	2007	2008	2009	2010	2011
Lophogastridae	*Lophogaster japonicus*	+	*	+	+	+	+
Mysidae	*Mysidacea* sp.	+	*	+	+	+	+
Penaeidae	*Metapenaeopsis provocatoria owstoni*	++	++	++	++	++	++
	Metapenaeopsis lata	+++	++	++	++	++	++
	Metapenaeopsis mogiensis mogiensis			*	*	*	*
	Metapenaeopsis sibogae	+++	++++	++++	++++	++++	++++
	Metapenaeopsis acclivis	+	+	+	++	++	++
	Parapenaeus fissuroides fissuroides	+++	+++	+++	++	++	++
	Parapenaeus investigatoris		*	*	*	*	*
	Parapenaeus lanceolatus	++	++	++	++	++	++
	Parapenaeus sextuberculatus		*		*		*
	Parapenaeus fissurus	*	*	*	*	*	*
	Trachysalambria curvirostris	++++	++++	++++	++++	++++	++++
Sicyoniidae	*Sicyonia curvirostris*			*	*	*	*
	Sicyonia cristata		*	*	*	*	*
Solenoceridae	*Haliporoides sibogae*	++	++	++	++	++	++
	Hymenopenaeus equalis	+	+	+	+	+	+
	Solenocera melantho	++++	++++	++++	++++	++++	++++
Pasiphaeidae	*Pasiphaea japonica*	+	+++	+++	+	++	+
Palaemonidae	*Palaemonidae* sp.		*		*	*	*
Alpheidae	*Alpheus digitalis*		+		*	*	
	Alpheus japonicus	+	*	+		*	+
	Alpheus kagoshimanus	+	+	+	+	+	+
	Alpheus macroskeles	+	+	+	*	+	*
Hippolytidae	*Latreutes planirostris*	*		*			
Processidae	*Processa kotiensis*	+	*	+	+	+	+
	Plesionika lophotes	*			*		
Pandalidae	*Plesionika semilaevis*	++++	++++	++++	++++	++++	++++
	Plesionika izumiae	++++	++++	++++	++++	++++	++++
Crangonidae	*Aegaeon lacazei*	*	*	*	*	*	*
	Crangon affinis	++++	++++	++++	++++	++++	++++
	Parapontocaris levigata		*		*		*
	Pontocaris pennata	+		+		+	*

Table 3-3. *continued*

Family	Species	2006	2007	2008	2009	2010	2011
Axiidae	*Axiidae* sp .	*	*	+		*	
Palinuridae	*Palinurus sp. (Phyllosoma)*			*	*		*
Scyllaridae	*Ibacus ciliatus*	+	+	+	+	+	+
Galatheidae	*Galathea* sp.	*	*		*		*
	Munida sp.	+	+	+	+	+	+
Porcellanidae	*Porcellanella picta*		*		*		*
Homolidae	*Homolomannia sibogae*	*		*		*	
Latreilliidae	*Eplumula phalangium*	+	*	*			
Calappidae	*Mursia curtispina*			+		*	*
Dorippidae	*Ethusa sexdentata*	*	*	*		*	*
Goneplacidae	*Carcinoplax longimana*	+			*	*	*
	Lophoplax takakurai	*	*	*	*	+	*
Leucosiidae	*Myra fugax*			*	*	*	*
	Philyra platycheira	*					
Majidae	*Maja japonica*				+		
	Majidae sp.	*	*	*	+	*	*
	Naxioides mammillata	*	*	*	*	*	*
	Phalangipus hystrix				*	*	*
	Pugettia incisa	*	*	*	*	*	*
Portunidae	*Charybdis (Charybdis) miles*	+		*	*	*	*
	Charybdis (Gonioneptunus) bimaculata	++	+++	+++	+++	+++	+++
	Portunus portunus	*		*		*	*
Xanthidae	*Xanthidae* sp.	*		*		*	
Pinnotheridae	*Tritodynamia* sp.		*	*	*		
Squillidae	*Lenisquilla lata*	+	++	*	+	+	*
	Oratosquilla Oratoria	*	+		*	*	
	Squilloides leptosquilla	*	+	+	+	+	+

NB:	<u>Key</u>	<u>Abundance</u>	<u>Classification</u>
	*	[<10 inds. /tow]	rare species
	+	[20- inds. /tow]	sporadic species
	++	[100- inds. /tow]	common species
	+++	[500- inds. /tow]	dominant species
	++++	[1000+ inds. /tow]	highly dominant species

Table 3-4. Mollusca species composition from experimental trawl surveys in Kagoshima Bay, southern Japan during 2006-2011 onboard the *Nansei Maru* ship showing relative abundance by species and family

Family	*Species*	2006	2007	2008	2009	2010	2011
Buccinidae	*Buccinum middendorffi*	*	*		+	*	*
Cardiidae	*Vasticardium burchardi*		+		+		+
Corbulidae	*Solidicorbula erythrodon*	*	*	*		*	*
	Portlandia sp.	+	*			+	*
Enoploteuthidae	*Abralia (Heterabralia) andamanica*	++++	++	+	++	++++	++
Histioteuthidae	*Histioteuthis* sp.	*	*			*	*
	Histioteuthis corona inermis	++				++	
Loliginidae	*Loligo edulis*	++++	+++	++++	+++	++++	+++
	Loligo (Heterololigo) sp.			*	*	*	*
Mactridae	*Raetellops pulchellus*	+	++	+	+	++	+
Nassariidae	*Nassarius* sp.	+	*		*	+	*
Nuculanidae	*Portlandia lischkei*	+	++	*	*	+	++
Nuculidae	*Acla divaricata divaricarta*		*	*	++		*
Octopodidae	*Octopus vulgaris*	*	*	*	*	*	*
	Octopus minor	*	*	*	*	*	*
	Octopus sp.		+		+		+
Ovulidae	*Volva volva*		+	*	*		+
Pectinidae	*Pecten albicans*	+	*			+	*
	Delectopecten macrocheiricolus		*		+		*
	Pecten sp.	+		*	+	+	
Ranellidae	*Cymatium lotorium*	*		*		*	
	Cymatium sp.		*		*		*
Sepiidae	*Sepia lycidas*	+	*	*	*	+	*
	Sepia (Platysepia) esculenta	*	++	+	+	*	++
	Sepia (Platysepia) madokai	++	+			++	+
	Sepia (Doratosepion) lorigena		*		*		*
Sepiolidae	*Sepiolina nipponensis*	+++	++++	+		+++	++
	Euprymna morsei		+	+	+		+
Turridae	*Inquisitor flavidula*	*	*			*	*

NB:

Key	Relative abundance	Classification
*	[<5 inds. /tow]	Rare species
+	[5~ inds. /tow]	Sporadic species
++	[10~ inds. /tow]	Common species
+++	[20~ inds. /tow]	Dominant species
++++	[50+ inds. /tow]	highly dominant species

Table 3-5. Fish biomass estimations (Mean ± SD) by strata and number of species from the experimental trawl surveys during 2006-2011 in Kagoshima Bay based on effective tow durations according to Fulanda and Ohtomi (2011)

Strata	2006		2007		2008	
	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	21	560.2 ± 19.9	18	479.8 ± 16.3	22	672.2 ± 25.5
St.2	21	639.1 ± 18.0	26	514.9 ± 15.7	32	570.0 ± 21.8
St.3	31	709.4 ± 27.9	29	591.5 ± 17.9	23	189.3 ± 4.5
St.4	33	406.8 ± 11.7	31	194.0 ± 4.7	26	396.8 ± 15.3
St.5	23	394.1 ± 11.9	32	696.7 ± 20.5	27	613.6 ± 18.3
St.6	48	301.8 ± 5.4	34	201.6 ± 6.4	34	304.2 ± 7.8
St.7	38	951.3 ± 24.9	37	854.3 ± 27.1	36	675.3 ± 12.4
St.8	50	*874.4 ± 23.9	33	383.0 ± 9.5	33	204.4 ± 6.8

Strata	2009		2010		2011	
	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	26	*1567.3 ± 59.0	29	298.2 ± 8.9	22	233.7 ± 12.3
St.2	25	617.1 ± 22.0	20	320.1 ± 8.9	25	296.6 ± 7.1
St.3	30	296.2 ± 6.2	32	248.8 ± 5.4	32	190.8 ± 4.6
St.4	29	411.7 ± 9.7	24	415.9 ± 9.3	31	684.6 ± 18.6
St.5	25	507.3 ± 17.2	25	680.5 ± 25.3	29	253.3 ± 8.4
St.6	32	767.9 ± 30.2	24	594.7 ± 28.9	23	27.5 ± 0.8
St.7	48	835.4 ± 14.5	33	1080.2 ± 26.1	33	1075.7 ± 45.2
St.8	32	199.7 ± 4.7	30	171.3 ± 3.1	40	144.7 ± 3.6

Table 3-6. Crustacean biomass estimations (Mean ± SD) by strata and number of species from the experimental trawl surveys during 2006-2011 in Kagoshima Bay based on effective tow durations according to Fulanda and Ohtomi (2011)

	2006		2007		2008	
Strata	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	10	83.3 ± 3.9	9	5.3 ± 2.6	11	100.4 ± 4.7
St.2	14	132.0 ± 6.1	11	191.4 ± 8.9	11	221.4 ± 10.3
St.3	10	330.6 ± 15.4	15	231.7 ± 10.8	13	513.4 ± 23.9
St.4	17	553.6 ± 25.7	16	654.7 ± 30.4	21	732.1 ± 34.0
St.5	20	819.9 ± 38.1	15	583.6 ± 27.1	18	871.9 ± 40.5
St.6	10	24.6 ± 1.1	7	17.2 ± 0.8	3	15.4 ± 0.7
St.7	16	392.8 ± 18.3	16	420.0 ± 19.5	11	492.7 ± 22.9
St.8	5	13.9 ± 0.6	6	13.1 ± 0.6	4	7.9 ± 0.4

	2009		2010		2011	
Strata	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	9	85.8 ± 6.4	16	56.9 ± 12.8	14	103.3 ± 4.6
St.2	8	135.9 ± 19.6	14	197.0 ± 28.0	16	227.9 ± 28.9
St.3	10	340.4 ± 20.4	12	238.6 ± 45.5	9	428.5 ± 29.0
St.4	13	673.6 ± 52.3	26	683.2 ± 54.5	24	706.8 ± 27.1
St.5	17	844.0 ± 29.2	21	600.7 ± 39.7	19	897.6 ± 33.9
St.6	2	25.3 ± 6.1	11	17.1 ± 3.4	9	15.8 ± 3.0
St.7	10	404.3 ± 31.4	17	432.3 ± 23.0	15	854.3 ± 27.1
St.8	3	14.3 ± 0.5	15	13.5 ± 0.7	8	383.0 ± 9.5

Table 3-7 Molluscs biomass estimations (Mean ± SD) by strata and number of species from the experimental trawl surveys during 2006-2011 in Kagoshima Bay based on effective tow durations according to Fulanda and Ohtomi (2011)

	2006		2007		2008	
Strata	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	2	25.1 ± 7.1	2	3.7 ± 1.1	2	29.9 ± 8.5
St.2	4	*85.3 ± 24.1	3	4.1 ± 1.1	3	*76.5 ± 21.6
St.3	3	7.5 ± 2.1	3	3.4 ± 1.0	2	45.9 ± 13.0
St.4	4	29.1 ± 8.2	4	4.9 ± 1.4	4	*73.3 ± 20.7
St.5	5	38.0 ± 10.7	6	22.3 ± 6.3	5	60.4 ± 17.1
St.6	3	20.6 ± 5.8	2	*272.8 ± 77.0	1	*190.2 ± 53.7
St.7	7	31.0 ± 8.8	5	27.6 ± 7.7	3	27.6 ± 7.8
St.8	2	28.9 ± 8.2	3	37.6 ± 10.6	4	62.6 ± 17.7

	2009		2010		2011	
Strata	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD	No. of Species	Biomass (kg/km^2) Mean ± SD
St.1	3	16.2 ± 5.6	2	44.2 ± 15.3	2	37.1 ±12.8
St.2	3	6.7 ± 2.3	4	*102.7 ± 35.6	3	*126.2 ± 43.7
St.3	2	30.9 ± 10.7	4	*106.7 ± 37.0	5	11.1 ± 3.8
St.4	5	42.6 ± 14.7	5	*104.3 ± 36.1	7	43.0 ± 14.9
St.5	6	38.4 ± 13.3	6	95.8 ± 33.2	5	56.2 ± 19.5
St.6	3	33.7 ± 11.7	3	9.1 ± 3.1	2	30.4 ± 10.5
St.7	5	13.6 ± 4.7	5	34.0 ± 11.8	5	45.8 ± 15.9
St.8	2	50.0 ± 17.3	6	14.6 ± 5.0	3	42.7 ± 14.8

3.1.5 Discussion

Biomass estimations for fish and shellfish species in Kagoshima Bay southern Japan conducted using experimental trawl surveys during 2006-2011 provide a baseline assessment of the stock status in the Kagoshima Bay fishery. The overall results of the biomass estimations for the demersal fish and shellfish species in Kagoshima Bay using experimental trawl surveys indicate a number of considerations. The estimated CPUE and abundances show significant variations from one area of the bay to the other with clear demarcations of basin and channel topographies. In the present study, higher abundances were recorded in the central basin as compared to the bay head and bay mouth. Secondly, the species biomass appear to radiate out from the central basin to the bay head and bay mouth with clear gradual decrease from the central basin St. 5 towards the St. 4, St. 6 and St. 7. Thirdly, wide spatial-temporal variations were noted in the biomass estimations for some of the sampling strata due to the occurrence of bigger sized species such as sharks and rays as well as Octopus for the southern Sts. 6 in central basin and St. 3 in the channel area. However, the biomass estimations in the present study were within the reported ranges for demersal species in the Pacific and south Pacific region. The biomass estimations for Kagoshima Bay, southern Japan are within ranges reported for the Pacific Ocean fisheries: 3.4kg/ha for Pisces in the Pacific Coast of North-eastern of Japan at 100-200 m water depths (Fujita et. al., 1995); 1.6-11.5 kg/ha for Pisces off Sendai Bay, Japan (Fujita et. al., 1993); 470 kg/km^2 for Pisces in Manilla Bay, Philippines (MADECOR, 1995); 1,310 kg/km^2 for Pisces in San Miguel Bay, Philippines (Soliman and Dioneda, 1997) and 400 kg/km^2 for Crustacea off the Pacific Coast of Costa Rica (Jesse, 1996) just to mention afew. These biomass estimations for the demersal species Kagoshima Bay, southern Japan provide valuable data and information base for future analysis incorporating the catchability coefficient of individual species. Further, a time-series analysis of Kagoshima Bay resource using fishery independent distribution data for each species in Kagoshima Bay fishery is recommended since catchability coefficients in the present study were set at X=1 for all species since no data was available for the vulnerability of the individual species to the gear used. Moreover, a few pelagic or mesopelagic species such *Trachurus japonicus* probably caught during the descent or ascent of the trawl net was not excluded from the current analysis since data on the distribution structure of these species with reference to water depth and ontogenetic shifts in localized habitat preference in the sampling stations bay is lacking.

The results of biomass estimations for fish, crustaceans and molluscs varied greatly: the Pisces biomass was on average 1.5-2.0 times more than Crustacea biomass and about 7-20 times the values estimated Mollusca. However, research has shown that crustaceans tend to jump over the trawl net during towing hence the biomass of crustaceans may be slightly higher than currently estimated. Moreover, though less significant, smaller species may also be under-estimated due to predator-prey relationships where the larger species prey on the smaller individuals as the towing progresses. During the present study, observations of predatory species such as *Rexea prometheoides* with fresh shrimps in mouth and gut were common suggesting a likely underestimation of the prey species.

The variations in the estimated biomass for the fish and shellfish species may also be attributed to a number of factors. Godo et. al. (1990) noted in the estimation of species biomass from trawl surveys is often influenced by oceanographic factors including rough bottoms and sudden changes in trawl geometry which disturb fish aggregations in the path of the fishing gear. Consequently, some degree of variability in the biomass estimations in the present study may be attributed to the nature of the bottom in Kagoshima Bay which has greatly been shaped by the Sakurajima volcanism as well as the bottom water current patters in the bay. Bodegat et. al. (2002) observed that topographic irregularities in the bay results in almost six different environments namely: head, margin, slope, basin, mouth and open sea. Moreover, the bay is influenced by the Kuroshio Current which enters from the southeast flowing northward along the west side of the Osumi Peninsula, then return southward along the east side of the Satsuma Peninsula before entering the central portion of the bay as a counter-clockwise eddy current. Therefore, these water circulation and bottom currents evidently influence species biomass in the bay. Additionally, the velocity of the water currents and velocity within the different zones of the bay with higher velocities in the bay mouth and channel area influence the bottom sediment structure and also account for the variations in the species aggregations and estimated biomass for fish and shellfish species in the bay.

During the study period, wide temporal variations in estimated biomass during 2006-2011 have triggered increasing concern development of the Kagoshima Bay fishery with shifts in the catches of dominant species. Analysis of the commercial catch data is therefore need to ascertain the influence of fishing which me account for the resultant changes in the biodiversity in Kagoshima Bay. Jennings and Kaiser (1998) highlighted the possibility of using survey data sets to investigate ecosystem effects of fishing and changes in biodiversity. Therefore, there is a need to broaden the present study protocols and monitoring of Kagoshima Bay, southern Japan to enlist both demersal and pelagic species using the various fishing gear used in fishery. Notwithstanding, the estimated biomass in Kagoshima Bay showed variations by strata and clear shifts in dominant species were discernible from the present analysis.

3.1.6 Conclusions

The Kagoshima Bay fishery presents a complex resource calling for specific fishery management strategies. However, there has been a considerable lack of data on stock-size and socio-economic conditions of the fishery. The estimated biomasses for fish and shellfish species were within ranges reported for the other fisheries within the Pacific Ocean. Therefore, the present study presents good estimates on biomass for the demersal fish and shellfish in the bay for future analysis of the fishery. The use of calibrated tow durations provided for higher precision in the estimations of the fish and shellfish biomass in the bay but investigations for catchability of the fish and shellfish species in Kagoshima Bay is important to ensure higher precision in the estimation of biomass for individual species. Furthermore, variations due to terrain, predation and other factors should be taken into consideration in future studies in order to increase the precision of the present estimations. The observed annual variations in fish and shellfish biomass call for reconciliation of experimental trawl survey data with commercial catch analysis in order to explain the observed trends. Noting that the dynamics of top predators in marine ecosystems greatly influences stock dynamics and catches of target species, this analysis recommended for a holistic approach for assessment of the demersal fish and shellfish in the bay by trophic analysis in order to provide a clearer understanding of Kagoshima Bay ecosystem. The present analysis provides a good base for future stock assessment of Kagoshima Bay fishery as well assessment of the distribution structure of the demersal fish and shellfish assemblages in the bay.

3.2 Demersal fish and shellfish assemblages in Kagoshima Bay

3.2.1 Summary

The structure of the demersal fish and shellfish assemblages of the Kagoshima Bay, southern Japan was studied based on 304 trawls conducted during 2006-2011. The bay was stratified into four strata and eight sampling stations with water depths ranging from 69 to 238 m. Species abundance and distribution was significantly influenced by water depth and oceanographic characteristics of the study areaa. Highest abundances were found in the stations of the central basin at >100 m. Based on Shannon-Wiener diversity and Pielou's evenness indices, the abundance and composition of the fish and shellfish species in the bay were clustered into three groups: i) bay head and channel area, ii) central basin, and iii) bay mouth.

Ordination by principal component analysis (PCA) showed clear sentinel and indicator species for the fish and shellfish signalling possible influence of bathymetric and oceanographic factors for Pisces, Crustacea and Mollusca groups which exhibit varying habitat preferences. Pisces assemblages showed dominance of *A. sciistius*, *Chelidoperca hirundinacea* and *Hoplostethus crassipinus* in central basin, *C. jordani*, *Hapalogenys kishinouyei* and *Conger myriaster* in bay head and channel area, and *Squatica nebulosa* and *D. bennetti* in the bay mouth. In Crustacea, *T. curvirostris* dominated the channel area and bay head. *P. semilaevis*, *Metapenaeopsis sibogae* and *P. fissuroides fissuroides* dominate the central basin while the bay mouth was dominated by *M. provocatoria owstoni*. Mollusca was represented by *O. vulgaris*, *R. pulchellus* and *Sepia* species in the bay head and bay mouth, and *Euprymna morsei*, *A. (divaricata) divaricata* and *Inquisitor flavicula* in central basin. The species assemblages show a clear separation in relation to bottom type, which is interpreted as the result of preferences for muddy bottom sediments in central basin and inner bay, and

sandy to gravel sediments in the channel area and bay mouth. The combined influence of water depth, bottom currents and type of bottom sediment has also been shown to shape the structure and dynamics of the marine species assemblages.

3.2.2 Introduction

Over the last decades, understanding of the nature of ecosystems has greatly evolved and there is a growing realization that ecosystems are complex, open, robust, and dynamic (Foster, 1988; Clark, 1990; McClachlan et. al., 2000). Both natural and anthropogenic disturbances play an important role in the establishment and development of ecosystems, and hence concern has shifted fisheries management from population to an ecosystem approach (Hall and Mainprize, 2004). The impacts of fishing on marine ecosystems are wide, comprising both direct impacts on abundance, size and species composition and population parameters as well as indirect impacts such as trophic shifts and habitat disturbance acting in short and long term temporal scales (Pauly et. al., 1988; Stevens et. al., 2000). Several researchers have documented these impacts using community metrics including parametric analysis tools, diversity indices and size-based indicators (Rice and Gislason, 1996; Hall and Greenstreet, 1998; Hall, 1999; Rochet and Trenkel, 2003). Further, Rochet and Tenkel (2003) observed that detection of the most relevant ecological indicators needed to better understand the impacts of fishing on fish and shellfish assemblages is complex. Consequently, several indicators should be incorporated to fully describe fishing-induced changes in species assemblages. However, there is a lack of pristine areas and hence the selection of unequivocal biological reference points to better understand the re-assemblage of fish communities in response to fishing has remained an big challenge (Steele and Schumacher, 2000; Gristina et. al., 2006)

In Japan, fisheries are of a rather particular nature; the importance of seafood in the national diet and demand for seafood is particularly pronounced in the country (Schmidt, 2003). Secondly, the country has a long tradition of coastal community based fisheries management that has been used to ensure sustainability in resource exploitation. Consequently, Japan has one of the world's oldest and most successful marine fishery co-management regimes (Lim et. al., 1995; Pomeroy and Berks, 1997). In Kagoshima Bay, small scale bottom seine fisheries form the bulk of fishing ventures within the coastal fisheries targeting a number of fish and decapod crustaceans including commercially important species such as deep-water mud shrimp *S. melantho*, the pandalid shrimp *P. semilaevis* and the southern rough shrimp *T. curvirostris* as well as stomatopod crustaceans such as *Squilloides leptosquilla* (Ohtomi 2001). Commercially important species in the bay include *M. griseus* and *M. wakiyae* (Acropomatidae), *T. japonicus* , *Seriola dumerili* and *Kaiwarinus equula* (Carangidae), *C. hirundinacea* (Serranidae), *H. crassispinus* (Trachichthyidae). However, many fish species of the bottom seine fishery are discarded as bycatch including the dominant grenadier *C. jordani* (Macrouridae) and goby *A. sciistius* (Gobiidae).

The management of the fishery lies mainly under the coastal fishery rights system (Yamamoto, 1995; Lim et. al., 1995) with fisheries cooperative associations (FCAs) controlling fishing in Kagoshima Bay. The fishery is heavily exploited and some studies have reported a decline in the catches of individual species as well as a realignment of the target species by fishers (Fulanda and Ohtomi, 2009). However, although biomass of a few species appears to suggest some level of overfishing, the impact of fishing on the demersal fishery has received little attention and assessment of fish and shellfish assemblages in the bay is clearly lacking. The central basin of the bay is wide and easily accessible to numerous fishing villages mostly along the central basin and bay head coasts. Notwithstanding, the central basin fishing grounds are rich, characterised by wide variations in oceanographic features and bathymetry. The central basin is home to numerous fishing ports including Kagoshima, Kiire, Iwamoto and Tarumizu among others. The bay head is calm with weak currents and its accessibility also subjects the area to a relatively high fishing pressure. The bay mouth in the south is characterised by strong currents from the Pacific and thus the area is exploited by a fewer vessels and the index of fishing pressure in this area is, on average low. The channel area joining the central basin and bay head is not directly subjected to fishing pressure like the rest of the bay, and may be considered a "no-seine" zone. This variability in the bathymetry and oceanographic features in Kagoshima Bay results in wide variations in the fishing pressure indices and hence may influence the assemblages of fish and shellfish in the bay. Therefore, this study investigated the distribution structure of fish and shellfish assemblages in Kagoshima Bay comparing species biomass, diversity and community ecological structures in the areas of the bay: bay head, channel area, central basin and bay mouth, which are subjected to varying levels of fisheries exploitation and maritime activity.

3.2.3 Material and Methods

Experimental trawl surveys have been conducted since March 2003 through 2011 onboard *Nansei Maru* as described in study 2-1. For the purpose of this study, demersal fish assemblages and the distribution structure were investigated using 2006-2011 data when standardization of most of the important experimental survey protocols for stock assessment and estimation of abundance indices in deeper water bottom trawl surveys had been completed. Standardized sampling protocols and constant sampling procedures were maintained throughout the survey period with polling frequencies on data loggers set at 1 min. intervals as described in study 2-1.

All species of the bottom trawl fishes were sorted at each haul and identified to species level and the total numbers counted and total weight for each species determined on an electronic weighing balance (Shimadzu BW3200D, Shimadzu, Japan) to an accuracy of 0.1 g. To ensure continuity of the survey time series for the trawl surveys, all catch was standardized as catch per unit of swept area (CPUE) according to Fulanda and Ohtomi (2011). Abundance and biomass indices, standardized from CPUE (kg/km^2) were computed for all none-zero catch hauls for the fish and shellfish species. Hydrological conditions including water temperature, depth and salinity were recorded for all tows using Compact-TD and Compact-CT data loggers (JFE Advantech, Japan) attached to the headrope as described in section 1-3. To assess the fish and shellfish assemblages in the Kagoshima Bay, biomass estimations were conducted using the calibrated tow durations as described in determination of effective tow durations and fishing time in section 2.1 and 2.2.

Data analysis was conducted using MS. Excel and Community Analysis Package (CAP-IV), Species Diversity and Richness (SDR-IV) and Ecological Community Analysis (ECOM-II) (Pisces Conservation, UK). Further, Paleontological Statistics (PAST) (Hammer et. al., 2001) was used to analyse for ecological diversity factors including taxonomic diversity and distinctness. Prior to analysis, all data was tested for homogeneity using Levene test) and where necessary, the data was normalized using fourth-root transformation. Variations in spatial distribution of the main ecological groups by sampling stations and strata were analyzed and grouped by strata in the bay head, channel area, central basin and bay mouth areas of Kagoshima Bay. All tests were considered significant at a probability level of $p<0.05$.

The spatial-temporal variations in species diversity between the sampling stations and strata in Kagoshima Bay, and between the years 2006-2011 were analyzed using the Shannon-Wiener *H*' (Shannon and Wiener, 1963) and Shannon equitability *sensu* Pielou evenness index *J'* (Pielou, 1966) indices, which combine information on species richness and the abundance distribution among the species:

Shannon-Wiener index $$H' = -\sum_{i=1}^{S} pi \ln(pi) \text{ ………………………. Eqn. 4-(i)}$$

Pielou's evenness index $$J' = \frac{H'}{H_{\max}} = \frac{H'}{\ln S} \quad \text{……………………….Eqn. 4-(ii)}$$

where *pi* is the proportion of total samples belonging to i^{th} species and *S* is the number of species in the samples.

Comparison of the diversity and evenness indices among the sampling stations was conducted using non-parametric analysis of variance on the medians (Kruskal-Wallis test) followed by post-hoc multiple comparison ($p=0.05$) wherever significance difference were detected by the analysis of variance test. The post-hoc multiple comparison were conducted using the pair-wise Man-Whitney test, and the test *p* values for all $N_p=G(G-1)/2$ pairs of groups multiplied with *Np* as a conservative Bonferroni correction for the multiple testing or family-wise error (Zar, 1996) according to procedures in the PAST software (Hammer et. al., 2001).

To take into account the ecological and taxonomic structure of the community, Taxonomic diversity (Δ), Taxonomic distinctness (Δ*) and distinctness (Δ+) (using presence/absence data) indices were calculated in PAST (version 2.1.3) according to the following equations:

$$\Delta = \frac{\left[\sum\sum_{i<j} W_{ij}X_iX_j + \sum_{i} X_i(X_i-1)/2\right]}{\left[\sum\sum_{i<j} X_iX_j + \sum_{i} X_i(X_i-1)/2\right]} \text{ …………………………… Eqn. 4-(iii)}$$

$$\Delta^* = \frac{\left[\sum\sum_{i<j} w_{ij}x_ix_j\right]}{\left[\sum\sum_{i<j} x_ix_j\right]} \text{ ……….……………...……………..…Eqn. 4-(iv)}$$

$$\Delta^{+} = \frac{2\left[\sum i \sum_{i<j} w_{ij}\right]}{\left[s(s-1\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 4-(v)}$$

where x_i denotes the abundance of the i^{th} of S species observed, $(\sum_{i<j} x_i)$ is the total number of individuals in the sample and *ωij* is the weight given to the path length linking species *i* and *j* in the taxonomy. The taxonomic weight, *ωij* is fixed for any given pair of species, but since the taxonomic species composition varies between communities, the contribution of any given species to the community-wide taxonomic distance also varies in a similar way. Consequently, *ωij* were determined according to Clarke and Warwick (1998).

Lastly, to assess the demersal fish and shellfish assemblages in Kagoshima Bay, southern Japan, multivariate clustering methods and ordination techniques (Field et. al., 1982) were used. Analysis of Similarity (ANOSIM) and Similarity Percentage (SIMPER) (Clarke, 1993), cluster analysis using the Euclidean distance method and principal component analysis (PCA) were used to infer on the structure of the demersal fish and shellfish community, species distribution patterns and the influence of the main physico-chemical parameters including sea bottom temperature and conductivity on the spatial distribution of the fish and shellfish species. To test for differences across years and sampling strata, one-way ANOSIM methods were used while two-way SIMPER analysis was used to identify the typifying and discriminating species groups that contribute to similarity and dissimilarity within and between the sampling strata of Kagoshima Bay during 2006-2011. Both ANOSIM and SIMPER analysis use the Bray-Curtis measure of similarity (Bray and Curtis, 1957) and the SIMPER technique further breaks down the % contribution of each species or group to the observed similarity (or dissimilarity) between sampling strata thus allowing for identification of species that are most important in creating the observed pattern of similarity. Differences in environmental variables including mean water depth and sea bottom temperature among stations were also tested.

3.2.4 Results

In the present study, analysis of the demersal fish and shellfish in assemblages in Kagoshima Bay was conducted on a total of 144 species of Pisces, 60 species of Crustacea and 29 species of Mollusca excluding the rare and sporadically occurring species during the 2006-2011. An additional rare and/sporadically occurring 28 species Pisces, 64 species of Crustacea and 22 species of Mollusca, or specimens identified only to the genus level have been recorded in the bay since the start of the experimental trawl surveys in 2003. However, some of the species were recorded from <5 tows out of the more than 540 tows spread over the present study period from 2003 through 2011.

During 2006-2011, the overall number of species recorded in sampling stations of Kagoshima Bay, southern Japan appears quite stable, an indication that within-strata variations in species composition was generally insignificant during this period. The bay mouth recorded 21-50, 3-14 and 2-6 species of fish, crustaceans and molluscs, respectively while in the bay head the number of species ranged 33-61 for fish, 17-29 species of crustaceans and 5-8 species of molluscs. The central basin recorded the highest number of species, ranging 99-161 species of fish, 40-86 species of crustaceans and 13-31 species molluscs, respectively. The number of species (minimum, maximum and mean ± SD) by sampling strata in Kagoshima Bay, southern Japan during 2006-2011 is shown in Table 3-8. Based on the total number of species recorded in the haul samples at each sampling station, the fish community at the central basin was most diverse with 33-48 fish, 17-24 crustaceans and 7-10 mollusc species followed by the bay mouth with 21-50 species of fish, 14 crustacean species and 8 species of molluscs.

Table 3-8. Species numbers by sampling strata and area based on results of experimental trawl surveys in Kagoshima Bay, southern Japan during 2006-2011. The data shows minimum, maximum and the mean ± standard deviation (SD) by station and area of the bay

Zone	Strata	Fish			Crustacea			Mollusc		
		Min.	Max	Mean ± SD	Min.	Max	Mean ± SD	Min.	Max	Mean ± SD
	St.1	18	29	22 ± 4	9	15	12 ± 3	2	3	2 ± 1
	St.2	15	32	24 ± 5	8	14	13 ± 2	3	5	4 ± 1
Bay head		33	61		17	29		5	8	
Channel are	St.3	19	32	28 ± 4	10	17	13 ± 3	2	6	3 ± 1
	St.4	23	33	28 ± 4	13	24	20 ± 4	4	7	5 ± 1
	St.5	23	32	28 ± 3	15	21	19 ± 2	5	10	6 ± 2
	St.6	23	48	33 ± 9	2	24	9 ± 6	1	7	3 ± 1
	St.7	30	48	35 ± 6	10	17	15 ± 3	3	7	5 ± 1
Central basin		99	161		40	86	0	13	31	
Bay mouth	St.8	21	50	34 ± 8	3	14	9 ± 5	2	6	3 ± 1

Further, analysis of the species assemblages in Kagoshima Bay showed that the Pisces community was dominated by *C. jordani* (24.1%) and by six additional species that together accounted for over 56.6% of the total numbers: *A. sciistius* (9.4%), *M. griseus* (8.2%), *H. crassispinus* (5.6%), *Champsodon snyderi* (4.4%), *Synagrops philippinensis* (1.8%) and, *C. hirundinacea* and *Apogon kiensis* accounting for 1.6% each (Table 3-2). On the other hand, the Crustacea species assemblages were dominated by fewer species, with *P. semilaevis* (66.4%) together with seven other species accounting for 95.5% of the total numbers, including *M. sibogae* (8.0%), *Plesionika izumiae* (6.9%), *T. curvirostris* (6.1%), *Crangon affinis* (3.3%), *S. melantho* (3.0%) and *C. (Gonioneptunus) bimaculata* (1.9%). In the molluscs group, the most dominant species was *R. pulchellus* accounting for 33.6% of the total catch by numbers followed by *A. (divaricata) divaricarta* at 28.3% and *A. (Heterabralia)* *andamanica* at 14.4%, which together with four other species: *E. morsei* (8.9%), *S. (Platysepia) madokai* (5.4%) and *Sepiolina nipponensis* (4.9%) all accounting for 95.5% of the total numbers of the mollusc species samples. Other notable mollusc species recorded in the trawl hauls during this study period included *Portlandia lischkei* (1.7%), *S.* (*Platysepia) esculenta* (0.6%), *I. flavicula* (0.5%) and *Loligo edulis* (0.4%). The percentage composition of the fish and shellfish experimental trawl hauls in Kagoshima Bay, southern Japan during 2006 through 2011 is shown in Table 3-9.

Analysis of the fish and shellfish assemblages in Kagoshima Bay were conducted using ecological diversity indices to infer on the spatial-temporal distribution of the species and the diversity and richness of the demersal species assemblages. Results showed that Shannon-Wiener *H*' diversity, Pielou's evenness *J*' and Taxonomic diversity Δ were generally low in the bay head and channel area Sts. 1, 2 and 3 with mean values of 1.64 to 1.73, 0.51 to 0.57, 0.93 to 0.97 for the Shannon-Wiener *H*', Pielou's *J*' evenness and taxonomic diversity (Δ), respectively. It was noted that the sheltered sampling stations of the central basin (St. 4 in the northern edge south of the Sakurajima, and St. 7 along the Satsuma Peninsula coast) generally recorded higher values with Shannon-Wiener *H*' diversity of 2.11 to 2.33, Pielou's *J*' evenness of 0.62-0.65 and Taxonomic diversity (Δ) of 1.15 to 1.23, respectively. However, the highest species diversity and evenness was recorded in the more dynamic environments including the bay mouth station St. 8 with 2.49, 0.69 and 1.31 for Shannon-Wiener index *H*', Pielou evenness *J*' and Taxonomic diversity (Δ), respectively. On the contrary, Taxonomic distinctness (Δ*), and distinctness calculated on species presence/absence (Δ+) were highest in the channel area St. 3 and the central basin Sts. 5, and ranged 4.01 to 4.02 for taxonomic distinctness (Δ*) and 4.05 to 4.08 for distinctness Δ+ (based on species presence/absence data).

Table 3-9. Dominant species of fish and shellfish (crustaceans and molluscs) in Kagoshima Bay, southern Japan based on experimental trawl surveys conducted during 2006-2011

Fish	%	Crustaceans	%	Molluscs	%
Caelorinchus jordani	24.1	*Plesionika semilaevis*	66.4	*Raetellops pulchellus*	33.6
Amblychaeturichthys sciistius	9.4	*Metapenaeopsis lata*	8.0	*Acla divaricata divaricarta*	28.3
Malakichthys griseus	8.2	*Plesionika izumiae*	6.9	*Abralia (Heterabralia) andamanica*	14.4
Hoplostethus crassispinus	5.6	*Trachysalambria curvirostris*	6.1	*Euprymna morsei*	8.9
Champsodon snyderi	4.4	*Crangon affinis*	3.3	*Sepia (Platysepia) madokai*	5.4
Synagrops philippinensis	1.8	*Solenocera melantho*	3.0	*Sepiolina nipponensis*	4.9
Chelidoperca hirundinacea	1.6	*Charybdis (Charybdis) bimaculata*	1.9	*Portlandia lischkei*	1.7
Apogon kiensis	1.6	*Parapenaeus fissuroides fissuroides*	1.6	*Sepia (Platysepia) esculenta*	0.6
Pollichthys mauli	1.3	*Pasiphaea japonica*	1.1	*Inquisitor flavidula*	0.5
Bembrops curvatura	1.3	*Squilloides leptosquilla*	0.5	*Loligo edulis*	0.4
Others (165 species)	40.7	Others (75 species)	1.2	Others (23 species)	7.6

The central basin edge Sts. 6 and 7 and the bay mouth St. 8 generally showed lower values: 3.74-3.77 and 3.83-3.88 for taxonomic distinctness (Δ*) and (Δ+). The results of the ecological diversity indices: Shannon-Wiener index *H'*, Pielou index *J'*, Taxonomic diversity (Δ), Taxonomic distinctness (Δ*) and Taxonomic distinctness (Δ+) (using presence absence data) calculated for each year and sampling station/strata during the study period 2006-2011 are shown in Table 3-10.

Further, non-parametric analysis of variance by Kruskal-Wallis (variance on medians) test followed by post-hoc multiple comparison ($p<0.05$) (Man-Whitney pair-wise test with Bonferroni family-wise error correction) were conducted to compare the species diversity and evenness indices among the sampling stations (Table 3-11). The Shannon-Wiener H' diversity and Pielou's evenness J' showed significant differences ($p<0.05$) among the sampling strata of the bay: bay head Sts. 1 and 2 were significantly different from the central bay Sts. 4, 5 and 7 as well as the bay mouth St. 8 which also recorded significant difference in evenness with the channel areas St. 3. Similarly, the central basin Sts. 4 and 5 also varied significantly from central basin edge St. 7 and the bay mouth St. 8. These results suggest some distinct patterns in species diversity and evenness isolating areas of the bay into bay mouth, central basin mid Sts. 4 and 5, edge St. 7, the channel area St. 3, and the bay head Sts. 1 and 2 as shown in Table 3-11. On the other hand, Taxonomic diversity (Δ) isolated the bay head St. 1 from the adjacent St. 2, the channel area St. 3 and central basin St. 4'; St. 2 vs. Sts. 3 and 7; and St. 5 vs. Sts. 6, 7 and 8. Other indices including Taxonomic distinctness (Δ*) and distinctness with presence/absence data (Δ+) showed more of the sampling stations in Kagoshima Bay: significant differences were calculated when comparing: St. 1 vs. Sts. 3, 5 and 7; St. 2 vs. Sts. 6, 7 and 8; St. 3 vs. Sts. 7 and 8 and St. 5 vs. Sts. 6, 7 and 8 areas of Kagoshima Bay.

Based on the Taxonomic diversity (Δ), Taxonomic distinctness (Δ*) and distinctness

Table 3-10. Ecological diversity indices: Shannon-Wiener, Pielou evenness, Taxonomic diversity, Taxonomic distinctness (Δ*) and (Δ+) by year and sampling station in Kagoshima Bay, Japan. Bolded **1.23**$^{+}$ shows highest diversities and distinctness during 2006-2011

	Shannon Wiener index *H'*							
Yr	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
2006	1.06	1.60	2.01	**2.28**$^{+}$	**2.21**$^{+}$	2.12	**2.35**$^{+}$	**2.76**$^{+}$
2007	2.01	1.84	1.70	**2.27**$^{+}$	**2.22**$^{+}$	1.90	**2.50**$^{+}$	**2.99**$^{+}$
2008	1.73	1.67	1.67	**2.32**$^{+}$	2.07	1.38	**2.44**$^{+}$	**2.26**$^{+}$
2009	1.52	1.27	1.10	1.85	1.48	1.89	1.94	**2.76**$^{+}$
2010	1.71	1.67	1.74	1.95	1.58	**2.77**$^{+}$	**2.39**$^{+}$	**2.34**$^{+}$
2011	2.01	**2.27**$^{+}$	**2.47**$^{+}$	2.04	1.63	1.54	**2.40**$^{+}$	1.98
	Pielou index *J'*							
	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
2006	0.41	0.52	**0.61**$^{+}$	**0.63**$^{+}$	**0.60**$^{+}$	0.49	**0.62**$^{+}$	**0.71**$^{+}$
2007	**0.61**$^{+}$	0.54	0.47	**0.72**$^{+}$	**0.63**$^{+}$	0.50	**0.68**$^{+}$	**0.78**$^{+}$
2008	0.56	0.48	0.46	**0.67**$^{+}$	0.59	0.39	**0.67**$^{+}$	**0.64**$^{+}$
2009	0.55	0.43	0.47	0.56	0.48	0.52	0.59	**0.77**$^{+}$
2010	**0.71**$^{+}$	0.50	0.47	0.56	0.41	0.79	**0.67**$^{+}$	**0.66**$^{+}$
2011	**0.65**$^{+}$	**0.64**$^{+}$	**0.74**$^{+}$	**0.61**$^{+}$	**0.48**	**0.44**	**0.67**$^{+}$	**0.60**$^{+}$
	Taxonomic diversity Δ							
	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
2006	3.53	3.77	4.04	3.88	4.00	3.89	3.68	3.83
2007	3.73	3.79	3.96	3.56	3.96	3.68	3.57	3.79
2008	3.63	3.79	3.87	3.77	3.83	3.58	3.67	3.61
2009	3.72	3.81	3.87	3.77	3.75	3.67	3.66	3.71
2010	3.64	3.77	3.92	3.90	4.01	3.73	3.66	3.60
2011	3.65	3.81	3.77	3.79	3.82	3.64	3.60	3.62
	Taxonomic Distinctness Δ*							
	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
2006	3.81	**3.93**$^{+}$	**4.18**$^{+}$	**3.98**$^{+}$	**4.10**$^{+}$	**3.93**$^{+}$	3.77	3.88
2007	3.87	3.91	**4.07**$^{+}$	3.70	**4.07**$^{+}$	3.75	3.67	3.84
2008	3.82	3.92	**3.99**$^{+}$	3.88	**3.94**$^{+}$	3.67	3.76	3.71
2009	3.90	**4.00**$^{+}$	3.97	3.88	3.91	3.74	3.76	3.77
2010	3.94	3.90	**4.03**$^{+}$	**4.01**$^{+}$	**4.11**$^{+}$	3.81	3.76	3.69
2011	3.83	3.90	3.88	3.93	**3.94**$^{+}$	3.75	3.70	3.72
	Taxonomic Distinctness Δ+							
	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
2006	3.87	**4.03**$^{+}$	**4.27**$^{+}$	**4.08**$^{+}$	**4.17**$^{+}$	3.96	3.97	3.96
2007	3.93	3.93	**4.03**$^{+}$	3.63	**4.16**$^{+}$	3.80	3.85	3.87
2008	3.82	3.97	**4.04**$^{+}$	**4.02**$^{+}$	**4.00**$^{+}$	3.70	3.89	3.86
2009	3.98	**4.01**$^{+}$	3.96	3.87	3.96	3.76	3.88	3.88
2010	3.93	3.95	**4.07**$^{+}$	**4.03**$^{+}$	**4.14**$^{+}$	3.93	3.87	3.74
2011	3.77	3.91	3.94	3.91	**4.04**$^{+}$	3.87	3.82	3.76

with presence/absence data (Δ+), the sampling stations in Kagoshima isolated the bay head Sts. 1and 2, the channel area St. 3 and the central basin St. 5 against the rest of the sampling stations within the bay head, central basin and bay mouth. Furthermore, both taxonomic distinctness (Δ*) and (Δ+) highlight significant differences between the bay head Sts. 1 and 2 and central basin Sts. 5, 6 and 7 well as between St. 5 in the deeper area of the central basin with St. 6 and 7 and bay mouth St. 8.

Further, cluster analysis of the demersal assemblages of fish and shellfish in Kagoshima Bay was conducted using Ward's (1963) squared Euclidean distance method. The results of the fish species diversity and evenness in the sampled strata revealed some similarity in the Shannon-Wiener *H'* diversity and Pielou's *J'* evenness indices values in the four zones of the bay with three clusters grouping: the bay head Sts. 1 and 2, and the channel area St. 3; the bay mouth and central basin edge Sts. 6, 7 and 8; and the central basin inshore Sts. 4 and 5 as shown in Figure 3-4. Similarly, cluster analysis of the crustacean species diversity and evenness revealed three clusters: Sts. 4 and 5; Sts. 6 and 8; and Sts. 1, 2, 3 and 7 as shown in Figure 3-2. On the other hand, the diversity and evenness of the mollusc species also showed three clusters of the sampling stations in Kagoshima Bay with the bay head St. 8 isolated from the rest of the strata with the other two clusters as: Sts. 1, 2, 4 and 7, and St. 3, 5 and 6 as shown in Figure 3-3. These results suggest that the species diversity and evenness in Kagoshima Bay varies widely between the strata and areas of the bay: the bay mouth, central basin and, the bay head and channel area as shown by the clusters of the Shannon-Wiener *H'* diversity and Pielou's *J'* evenness indices.

Table 3-11. Results of post-hoc multiple comparison tests for differences in species diversity, evenness and taxonomic distinctness between the sampling strata in Kagoshima Bay, southern Japan. [a] denotes significance at $p<0.05$

Shannon Wiener index H'

Station	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
St. 1	0.94	0.87	**0.03**[a]	0.47	0.47	**0.01**[a]	**0.01**[a]
St. 2		0.58	**0.02**[a]	0.94	0.47	**0.01**[a]	**0.01**[a]
St. 3			0.13	0.94	0.69	0.07	0.03
St. 4				0.17	0.30	**0.04**[a]	0.09
St. 5					0.94	**0.02**[a]	**0.02**[a]
St. 6						0.09	0.07
St. 7							0.69

Pielou index *J'*

Station	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
St. 1	0.17	0.52	0.42	0.42	0.23	0.17	0.08
St. 2		0.69	**0.03**[a]	0.94	0.69	**0.01**[a]	**0.01**[a]
St. 3			0.15	0.69	0.94	0.09	**0.04**[a]
St. 4				0.11	0.07	0.42	0.17
St. 5					0.81	**0.02**[a]	**0.01**[a]
St. 6						0.07	0.07
St. 7							0.47

Taxonomic diversity Δ

Station	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
St. 1	**0.01**[a]	**0.01**[a]	**0.04**[a]	**0.01**[a]	0.47	0.94	0.94
St. 2		**0.04**[a]	0.94	0.07	0.07	**0.01**[a]	0.17
St. 3			0.13	0.87	0.02	0.01	0.01
St. 4				0.17	0.23	0.07	0.34
St. 5					**0.02**[a]	**0.01**[a]	**0.02**[a]
St. 6						0.30	0.94
St. 7							0.42

Taxonomic Distinctness Δ*

Station	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
St. 1	0.07	**0.01**[a]	0.30	**0.01**[a]	0.05	**0.01**[a]	0.09
St. 2		0.13	0.75	0.05	**0.04**[a]	**0.01**[a]	**0.01**[a]
St. 3			0.09	1.00	0.01	**0.01**[a]	**0.01**[a]
St. 4				0.09	0.11	**0.01**[a]	0.07
St. 5					**0.01**[a]	**0.01**[a]	**0.01**[a]
St. 6						1.00	0.94
St. 7							0.52

Taxonomic Distinctness Δ+

Station	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
St. 1	0.09	**0.01**[a]	0.42	**0.01**[a]	0.42	0.94	0.42
St. 2		0.11	0.94	**0.04**[a]	0.03	**0.02**[a]	**0.02**[a]
St. 3			0.20	0.58	**0.01**[a]	**0.01**[a]	**0.01**[a]
St. 4				0.09	0.26	0.26	0.20
St. 5					**0.01**[a]	**0.01**[a]	**0.01**[a]
St. 6						0.42	1.00
St. 7							0.47

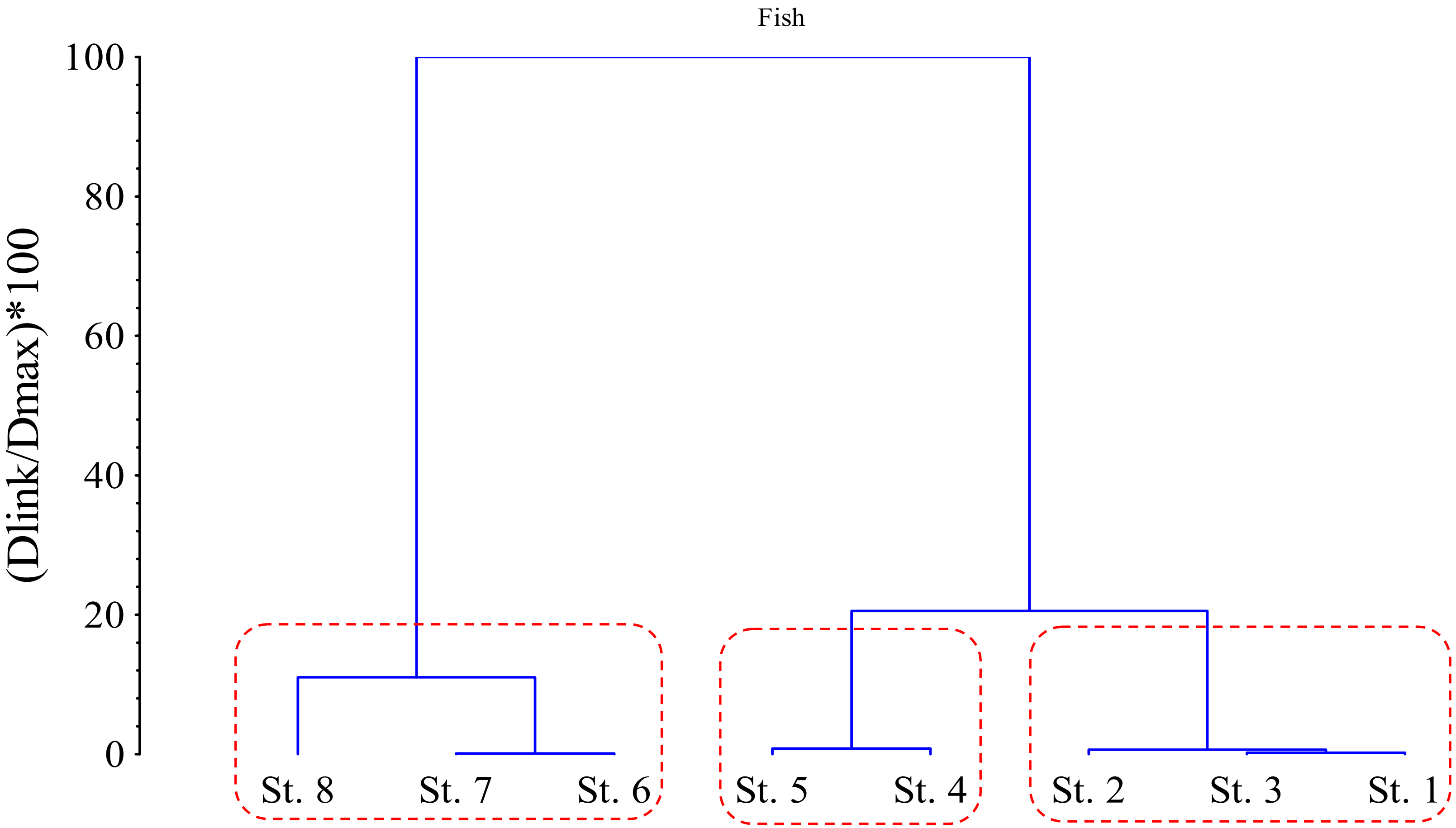

Figure 3-1. Hierarchical clustering (Ward's 1963 squared Euclidean distance method) by Shannon-Wiener *H'* diversity and Pielou's *J'* evenness for fish species in the sampling strata of Kagoshima Bay, southern Japan during 2006-2011

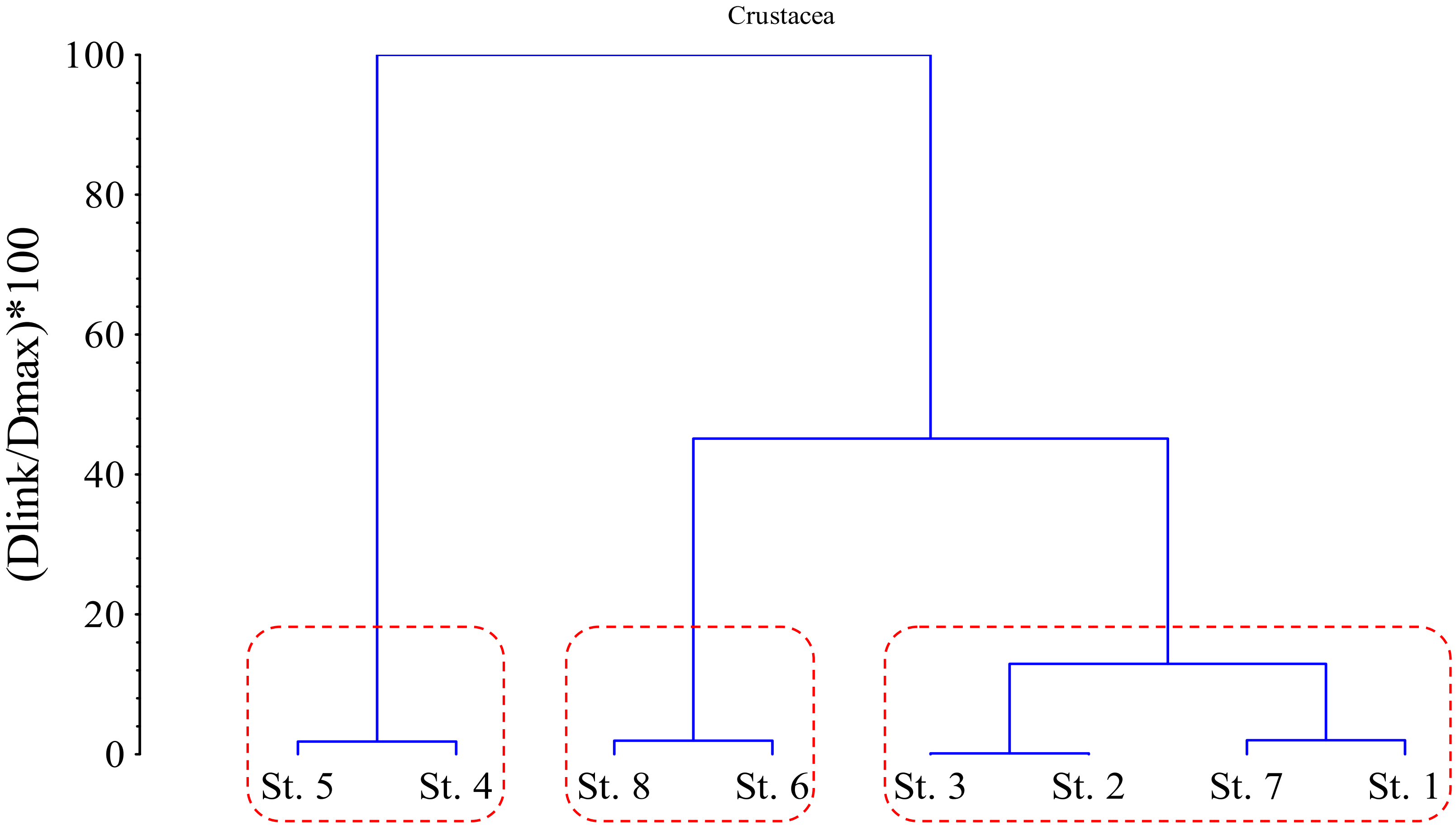

Figure 3-2. Hierarchical clustering (Ward's 1963 squared Euclidean distance method) by Shannon-Wiener *H'* diversity and Pielou's *J'* evenness for crustacean species in the sampling strata of Kagoshima Bay, southern Japan during 2006-2011

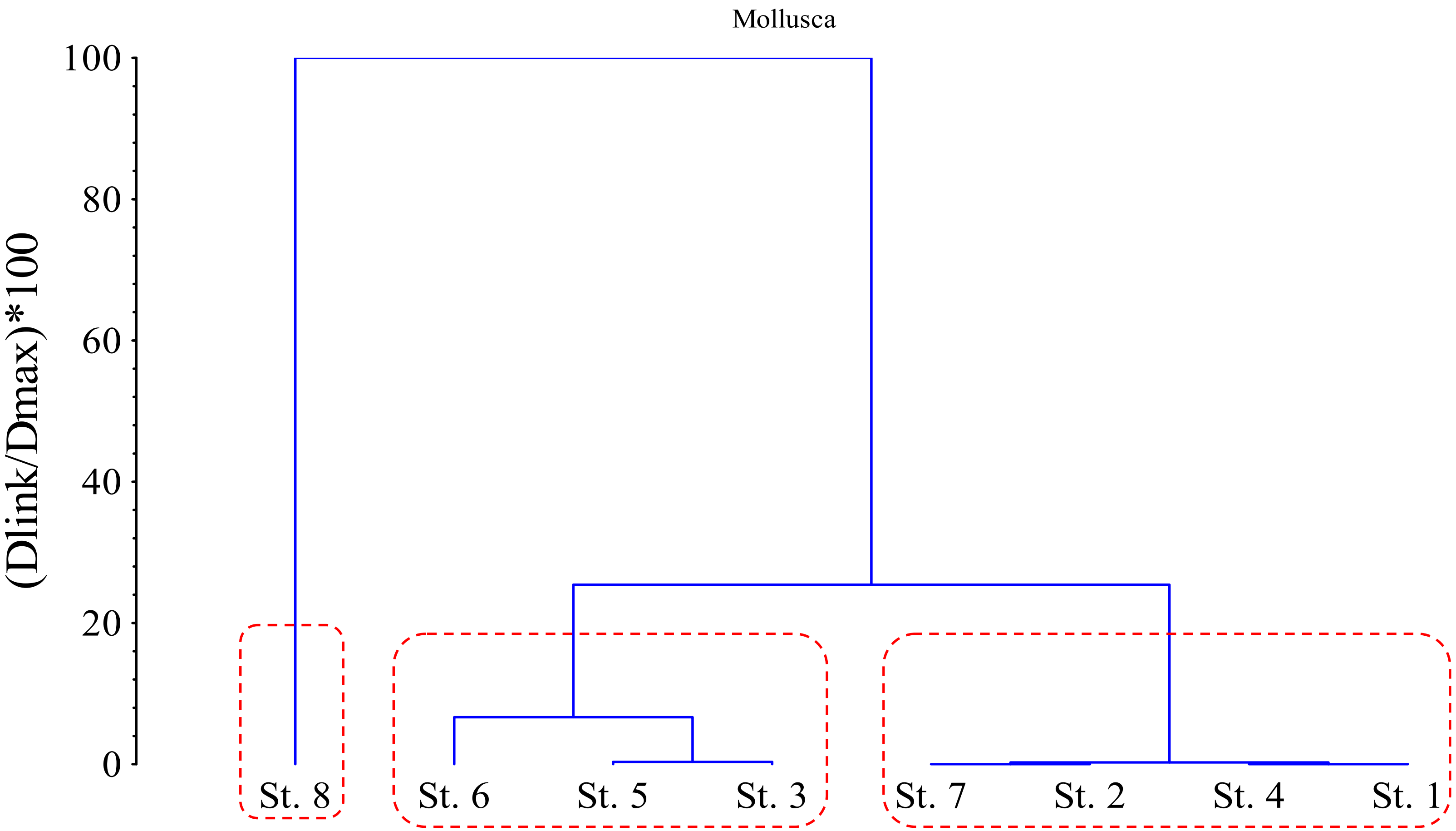

Figure 3-3. Hierarchical clustering (Ward's 1963 squared Euclidean distance method) by Shannon-Wiener *H'* diversity and Pielou's *J'* evenness for mollusc species in the sampling strata of Kagoshima Bay, southern Japan during 2006-2011

Lastly, ANOSIM, SIMPER and PCA analysis were conducted to investigate the spatial-temporal variations in species assemblages and the factors influencing these distributions. The results of the one-way ANOSIM analysis performed on sea bottom temperature and conductivity show that there are no significant differences ($p>0.05$) between the sampling stations of the bay head, channel area, central basin and bay mouth despite the variations in water depth and bathymetric features of the four zones.

Secondly, the results of two-way ANOSIM analysis for differences between the sampling strata Sts. 1-8 and across the study period years 2006-2011 were significant ($p<0.05$). Further, two-way SIMPER analysis showed that 42.59% average similarity between the sampling stations and 90.8% within-strata similarity was attributed to 32 species of fish and shellfish: 11 fish, 13 species of crustaceans and 8 species of molluscs (Table 3-3). The variations in species composition of the fish and shellfish species in the study area were attributed to the higher abundance of shellfish species in the channel area and central basin including *Metapenaeopsis sibogae*, *Charybdis (Charybdis) bimaculata, Plesionika semilaevis*, *Parapenaeus fissuroides fissuroides*, *Sepia (Platysepia) madokai*, *Trachysalambria curvirostris*, *Plesionika izumiae*, *Solenocera melantho* and *Crangon affinis*. The most abundant fish species contributing to the higher similarity between strata and years included *Caelorinchus jordani*, *Benthosema pterotum* and *Amblychaeturichthys sciistius*.

Further, ordination of the species contributing to similarities in the sampling stations (from the two-way SIMPER analysis) was conducted using principal component analysis (PCA) to isolate the sentinel and indicator species in each of the strata. The results showed distinct differences across strata: fish species assemblages showed dominance of *P. mauli* in the central basin and channel area while *C. jordani*, *Apogon kiensis* and *A. semilineatus* in the southern central basin Sts. 5 and 6, and *A. divaricata divaricata* and *B. pterotum*, *M. griseus*, *A*, *sciistius* in the St. 7 of central basin. On the other hand, ordination results for crustacean species *T. curvirostris*, *P. izumiae*, and *C. affinis* as indicator species in the bay head St. 1 and channel area St. 3 while the bay head St. 2 and bay mouth St. 8 were typified by *M. sibogae*. The central basin Sts. 4, 5 and 7 were characterised by *C.* (*Charybdis*) *bimaculata* and *P. semilaevis*. In the case of molluscs, the northern areas of the bay at bay head Sts. 1 and 2 and Channel area St. 3 were characterised by *E. morsei* and *R. pulchellus* while *S.* (*Platysepia*) *madokai* was the indicator species in the southern Sts. 6 and 8 towards the bay mouth. The central basin Sts. 4, 5, 7 were typified by *A.* (*divaricata*) *divaricata*.

Table 3-12. SIMPER analysis of the species composition from experimental trawl surveys in Kagoshima Bay, southern Japan during 2006-2011. Only 32 out of 175 species of fish and shellfish contributed the 90.8% similarity between strata

Species	Average abundance	Average similarity	% contribution
Metapenaeopsis lata [c]	2.7	3.4	8.0
Charybdis (Charybdis) bimaculata [c]	2.2	2.7	6.4
Plesionika semilaevis [c]	2.9	2.6	6.0
Parapenaeus fissuroides fissuroides [c]	2.1	2.5	6.0
Sepia (Platysepia) madokai [m]	1.5	2.2	5.1
Trachysalambria curvirostris [c]	2.3	2.1	4.9
Plesionika izumiae [c]	2.4	2.1	4.9
Solenocera melantho [c]	2.1	2.0	4.7
Crangon affinis [c]	2.1	1.8	4.2
Caelorinchus jordani [f]	1.7	1.6	3.9
Euprymna morsei [m]	1.5	1.6	3.7
Abralia (Heterabralia) andamanica [m]	1.2	1.2	2.9
Benthosema pterotum [f]	1.5	1.2	2.8
Squilloides leptosquilla [m]	1.4	1.1	2.5
Amblychaeturichthys sciistius [f]	1.2	0.9	2.1
Pasiphaea japonica [c]	1.4	0.8	1.9
Malakichthys griseus [f]	1.2	0.8	1.9
Metapenaeopsis acclivis [c]	0.9	0.8	1.8
Champsodon snyderi [f]	0.8	0.8	1.8
Hoplostethus crassispinus [f]	1.0	0.7	1.6
Cubiceps squamiceps [f]	0.8	0.7	1.6
Aegaeon lacazei [c]	0.8	0.6	1.4
Bembrops curvatura [f]	0.7	0.5	1.2
Raetellops pulchellus [m]	1.0	0.5	1.2
Acla divaricata divaricarta [m]	1.1	0.5	1.2
Lophogaster japonicus [c]	0.7	0.5	1.1
Chelidoperca hirundinacea [f]	0.6	0.5	1.1
Sepiolina nipponensis [m]	0.9	0.5	1.1
Bregmaceros japonicus [f]	0.6	0.4	1.1
Ibacus ciliatus [c]	0.7	0.4	1.0
Portlandia lischkei [m]	0.7	0.4	1.0
Pollichthys mauli [f]	0.7	0.4	1.0
			90.8

NB: [f] is fish , [c] is Crustacea and [m] is Mollusca

Based on experimental trawl surveys conducted during 2003-2011, fish and shellfish composition in the Bay head, Channel area, Central Basin and Bay mouth areas of Kagoshima Bay, southern Japan recorded an average similarity of 42.59 %, with 32 species contributing to 90.8% of the observed similarity between the sampled strata

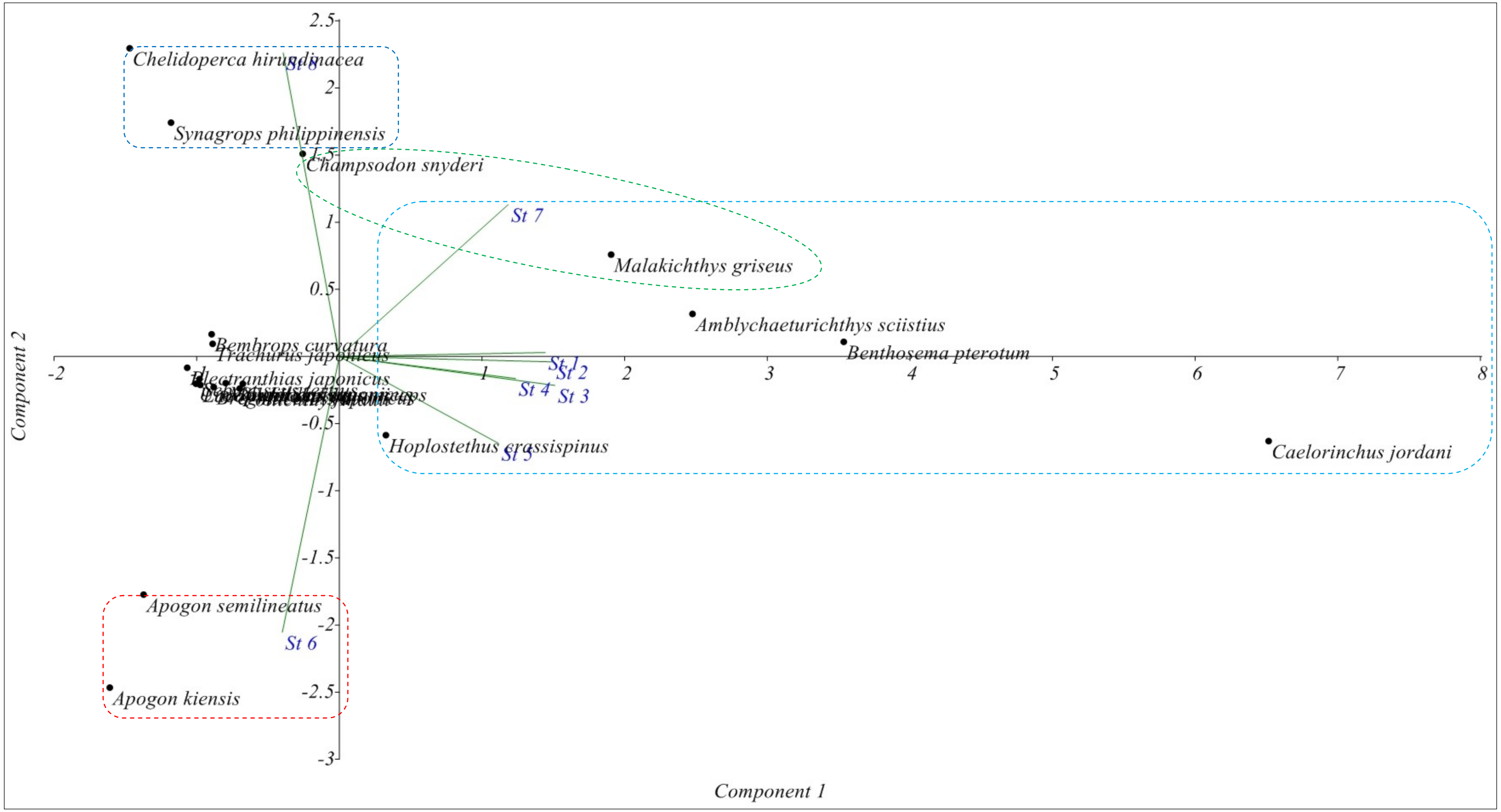

Figure 3-4. Principal Component Analysis (PCA) plot showing indicator fish species in Kagoshima Bay, southern Japan: bay head, channel area and central bay Sts. 1, 2, 3, 4, 5 and 7 with *C. jordani*, *B. pterotum*, *A. sciistius*, *M. griseus* and *H. crassispinus*; central basin edge St. 6 with *A. semilineatus* and *A. kiensis*; central basin St. 7 with *C. snyderi*, and the bay mouth St. 8 with *C. hirundinacea* and *S. philippinensis*

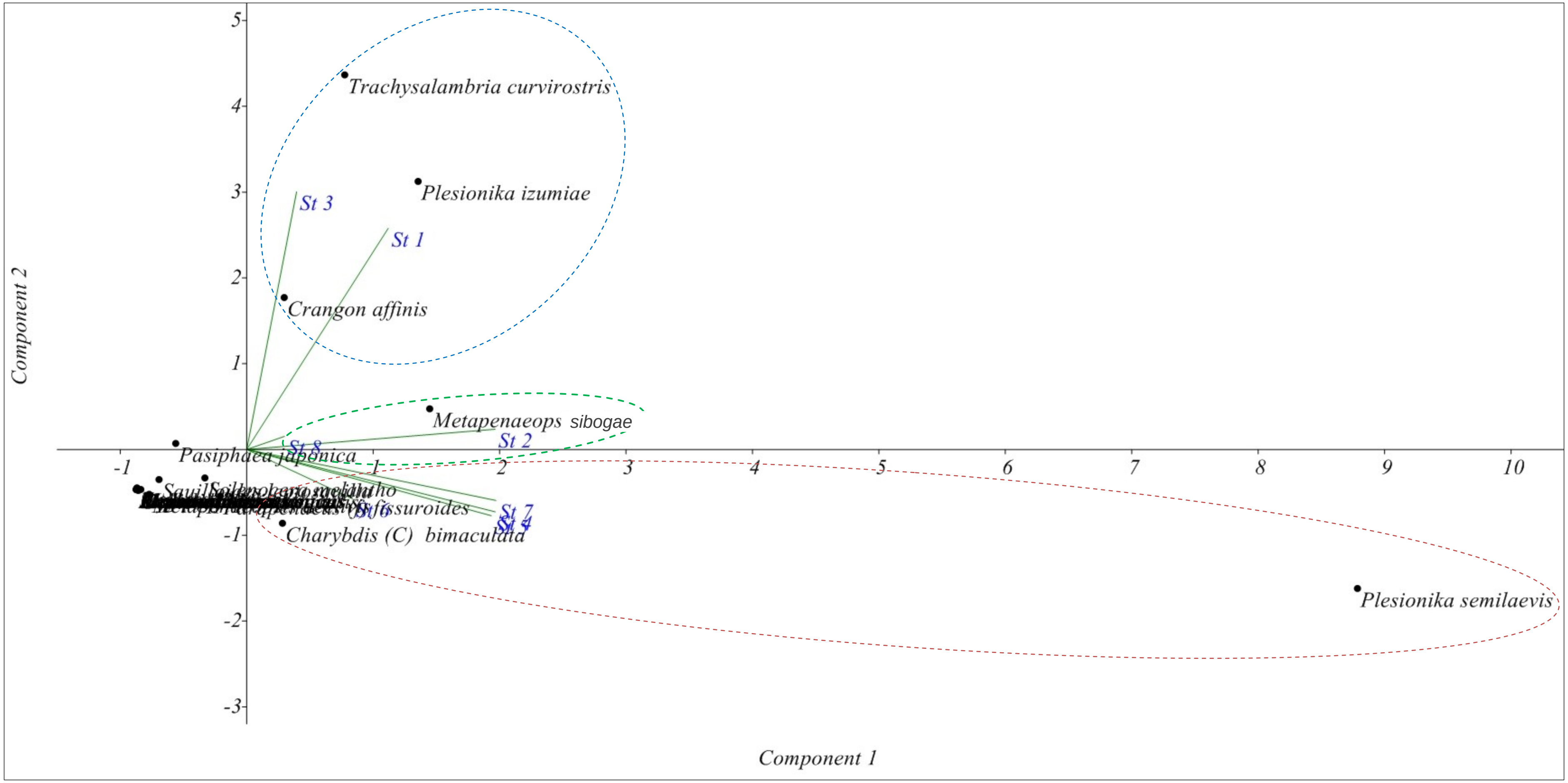

Figure 3-5. Principal Component Analysis (PCA) plot showing indicator crustacean species in Kagoshima Bay, southern Japan: bay head St. 1 and 2, and channel area St. 3 by *T. curvirostris*, *P., izumiae and C. affinis*, central basin Sts. 4, 5, 7 by *P. semilaevis, S. melantho and M. sibogae* and *C. (Charybdis) bimaculata*. *P. fissuroides fissuroides* also characterised the southern sampling Sts. 6, 7 and 8

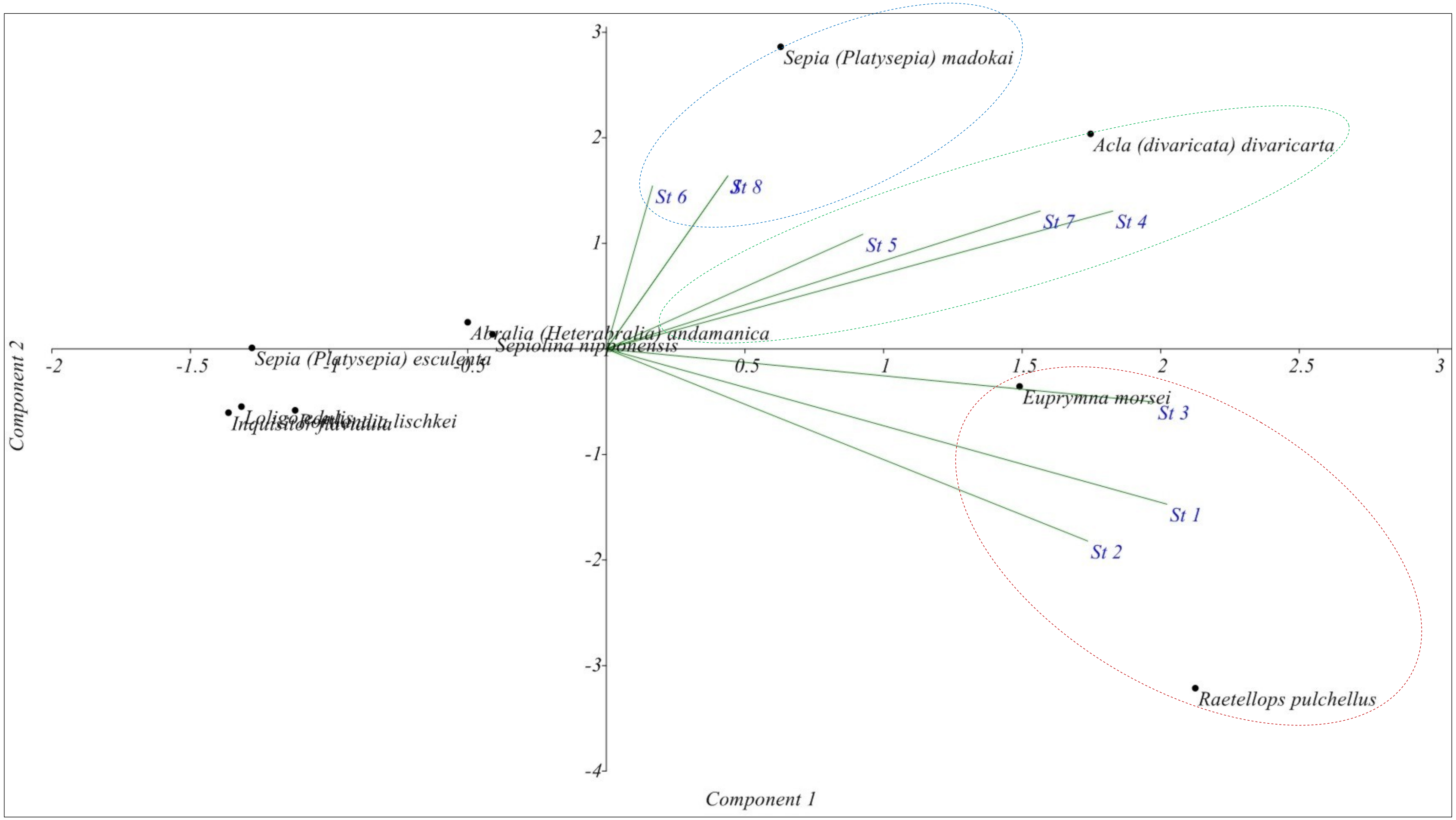

Figure 3-6. Principal Component Analysis (PCA) plot showing the indicator mollusc species in Kagoshima Bay, southern Japan: the bay head Sts. 1 and 2 and channel area St. 3 by *R. pulchellus* and *E. morsei*; central basin Sts. 4, 5 and 7 by *A. (divaricata) divaricata* and *A.* (*Heterabralia*) *andamanica*, and southern St. 6 and bay mouth St. 8 by *S.* (*Platysepia*) *madokai*

3.2.5 Discussion

The overall results of demersal fish and shellfish assemblages in Kagoshima Bay, southern Japan indicate two main considerations: firstly, the species biomass for fish and shellfish greatly vary from one area to the other, with highest CPUE and biomass recorded in the central basin; secondly, the areas of the bay (the basin habits; bay head and central basin, and the channel environments; channel area and bay mouth) show different fish community structures. The fish and shellfish assemblages in the basin environments; central basin Sts. 4, 5, 6 and 7 and bay head Sts. 1 and 2, and the channel environments; Channel area St. 3 and St. 8 appear quite similar with a pool of teloest species; *C. snyderi, M. griseus*, *A. sciistius*, *B. pterotum*, *H. crassispinus* and *C. jordani* in the basin environments and *C. hirundinacea*, *S. phillippinensis*, *A. semilieatus* and *A. kiensis* in the channel environments. In the crustacean assemblages, the bay head (Sts. 1 and 2) and channel area (St. 3) were similar and were characterised by penaeid, pandalid and crangonid species: *M. sibogae*, *T. curvirostris* and *C. affinis* while the southern areas central basin and bay mouth were dominated by *S. melantho* (Solenoceridae), *P. semilaevis* and *Charybdis* (*Charybdis*) *bimaculata* (Portunidae). On the other hand, molluscan species assemblages mainly isolated the bay head Sts. 1 and 2 and channel area St. 3 with *R. pulchellus*; the southern sampling Sts. 6 and 8 with *S.* (*Platysepia*) *madokai*; the central basin Sts. 4, 5 and 7 with *A.* (*divaricata*) *divaricata* and the Bay. The crustacea community in the southern Sts. 6 and showed clear symptoms of stress mainly attributed to the oceanographic factors and the nature of the bottom sediments in these current influence topographies. Therefore, the distribution structure of the fish and shellfish species suggest clear patterns with water circulation and currents in the bay. Moreover, the combined influence of water depth, bottom currents and type of sediments has also been shown to shape the structure and dynamics of marine species assemblages (Fager and Longhurst, 1968; Bianchi, 1992).

Generally, the results of the species diversity, ecological structure and multivariate analysis using classification and ordination by ANOSIM, SIMPER and PCA analysis were sensitive for detecting the spatial-temporal variations in demersal assemblages of the fish and shellfish species in Kagoshima Bay during the sampling period. The biocenotic indices including abundance, diversity and distinctness show a general decrease from the central basin radiating out north towards the bay head and southwards to the bay mouth and the central basin recorded the highest number of species: 161 fish, 86 crustacean and 31 molluscan species. Therefore, Kagoshima Bay demersal fisheries community is still species rich in all the three groups. These distribution structures are suggestive of clear influence of bathymetric characteristics and oceanographic factors including water currents. On the other hand, the bay head species assemblages may be subject to structuring by the volcanism within this caldera. Overall species distribution patterns in Kagoshima Bay shows that the different environments are characterized by different groups of assemblages in terms of fish, crustacea and mollusc which require different environments especially with regards to bottom sediments and water currents. Generally, the some dominant species accounted for a greater proportion of the biomass by each group, with seven fish species accounting 56.6% of the Pisces abundance while eight and seven species accounted for 95.5% each, of the Crustacea and Mollusca abundance, respectively. On the less dominant species in Pisces, 165 species accounted for 40.7% while in Crustacea and Mollusca, 75 and 23 species accounted for 1.2% and 7.6% of the species abundance, respectively suggesting that species dominance by biomass was highest in Crustacea, followed by Mollusca and Pisces in that order. This is confirmed by the results of SIMPER analysis which showed 42.6% average similarity between the sampling stations and 90.8% within-strata similarity attributed to 32 species: 11 Pisces, 13 Crustacea and 8 Mollusca species. Further, the ordinations results show clear indication of fewer sentinel/indicator species in Crustacea and Mollusca compared to the Pisces group.

Further, the diversity analysis and multivariate clustering methods were adequate to decipher the community structure Kagoshima Bay. However, they do not show whether the changes in the demersal fish and shellfish assemblages are in the direction of a climax community (presumably positive), or show stress attributable to natural or human-induced disturbance (presumably undesirable or negative). Consequently, future studies should embark on analysis of the additional community metrics and distribution structures including using tools such as Abundance-Biomass Comparisons (ABC) curves (Warwick, 1986). The ABC analysis may be also very useful for monitoring any ecosystem disturbance by comparing dominance in terms of abundance with dominance in terms of biomass. Similar studies using this technique have been conducted in marine benthic communities to determine the expected changes in response to ecosystem disturbance (Warwick et. al., 1987). Moreover, the ABC analysis takes into account the number of species included in the analysis. Consequently, the ABC index has a main advantage is that an appropriate data set for any of the sampling stations or period would allow the status of the community to be evaluated without the need for a spatial or a temporal control against which to compare the index obtained, since analysis makes a snap-shot comparison of the biomass with abundance for the same sampling areas and periods (Clarke and Warwick, 1994).

Notwithstanding, the results of the present study and analysis of the demersal fish and shellfish species in Kagoshima Bay clearly provides information of the spatial and temporal variations within the sampling stations, dominant species and indicator/sentinel species in each of the areas of the bay which may be suggestive of the influence of the coastal and anthropogenic activities within these areas. Therefore, the influence of fishing and other anthropogenic activities cannot be ignored. However, although the probable impacts of fishing and other anthropogenic activities within Kagoshima Bay cannot be excluded, the observed differences in composition and spatial assemblages of the fish and shellfish species in the bay appear consistent with the local hydrological processes including the water current patterns and influx of the warm Kuroshio water into the bay. Additionally, natural processes such as influence of volcanism and the effect of thermogenic methane from organic matter in bottom sediments within the bay head rather than fishing and fisheries related activities also need further research. However, there is need to investigate the influence of fishing and fishery related activities on the demersal fish and shellfish assemblages in this bay especially with regard to the larger target species which have a wide range of environmental preferences, in the most exploited fishing grounds of the bay. Lastly, the results of the preset study on the four areas of the bay investigated represent a useful tool to identify and understand the general pattern in the evolution of the exploited demersal communities in Kagoshima Bay for design of sustainable exploitation of the biological resources of this important fishery.

CHAPTER 4. LINKING FISHERIES TO ECOSYSTEM MANAGEMENT - TROPHIC ANALYSIS AND MODELLING

4.1 Stable isotope analysis of fish and shellfish in Kagoshima Bay fishery, southern Japan.

4.1.1 Summary

Sampling was conducted in Kagoshima Bay, southern Japan during 2009-2011 onboard the *Nansei Maru* as described in Section 2.1 and 2.1. The samples were chilled in ice and frozen at -30º C on arrival in the laboratory pending analysis. Muscle tissues were extracted by incision and oven-dried at 100º C for 48-72h in an oven. Dried samples were then ground to a homogenous powder using a motor and pestle. Bottom sediments (0-4 cm) were also collected using a triple core sample and dried, then ground into a homogenous powder. The fish and shellfish samples divided into two, and part acidified with 1 N Hydrochloric acid (HCl) containing 1.0% Platinum (II) chloride ($PtCl_2$, a combustion catalyst to remove inorganic carbon which would interfere with the isotope rations. Due to high content of inorganic carbon in sediments, all samples were acidified before analysis. The values of stable isotope signatures in fish varied from -18.6‰ to -12.5‰ and 4.2 to 14.8‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively while in shellfishes, the values were -17.3‰ to -12.9‰ and 5.77 to 11.76‰, respectively. Variations of the $\delta^{13}C$ and $\delta^{15}N$ signatures with body size were observed for all species and were attributed to ontogenetic shifts in dietary diets preferences within species and migrations associated with the different history stages. Sediments recorded lower isotope ratios. Based on the $\delta^{13}C$ and $\delta^{15}N$ ratios, the fish and shellfish species were grouped into 12 groups visualized "isotopic niche space" diagrams with three representative levels each for the fish and shellfish species. The $\delta^{13}C$ and $\delta^{15}N$ values in acidified and

non-acidified samples were significantly different ($p<0.05$) with higher $\delta^{13}C$ values but lower $\delta^{15}N$ isotope values in acidified samples compared to the non-acidified sample values.

4.1.2 Introduction

Stable isotopes are a powerful tool for the study of trophic linkages in dynamic coastal and marine systems (Michener and Schell, 1994). Isotope ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), on a parts per thousand basis relative to a standard, are used to infer the possible food items, trace carbon flows ($\delta^{13}C$‰) and trophic positions ($\delta^{15}N$‰) of animals and plants. The use of stable isotope ratios in studies of food web dynamics is based on the fact that the stable isotopic ratio of the diet is reflected in the isotopic ratio of the consumer. As animals metabolize their food, stable isotopes undergo a process known as fractionation or the enrichment or depletion of the heavy isotope relative to the light isotope as a result of certain physical and chemical processes (Post, 2002). Enrichment refers to the relative retention of the heavier of the two forms of stable isotopes for a particular element (^{13}C and ^{15}N) which is retained in the tissues of the consumer while a greater amount of the lighter isotopes (^{12}C and ^{14}N) is lost. When isotopic compositions are employed in the examination of diets and food web dynamics, it is important to realize that the isotopic compositions of different tissues of the study animal will reflect the diet of the animal during different temporal periods. Tissues that are rapidly replaced in the body will reflect the diet of the animal in the relatively recent past, and those tissues that do not have high turnover rates will reflect the diet over a longer span of time. This complication is also relevant to nitrogen isotopes. Complexities arising from this effect can be lessened to some extent by either using a sample that consists of a homogenization of the organism. It is also important to conduct the isotopic analysis on several organisms within the examined species, as individuals of the same species eating approximately the same diet may vary in their isotopic compositions (Michener and Schell, 1994). Numerous studies have examined and documented the utility of stable carbon isotopic analysis in studies of diet and trophic dynamics (Smith, 1972; DeNiro and Epstein, 1978; Tieszen et. al., 1983; Jackson and Harkness, 1987).

Like carbon isotopes, nitrogen isotopes are useful primarily in systems where there are two (or more) types of primary food sources that differ significantly in their $\delta^{15}N$. The enrichment of approximately 3‰ for nitrogen with each successive trophic level makes the nitrogen isotope values particularly useful in the study of trophic dynamics (Michener and Schell, 1994). The enrichment of nitrogen isotopes occurs either through the preferential excretion of ^{15}N-depleted nitrogen (i.e. higher in ^{14}N) in urea or ammonia or the preferential utilization of ^{15}N-enriched protein (or through a combination of both processes) (Michener and Schell, 1994).

Kagoshima Bay, southern Japan, may be defined as a breached, submerged caldera of the Sakurajima, which is an active volcano. Several studies have reported high concentrations of CO_2 and methane bubbled-up from the seabed, especially in the bay head (Horibe et. al., 1980; Craig and Horibe, 1994). In their study, Craig and Horibe (1994) also reported that the Ch_4 to ^3He ratios were about 1000 fold greater than Mid-Ocean Ridge Basalt (MORB) ratios. Furthermore, the observed rations showed resemblance to those found in hydrothermal vents characterised by thermogenic methane from organic matter in bottom sediments. This may suggest an injection of mantle helium from the Sakurajima Volcano bottom waters (Craig and Horibe, 1994). Moreover, CO_2 is also more enriched than Helium due to the more rapid transfer of helium to the atmosphere and this leaves the bay waters enriched in CO_2. The bottom sediments in Kagoshima Bay are also reportedly rich organic matter indicating a thermogenic methane contribution due to volcanic heat (Horibe et. al., 1980). Therefore, it is hypothesized that the energy sources in Kagoshima Bay comprise both microbial chemoautotrophic primary production and photosynthesis, with the former being the dominant source of ecosystem energy production especially the organic rich sediments of the bay head and central basin. Several studies have reported similar observations in the study of marine chemosynthetic-based ecosystems (Howarth and Teal, 1980; Brooks et. al., 1987; Fisher, 1990).

4.1.3 Materials and Methods

4.1.3.1 Sample sources and preparation

Fish and shellfish samples were collected in Kagoshima Bay during the experimental trawl surveys onboard the Nansei Maru, a training vessel of the Faculty of Fisheries, Kagoshima University, Japan. For the purpose of the present study, analysis was conducted on specimens collected during 2009-2010. Sampling was conducted using a simple trawl net (Nichimo LC-VI) as described in study 2.1 (Figure 1-3). Samples were chilled in ice and frozen (at -30º C) on arrival in the laboratory pending analysis. Prior to analysis, the frozen samples were thawed and sample tissue extracted by incision of the muscle. Intramuscular bones in the fish species and the exoskeleton in crustacean and molluscan species were carefully removed to ensure little interference of the bone materials on the stable isotope ratios. The muscle tissues were oven-dried at 100^{o} C for 48 to 72h in an electric drying oven (Advantec FS-620, Japan) at the laboratory of Marine Biology and Oceanography, Faculty of Fisheries, Kagoshima University. In very tiny species, further sorting of any remaining intramuscular bones was carefully conducted after drying and preparation. The dried samples were ground to a homogenous powder using a motor and pestle. Between samples, careful cleaning and drying of the grinding apparatus was done to ensure no cross contamination between different samples.

Similarly, bottom sediments were sampled using a triple core sample for the upper 0-4 cm sediments which are the depths of interest to the benthic organisms. The samples were chilled in ice onboard and frozen on arrival in the laboratory. Prior to preparation for isotope analysis, the samples were thawed and then dried in an electric oven (Advantec FS-620, Japan) at 60˚C, the ground into a homogenous fine powder using a mortar and pestle while taking care to avoid cross contamination between samples.

Generally, animal tissues and sediments often contain varying amounts of carbonates which may interfere with the results of the $^{13}C/^{12}C$ or $^{15}N/^{14}N$ stable isotope ratios. When analysing animal tissues, the samples may be analysed without acidification to remove the carbonates. However, in the case of sediments, acidification is but a necessary step for sediment samples subject to $\delta^{13}C$ analysis due to high amounts of carbonates resulting from natural geological processes including coral building especially in the marine environment. Consequently, all sediments were acidified as follows. Finely ground powdered samples of oven-dried muscle tissues or sediments were acidified to remove carbonates by direct application of 1 N Hydrochloric acid (HCl) containing 1.0 Platinum (II) chloride ($PtCl_2$), a combustion catalyst. The 1.0% $PtCl_2$ acid was prepared as 25 ml 10% $PtCl_2$ in 250 ml of 1 N HCl. Complete carbonate removal was confirmed by the absence of bubbling upon continued addition of the acid.

While stable $\delta^{13}C$ analysis is a useful tool for inference of trophic relationships in aquatic ecosystems, the vulnerability of carbonates necessitates careful sample preparation. Common methods involve simple treatments with a dilute acetic acid remove inorganic carbonates. Therefore, the effect of acidification on $^{13}C/^{12}C$ and $^{15}N/^{14}N$ stable isotope ratios of the fish and shellfish tissue samples was assessed as follows. Each sample was divided into two parts: a control, un-acidified samples, and second, samples acidified by treated for carbonate removal as follows. Fish samples were acidified by the direct application of 1 N

HCl containing 1.0% $PtCl_2$ following similar procedures to sediments treatment. The use of the 1.0% $PtCl_2$ containing HCL acid for treatment of fish samples is recommended due to the likely presence of powdered bone in the samples especially in small-sized species such as skinny cheek lantern *B. pterotum* and stareye lightfish *Pollichthys mauli*. On the other hand, the shellfish samples were treated by direct application of 1 N HCl only since the body tissues have no intra-muscular bones. Like in the treatment of sediments, complete carbonate removal in both fish and shellfish samples was confirmed by the absence of bubbling upon continued addition of the acid. Finally, all the acidified and un-acidified fish and shellfish samples, and the acidified sediment samples were again dried and ground to a fine homogenous powder, then placed in glass vials pending isotopic analysis.

4.1.3.2 Isotopic determination and data analysis

Isotopic analysis was conducted at the Faculties of Agriculture and Engineering, Miyazaki University on a using continuous flow organic elemental analyzer (Flash 2000, Thermo Scientific, Japan) coupled to a gas chromatograph analyser (EA Conflo IV- trace gas GC analyzer, Thermo Scientific, Japan) and a isotope ratio mass spectrophotomer (Delta V Advantage IRMS, Thermo Scientific, Japan) as follows. For the stable isotope analysis, varying 0.2-2 mg of fish and shellfish samples of homogenous material (varied by species isotope concentrations) was weighed into 4×6 mm tin capsules, while about 5.5-6.0 mg provided the optimal amount for sediment isotope analysis. Stable isotope abundance was the estimated by comparing ratio of isotopes $^{13}C/^{12}C$ and $^{15}N/^{14}N$ in sample to the International standards and results expressed in terms of ‰ deviation from the standard as:

$$\delta^{13}C = [(R_{SAMPLE} / R_{PDB})-1] * 1000 \text{ ....Eqn. 4-(i)}$$

$$\delta^{15}N = [(R_{SAMPLE} / R_{PDB})-1] * 1000 \text{ ....Eqn. 4-(ii)}$$

where R_{SAMPLE} is ratio of heavy isotope ($\delta^{13}C$ or $\delta^{15}N$) to the light isotope ($\delta^{12}C$ or $\delta^{14}N$) and R_{PDB} is the PDB isotopic ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$ (Peterson & Fry, 1987). All results are reported with respect to VPDB (Vienna / cretaceous Pee Dee Belemnite) for $\delta^{13}C$ and atmospheric nitrogen for $\delta^{15}N$.

The analytical precisions were ±0.02‰ and ±0.08‰ for nitrogen and carbon, respectively, based on estimations from standards analyzed together with the samples. The variations in food sources and the trophic levels of the fish and shellfish in Kagoshima Bay were therefore elucidated from the analysis of these naturally occurring stable isotope ratios. Data analysis was conducted as follows. First Student-tests were used to compare $\delta^{15}N$ and $\delta^{13}C$ values of the fish and shellfish in the Kagoshima Bay collected during 2006-2011. Secondly, ANOVA was used to compare the $\delta^{15}N$ and $\delta^{13}C$ between acidified and un-acidified samples. Statistical analyses were performed using Statistica 8.0 (StatSoft Inc., US).

4.1.4 Results

A total of 52 and 21 representative species of the fish and shellfish species in Kagoshima Bay, southern Japan were selected for isotopic analysis. Variations of $\delta^{13}C$ and $\delta^{15}N$ with body size as total length (TL), Pre-anal length (PAL), or carapace length (CL) were observed for all the species analysed in this study and was mainly attributed to dietary differences between species and ontogenic shifts in dietary preferences within species. The values of $\delta^{13}C$ and $\delta^{15}N$ in fishes varied from -18.6‰ to -12.5‰ and 4.2 to 4.8‰ respectively, while in shellfishes, the values were slightly lower at -17.3‰ to -12.9‰ and 5.77 to 11.76‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. The $\delta^{13}C$ against $\delta^{15}N$ bi-plots for all the fish and shellfish species analysed are shown in Figure 4-1. Variations of $\delta^{13}C$ and $\delta^{15}N$ with body size were observed for all species and were attributed to differences in diets at different stages of the lifecycle. On the other hand, bottom sediments recorded lower isotope ratios compared to the fish species but where comparable to several groups of the lower shellfish species.

Based on the $\delta^{13}C$ and $\delta^{15}N$ ratios, the fish and shellfish species were grouped into 12 distinct clusters or trophic niches of species groups as visualized "isotopic niche space" diagrams. Further analysis of these clusters produced three representative groups each for the fish and shellfish species in Kagoshima Bay, southern Japan (Figures 4-2 and 4-3).

The results of isotope ratios after acidification of selected fish and shellfish samples for removal inorganic carbon for samples collected during 2009-2011, Kagoshima Bay, southern Japan is shown in Table 4-1. The values of $\delta^{13}C$ and $\delta^{15}N$ in the acid-treated samples and un-acidified samples were significantly different ($p<0.05$). The acid-treated samples recorded higher $\delta^{13}C$ values but lower $\delta^{15}N$ isotope values indicating that inorganic carbon influenced the $\delta^{13}C$ values observed in the samples analysed.

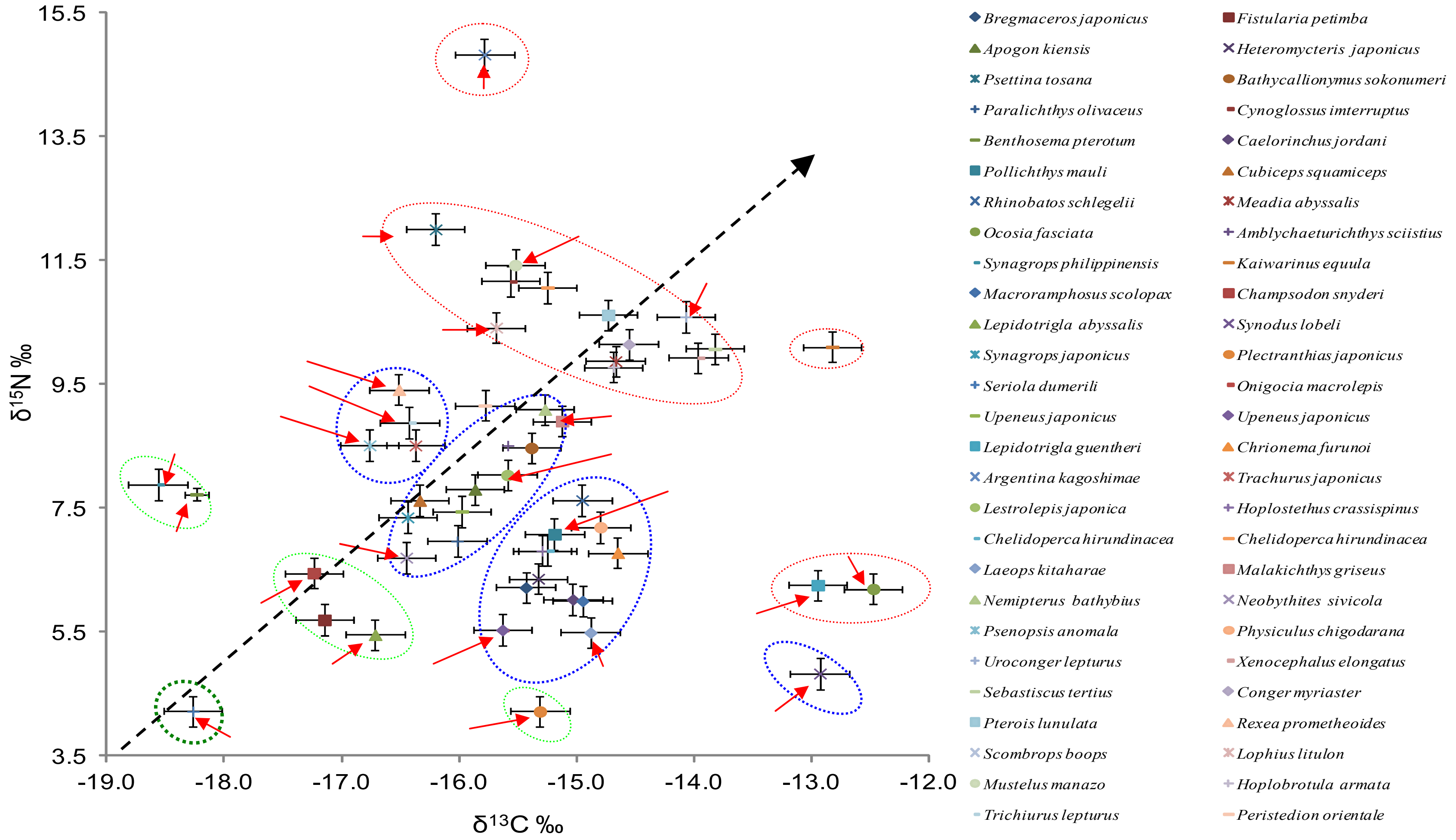

Figure 4-1. Stable carbon and nitrogen isotope ratios (‰, mean ±0.25) of fish and shellfish species in Kagoshima Bay, southern Japan. The dotted-line circles show grouping by "isotopic niche space" while the arrows highlight representative species in the groups. The expected increase in trophic position is by the arrow

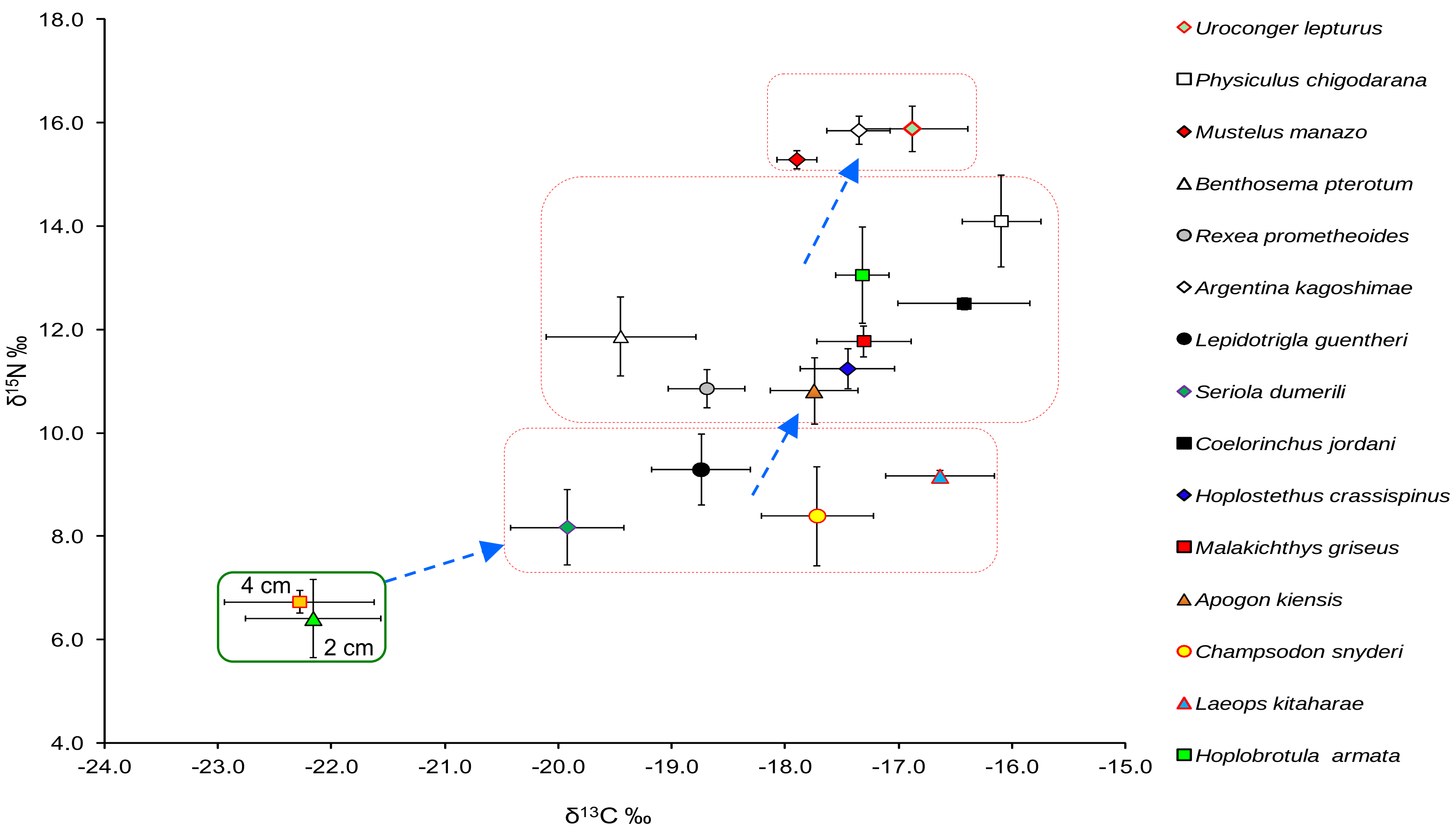

Figure 4-2. Stable carbon and nitrogen isotope ratios (‰, mean ± SD) of bottom sediments (0-2 and 2-4cm depth) and representative fish species in Kagoshima Bay, southern Japan. The boxes represent "isotopic niche spaces": the solid-line indicates lowest niche analysed in this study while the dashed-line boxes indicate higher consumers. The arrows denote expected trajectory of enrichment with increasing trophic position

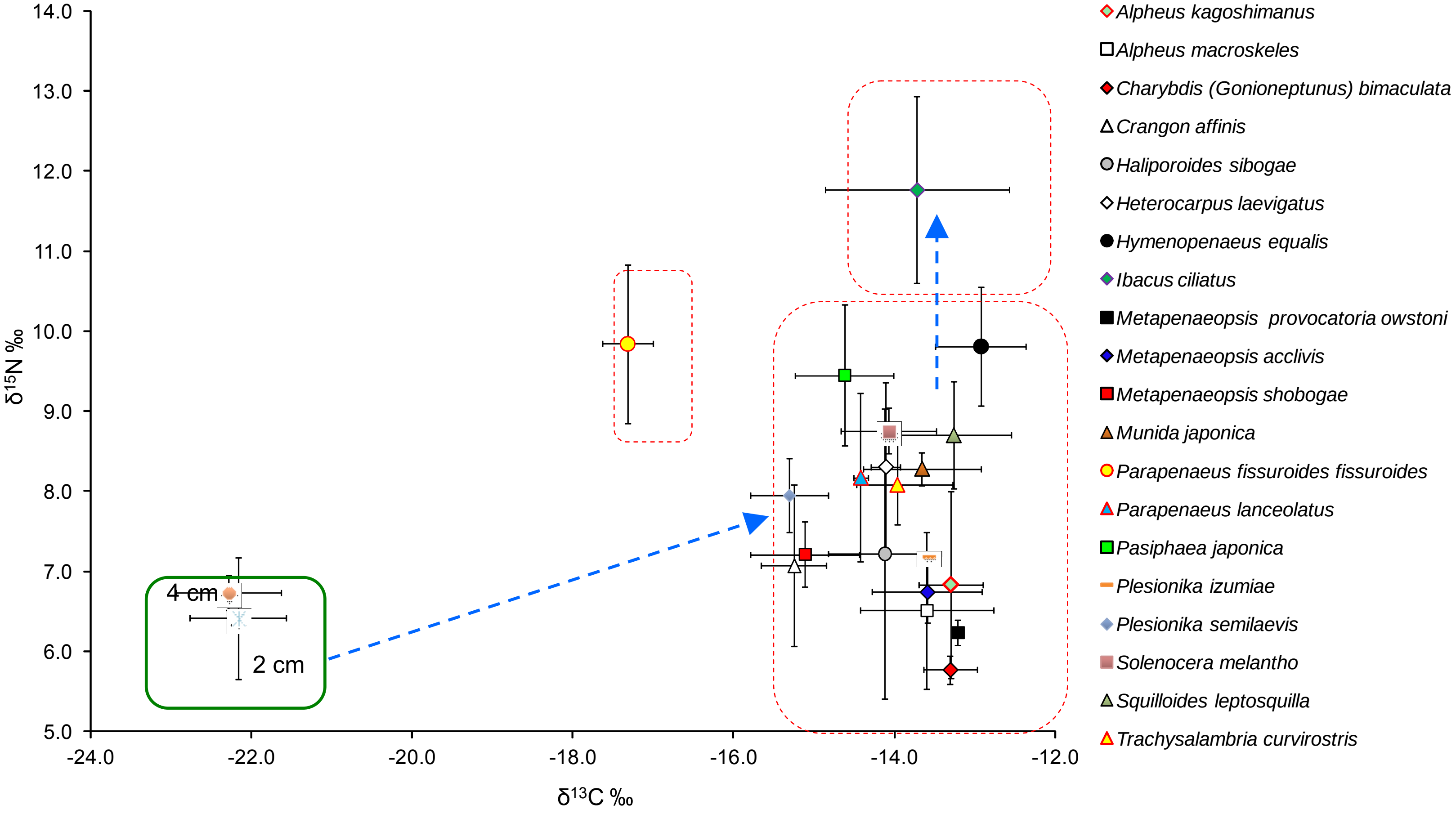

Figure 4-3. Stable carbon and nitrogen isotope ratios (‰, mean ± SD) of bottom sediments (0-2 and 2-4cm depth) and representative shellfish species in the Kagoshima Bay, southern Japan. Boxes represent "isotopic niche spaces": solid-line for lowest level trophic positions in the analysis in this study while dashed-line boxes for indicate higher consumers; the arrows denote expected trajectory of enrichment with increasing trophic position

Table 4-1. Effect of acidification of stable isotope ratios in selected fish species sampled during 2009-2011, Kagoshima Bay, southern Japan

		Acidified		Un-acidified	
Species	Length (mm)	$\delta^{15}N$ ‰ (Mean ± SD)	$\delta^{13}C$ ‰ (Mean ± SD)	$\delta^{15}N$ ‰ (Mean ± SD)	$\delta^{13}C$ ‰ (Mean ± SD)
Uroconger lepturus[a]	[a]231.4	15.9 ± 0.4	-16.9 ± 0.5	10.6 ± 0.7	-14.1 ± 0.9
Physiculus chigodarana[a]	226.8	14.1 ± 0.9	-16.1 ± 0.3	7.2 ± 0.8	-14.8 ± 1.1
Mustelus manazo[a]	383.9	15.3 ± 0.3	-17.9 ± 0.2	11.4 ± 0.6	-15.5 ± 0.9
Benthosema pterotum[a]	49.2	11.9 ± 0.8	-19.5 ± 0.7	7.7 ± 0.5	-18.3 ± 0.7
Rexea prometheoides[a]	304.4	10.9 ± 0.4	-18.7 ± 0.4	9.4 ± 1.4	-16.5 ± 1.2
Argentina kagoshimae[a]	156.6	15.9 ± 0.3	-17.4 ± 0.3	14.8 ± 0.9	-15.8 ± 0.3
Lepidotrigla guentheri[a]	156.1	9.3 ± 0.7	-18.7 ± 0.4	6.3 ± 0.4	-12.9 ± 0.5
Seriola dumerili[a]	143.6	8.2 ± 0.7	-19.9 ± 0.5	5.5 ± 0.3	-18.3 ± 0.6
Coelorinchus jordani[a]	*51.4	12.5 ± 0.1	-16.4 ± 0.6	6.0 ± 0.2	-15.1 ± 0.8
Hoplostethus crassispinus[a]	165.6	11.2 ± 0.4	-17.5 ± 0.4	6.8 ± 0.6	-15.3 ± 0.7
Malakichthys griseus[a]	181.6	11.8 ± 0.3	-17.3 ± 0.2	8.9 ± 0.5	-15.1 ± 0.3
Apogon kiensis[a]	6.0	10.8 ± 0.6	-17.7 ± 0.4	8.0 ± 0.9	-15.9 ± 0.8
Champsodon snyderi[a]	107.8	8.4 ± 0.9	-17.7 ± 0.5	6.5 ± 0.6	-17.3 ± 0.7
Laeops kitaharae[a]	179.7	9.2 ± 0.1	-16.6 ± 0.5	5.5 ± 1.3	-14.9 ± 0.6
Hoplobrotula armata[a]	399.8	13.1 ± 0.9	-17.3 ± 0.3	9.8 ± 0.9	-14.7 ± 0.2

[a] shows significant differences in the $\delta^{13}C$ and $\delta^{15}N$ isotope values between acidified and un-acidified samples ($p<0.05$) for all species.

* standard measurement in *C. jordani* was pre-anal length (PAL, mm).

Table 4-2. Effect of acidification of stable isotope ratios in selected crustacean species sampled during 2009-2011, Kagoshima Bay, southern Japan

		Acidified		Un-acidified	
Species	CL (mm)	δ^{15}N ‰ (Mean±SD)	δ^{13}C ‰ (Mean±SD)	δ^{15}N ‰ (Mean±SD)	δ^{13}C ‰ (Mean±SD)
Alpheus kagoshimanus	11.7	6.8 ± 1.2	-13.3 ± 0.9	6.8 ± 1.2	-13.3 ± 0.4
Alpheus macroskeles	8.8	7.0 ± 0.6	-14.1 ± 0.9	6.5 ± 0.9	-13.6 ± 0.8
*Charybdis (Gonioneptunus) bimaculata**	39.5	6.0 ± 1.2	-13.3 ± 0.3	5.8 ± 2.5	-13.3 ± 0.4
Crangon affinis	29.3	[a]8.5 ± 3.1	-14.8 ± 0.2	[a]7.1 ± 1.1	-15.3 ± 0.4
Haliporoides sibogae	39.5	[a]5.8 ± 2.5	-13.4 ± 0.2	[a]7.2 ± 1.8	-14.1 ± 0.7
Heterocarpus laevigatus	26.4	8.7 ± 0.2	-14.5 ± 0.5	8.3 ± 1.1	-14.1 ± 0.2
Hymenopenaeus equalis	23.7	9.8 ± 1.4	[a]-14.7 ± 0.4	9.8 ± 0.7	[a]-12.9 ± 0.6
Ibacus ciliatus	48.7	11.8 ± 1.2	-13.7 ± 1.1	11.8 ± 1.2	-13.7 ± 1.1
Metapenaeopsis provocatoria owstoni	26.4	5.7 ± 1.2	[a]-14.5 ± 0.4	6.2 ± 0.2	[a]-13.2 ± 0.1
Metapenaeopsis acclivis	36.1	[a]8.8 ± 1.8	-14.1 ± 0.4	[a]6.7 ± 0.4	-13.6 ± 0.7
Metapenaeopsis shobogae	17.6	[a]9.7 ± 0.4	-13.1 ± 0.6	[a]7.2 ± 0.4	-15.1 ± 0.4
Munida japonica	19.2	8.3 ± 0.2	-13.7 ± 0.7	8.3 ± 0.2	-13.7 ± 0.7
Parapenaeus fissuroides fissuroides	12.8	9.1 ± 2.4	[a]-14.1 ± 0.1	9.8 ± 1.0	[a]-17.3 ± 0.3
Parapenaeus lanceolatus	25.8	8.2 ± 1.1	-14.4 ± 0.1	8.2 ± 1.1	-14.4 ± 0.1
Pasiphaea japonica	18.4	[a]7.2 ± 0.4	-15.1 ± 0.4	[a]9.5 ± 0.9	-14.6 ± 0.6
Plesionika izumiae	14.3	7.3 ± 0.4	-13.9 ± 0.5	7.2 ± 0.4	-13.6 ± 0.6
Plesionika semilaevis	48.7	[a]11.8 ± 1.2	[a]-13.7 ± 1.1	[a]7.9 ± 0.5	[a]-15.3 ± 0.5
Solenocera melantho	25.8	8.2 ± 1.1	-14.4 ± 0.1	8.8 ± 0.3	-14.1 ± 0.6
Squilloides leptosquilla	13.9	8.7 ± 0.7	-13.3 ± 0.7	8.7 ± 0.7	-13.3 ± 0.7
Trachysalambria curvirostris	15.5	8.9 ± 0.9	-13.1 ± 0.2	8.1 ± 0.5	-13.9 ± 0.7

[a] Shows significant differences in the δ^{13}C or δ^{15}N isotope values between acidified and un-acidified samples ($p<0.05$) for some species.

* Standard measure for *C.* (*Gonioneptunus*) *bimaculata* was carapace width (CW, mm)

4.1.5 Discussion

This is the first study to elucidate the trophic relationships in fish and shellfish species using stable isotope techniques and trophic analysis. In the present study, only species of the experimental trawl surveys were analysed and hence extensive data on offshore prey and predator species was lacking. Furthermore, primary producers including plankton, benthic and epiphytic algae were not considered in the analysis. However, the available species reveal large isotopic differences which are in accordance to isotopic variations reported in the literature associated coastal or benthic habitats. Moreover, species which forage strictly on the bottom including shrimps and fish species such as *Laeops kitaharae* appeared to have higher $\delta^{13}C$ values than species pelagic predatory species such as *Seriola dumerili* and demersal T_2 predators including *C. snyderi* and *Lepidotrigla guentheri*.

The values of the stable $\delta^{15}N$ signatures of the fish and shellfish species analysed during 2009-2011 from in Kagoshima Bay, southern Japan, are in the 6-16‰ range of published values for most fish and shellfish species (McConnaughey and McRoy, 1979; Fry, 1988). However, it is noteworthy to indicate that the mean stable $\delta^{15}N$ signatures for sediments were higher than would be for primary producers and lower trophic levels, recording similar values to majority of the shellfish analysed in this study. If the sediments contained high amounts of benthic organisms and that the primary content was not plankton sinking from the water column as anticipated, with a diet-tissue fractionation factor of 3 and 4‰, then the likely range in $\delta^{15}N$ signatures for the benthic organisms in sediments appears between 4 to 8‰, similar to the analysed shellfish species in Kagoshima Bay. This implies that shellfish species don't feed solely on the benthic sediment food items but also forage sinking organic material from the water column resulting in relatively equal enrichment between the shellfish and bottom sediments. However, this could be simply an incidental part of relatively unselective feeding behaviour or the presence of trophic level T_2 organisms in bottom sediments leading to higher signatures as noted in this study. It is also likely that bottom sediments would give signatures of sinking organisms and materials including fish eggs, dead molluscs and crustaceans, placing the sediments at a higher trophic level.

The fish and shellfish species were clustered in clear feeding groups based on the isotope signatures. However, outlier species were evident, such *P. fissuroides fissuroides* and *I. ciliatus* which appeared in Trophic level T_2 and T_3 respectively. It is expected that the species are filter feeders slightly above the bottom sediments resulting in slightly higher stable $\delta^{13}C$ signatures than the rest of the shellfish species analysed. It's has been observed "offshore or pelagic" feeding species tend to have more negative $\delta^{13}C$ signatures than the "inshore or benthic" feeding species (Hobson, 1999). Consequently, it is postulated that the spatial distribution of the fish and shellfish species is likely to influence their isotopic signatures depending on the structure of the habitats given the wide variations between the bay head, the central basin, the channel area and bay mouth with *P. fissuroides fissuroides* distribution more to the "offshore" central basin and bay mouth than the coastal channel areas and bay head. Therefore the depleted $\delta^{13}C$ values reported in this study for the two species of shellfish may suggest slightly-above bottom foraging habits compared to the rest of the species while strict bottom feeders including shrimps could explain the relatively elevated $\delta^{13}C$ values recorded in the present study as noted in Figures 4-2 and 4-3. However, the lifecycle and longevity of these species is also likely to affect the stable $\delta^{13}C$ and $\delta^{15}N$ values. The between-species difference in $\delta^{15}N$ are, however, with the expected general differences in feeding preference of the fish and shellfish species analysed in this study. Moreover, differences in preferred food type would greatly influence the $\delta^{13}C$ signatures with species with most enriched muscle tissues being consistent with diets dominated by vegetation such as seagrass (Boon and Bunn, 1994; Jennings et. al., 1997). Due to the expected differences in inter-tissue signatures of $\delta^{13}C$ and $\delta^{15}N$ even within the same species, inter-specific comparisons of dietary intake of consumers through stable isotope analysis should essentially involve, where possible, the same tissues. However, with smaller species such as *B. pterotum*, obtaining the required muscle tissue for analysis may often be difficult due to presence of numerous inter tissue bones. Notwithstanding, the results of this study present an important step in the analysis of the trophic relationships of fish and shellfish in Kagoshima Bay using stable isotope techniques and trophic analysis.

4.2: Modelling of trophic relationships of fish and shellfish in the Kagoshima Bay, southern Japan

4.2.1 Summary

Trophic relationships in the fish and shellfish species in Kagoshima Bay, southern Japan were inferred from analysis of results of the stable carbon and nitrogen isotope ratios in body tissues of fish and shellfish in Kagoshima Bay. The ‰ increase in δ^{15}N and δ^{13}C in the fish and shell fish in Kagoshima Bay were analysed to assess the trophic positions (TP) of the various species in Kagoshima Bay, southern Japan according to Post (2002).

As stated in introduction, the d^{15}N in a consumer increases by 3.4‰ on average relative to prey eaten (Minagawa and Wada, 1984). In this study, the primary producer range was fixed as <3.4‰ with an average of 1.6‰. The primary consumers, including the lower trophic level crustaceans and were in the range of 3.5‰ to 6.0‰ δ^{15}N. The smaller species and bottom dwellers Juveniles of fish were secondary and tertiary consumers, while a large species such as *M. manazo* were at the highest trophic level (13.5‰). Thus, the distributions of δ^{15}N values revealed a food web comprising 4-5 trophic levels in Kagoshima Bay.

Cluster analysis for showed five trophic levels for both fish shellfish: T_1 (<3.3‰), T_2 (3.4‰~), T_3 (6.8‰~), T_4 (10.4‰~), T_5 (13.6‰~). The highest trophic level was represented by three fish species: *U. lepturus*, *A. kagoshimae* and *M. manazo*. Sediment samples registered similar δ^{15}N‰ values as the some shellfish species including *C.* (*Gonioneptunus*) *bimaculata* suggesting higher trophic level benthic organism in the sediments rich in organic carbon originating mainly from sinking zooplankton and dead nekton.

Therefore, the present study confirms that organic sediments in Kagoshima Bay present a lower trophic level T_1 and are an important source of food for the upper trophic level fishes and shellfishes especially the T_2 crustaceans. Future studies should also the importance of the organic and mineral discharges into the bay especially with reference to streams and rivers draining the urban centres, the agricultural farmlands and the Sakurajima area which is rich in volcanic sediments.

4.2.2 Introduction

In both terrestrial and aquatic ecosystems, food webs represent the predator–prey and energy flow relationships in ecosystems (Winemiller, 1996). Consequently, the understanding of the trophic relationships especially in marine species has become a necessary tool in the sustainable management of fisheries in the wider ecosystem concept (Winemiller and Layman 2005, Vander Zanden et. al., 2006).

Traditionally, food web studies have involved relatively simple qualitative analyses including stomach content analysis and simple inferences based on assumed prey-predator relationships both at the species and family levels. However, food and feeding habits of many species are often determined by natural availability and prey size among other factors. Moreover, other factors such as ontogenic shifts in feeding habits and cannibalism within species often add the intricate web of difficulties in elucidating the trophic relationships in aquatic ecosystems. Moreover, the sophistication of ecological questions has progressed beyond simple qualitative descriptions of food webs over recent years and to date, patterns of trophic overlap and resource use (Jepsen and Winemiller, 2002), the impacts of invasive species on food webs of native species (Vander Zanden et. al., 1999), trophic overlap among populations across ecosystems

(Campbell et. al., 2003), and the intricate restricting of food webs due to anthropogenic activities such as ecosystem modification and restoration (Gratton and Denno, 2006) cannot be overlooked. Furthermore, historical trophic relationships over tens to hundreds of years in aquatic ecosystems would be difficult to infer from simple studies of food webs (Perga and Gerdeaux, 2003; Vander Zanden et. al., 2003). Moreover, stable isotope techniques have come in handy in elucidating the trophic relationships and energy flow pathways in marine ecosystems (Fry, 2006). Consequently, these studies confirm the potential value of stable isotopes for studying ecological changes and addressing the growing demands of ecosystem conservation and management.

The use of stable carbon and nitrogen isotopes in ecological studies to trace trophic relationships (Michener and Schell, 1994) assumes that a predator contains heavier isotopes (^{15}N and ^{13}C) than its prey. Therefore, stable isotope values of consumer tissues integrate diet variation over an extended period, offering a powerful tool for characterizing trophic pathways. The mean trophic enrichment in $\delta^{13}C$ and $\delta^{15}N$ is about 0‰ to 1.0‰ and 3.0‰ to 4.0‰, respectively (De Niro and Epstein, 1978, 1981; Post, 2002).

The aim of this study was utilize stable isotopes techniques to infer on the trophic relations of fish and shellfish in Kagoshima Bay and provide data and information for sustainable management of the Kagoshima Bay ecosystem. This study addresses the need for better understanding of the ecosystem by using trophic analysis of stable $\delta^{13}C$ and $\delta^{15}N$ isotopes of fish and shellfish in the bay. The method complements traditional food web analysis to provide a set of statistical tools for quantitative food web and trophic analysis.

4.2.3 Materials and Methods

In this study, the results of the stable isotope analysis were subjected to trophic analysis to model the trophic relations in the fish and shellfish species in Kagoshima Bay based on the

2009-2011 experimental trawl survey. The ‰ increase in stable isotope $\delta^{15}N$ and $\delta^{13}C$ in fish and shell fish in Kagoshima Bay were analysed to assess the trophic positions (TP) of the various species in bay according to Post (2002) using equation:-

$$TP = \lambda + (\delta^{15}N_{consumer} - \delta^{15}N_{base}) / \Delta n \text{ ....Eqn. 4-(iii)}$$

where λ is the TP of the organism used to estimate $\delta^{15}N_{base}$, Δn is the enrichment in ^{15}N per trophic level, and $\delta^{15}N_{consumer}$ is direct measure of $\delta^{15}N$ for target species.

Since no fractionation data for primary producers including phytoplankton and benthic algae for inference as standard species for estimation of a $\delta^{15}N_{base}$ as a representative species with wide distribution, the mean aquatic enrichment of $\delta^{15}N = 3.4$ was used for all trophic estimations (Post, 2002). The stable isotope compositions (‰) were expressed relative to the PeeDee Belemnite standard (Farquhar and Richards, 1984).

4.2.4 Results

Cluster analysis showed five trophic levels for both fish shellfish (with inclusion of a primary producer trophic level (T_1) with $\delta^{15}N$ fixed at below the mean trophic enrichment of 3.4‰, resulting in: T_1 (<3.3‰), T_2 (3.4‰~), T_3 (6.8‰~), T_4 (10.4‰~) and T_5 (13.6‰~). The fish species were grouped into trophic levels T_3, T_4, T_5 while the shellfish fell within T_2 (together with bottom sediments), T_3 and T_4. The highest trophic level was represented by the fish species: *U. lepturus*, *A. kagoshimae* and *M. manazo*. The carbon and nitrogen stable isotopic ratios were all significantly different among the analyzed species.

As stated mentioned earlier, the $\delta^{15}N$ signature in a consumer increases by 3.4‰ on average relative to the prey eaten (Minagawa and Wada, 1984). In this study, the primary producer range was pegged at <3.3‰ with an average of 1.6‰. The primary consumers, including the lower trophic level crustaceans were in the range of 3.5‰ to 6.0‰ $\delta^{15}N$. The smaller species and bottom dwellers and juveniles of larger fish species were categorised as secondary and tertiary consumers, while large sized species predators such as *M. manazo* were categorised at the highest trophic level T_5 with $\delta^{15}N$ signatures of above 13.6‰. Thus, the distributions of $\delta^{15}N$ values revealed a food web comprising 4 to 5 trophic levels in Kagoshima Bay for the fish and shellfish species analysed.

The highest trophic level was represented by three key fish species: *U. lepturus*, *A. kagoshimae* and *M. manazo*. Sediment samples registered similar $\delta^{15}N$‰ values as the some shellfish species including *C.* (*Gonioneptunus*) *bimaculata* suggesting that higher trophic level organisms were likely resident as benthos in the sediments contributing to the richness of the bottom sediments in organic carbon. Therefore, the present study confirms that organic sediments in Kagoshima Bay present a trophic T_1 and are an important source of food for the upper trophic level fishes and shellfishes, and more importantly, for the next trophic level (T_2) crustaceans. Consequently, future studies should investigate the importance of the organic and mineral discharges into the bay especially with reference to streams and rivers draining the urban centres, agricultural farmlands and the Sakurajima area which are rich in volcanic sediments.

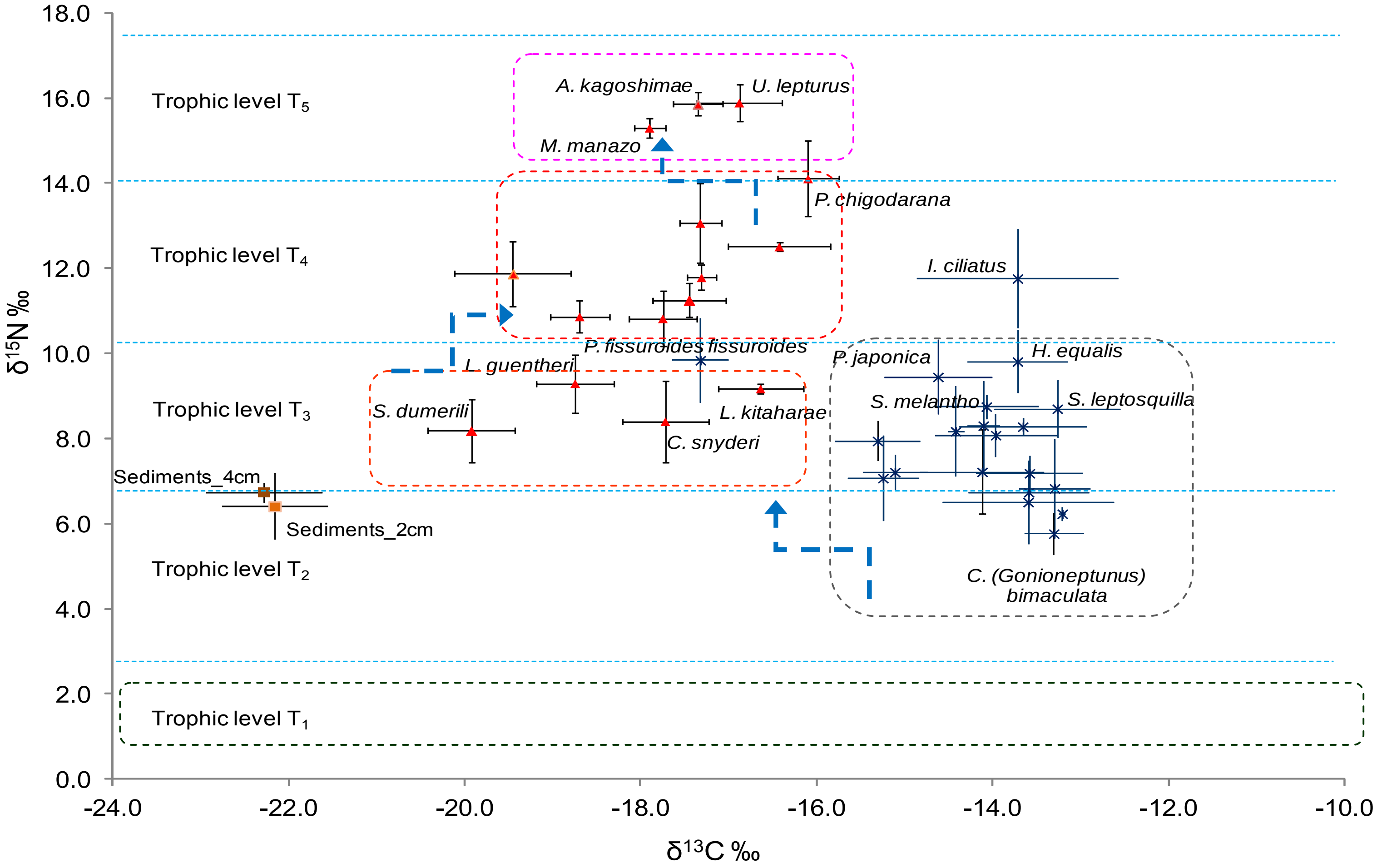

Figure 4-4. Stable isotope food web diagram for the fish and shellfish community in Kagoshima Bay, southern Japan. The symbols show the mean δ^{13}C and δ^{15}N of the representative species for each trophic group. The error bars show the ±SD from the mean. The dotted boxes show feeding guilds while the arrows show the generalized food web for fish and shellfish species in Kagoshima Bay, southern Japan

4.2.5 Discussion

This is the first study to elucidate the trophic relationships in fish and shellfish species using stable isotope techniques and trophic analysis. The results of the present study confirm that stable isotopes are a powerful tool for the study of trophic linkages in coastal and marine systems for inference on the possible food items and tracing of carbon flows (δ^{13}C‰) and trophic positions (δ^{15}N‰) of fish and shellfish in marine ecosystems. Numerous studies have examined and documented the utility of stable carbon isotopic analysis in studies of diet and trophic dynamics (Smith, 1972; DeNiro and Epstein, 1978; Tieszen et. al., 1983; Jackson and Harkness, 1987). The highest feeding species were *A. kagoshimae, U leptiurus* and *M. Manazo* with δ^{15}N‰ signatures averaging 15.0‰ to 16.0‰. Based on the average enrichment for each trophic step (Minagawa and Wada, 1984; Hobson and Welch, 1992), this suggests that these "top predators" in the analysed food web are feeding on average 3 to 4 trophic levels above the primary producers. The present analysis and trophic data generally confirms available dietary information on the analysed species.

The values of the stable δ^{15}N signatures of the fish and shellfish species in Kagoshima are in the range of published values for most of the fish and shellfish species which range from 6‰ to 16‰ (McConnaughey and McRoy, 1979; Fry, 1988; Hobson, 1999). However, it is noteworthy to note that the mean stable δ^{15}N signatures for sediments were higher than would be for primary producers and lower trophic levels, recording similar values to majority of the shellfish analysed in this study. If the sediments contained high amounts of benthic organisms and that the primary content was not plankton sinking from the water column as anticipated, with a diet-tissue fractionation factor of 3‰ to 4‰, then the likely range in δ^{15}N signatures for the benthic organisms in sediments appears between 4‰ to 8‰, similar to the values obtained for the shellfish species in Kagoshima Bay. This indicates that the shellfish species don't feed solely on benthic food items in the sediments but also forage sinking organic material from the water column. This may explain the relatively equal $\delta^{15}N$ enrichment between the shellfish and bottom sediments analysed in Kagoshima Bay. However, these results may also suggest an incidental part of relatively unselective feeding behaviour or the presence of trophic level T_2 organisms in bottom sediments, would explain the relatively high $\delta^{15}N$ signatures in the bottom sediments of the bay as noted in this study. It is also likely that the bottom sediments would give C and N signatures of dead mesopelagic and pelagic species and materials including fish eggs, dead molluscs and crustaceans, placing the sediments at a higher trophic level.

CHAPTER 5: GENERAL DISCUSSION

The computation of effective tow duration using the Compact-TD loggers attached to the trawl net in combination with bottom depth echo-sounder and other onboard instrumentation provides a more precise method for estimation of abundance indices in bottom trawl surveys. The use of preset tow durations results in highly biased estimations of species abundance. Subsequently, use of the estimated abundance indices in defining resource exploitation strategies is likely to augment the poor state of management in many fisheries worldwide. Wallace and West (2006) mainly attributed variation between the preset and effective tow durations to hauling lag, or delays in retrieval of the fishing gear after the trawl winches were engaged, resulting in extended towing time. Systematic variation in trawl catchability with time due to changes in trawl geometry has also been shown to influence average catchability with change in tow duration (Godo et. al., 1990; Walsh, 1991). Other factors such as escapement under the footrope have also been shown to influence catchability, and abundance estimations (Godo et. al., 1990; Walsh, 1991). However, since escapement is a strongly size selective process (Godo et. al., 1990; Walsh, 1991; Somerton and Otto, 1999), future surveys for abundance estimations should incorporate studies on species' length-frequency distribution by tow in order to assess the escapement factor and its influence on the estimation of abundance indices for different species.

The present method derived from monitoring of the performance of the trawl net using depth profiles from the Compact-TD loggers and synchronized with data for echo-sounder bottom depth was evaluated on 304 hauls in Kagoshima Bay, southern Japan. The Compact-TD loggers recorded consistent performance on the simple trawl net used onboard the Nansei Maru ship. Effective tow durations were more accurately computed by calibration of the exact timing of trawl net-sea bottom contact and hauling times, when compared with the conventional method of registering preset tow duration at the ship's bridge using pre-established warp lengths. Therefore, the established method provides for more precise estimation of effective tow duration (and actual fishing time) and can be easily adapted for use in bottom trawl surveys for abundance estimations in different fisheries including deeper-water fishing grounds.

In this study, it was noted that decreases in CPUE and biomass estimations for longer tow durations, suggesting possible saturation of the trawl net by the total haul of all species and probable skipping of the ground rope over the sea bottom, may be factors influencing the catchability and abundance estimations for individual species. Consequently, the bias in estimated abundance indices is likely to be higher for longer tow durations, especially in multispecies fisheries. Future studies using trawl monitoring systems that include bottom contact sensors and trawl catch sonars are needed to establish footrope bottom tending and catch saturation under different preset tow durations. Continuous monitoring of the trawl net mouth opening height and wingspread should also be conducted using dual Compact-TD loggers and trawl sonars, respectively, to establish the behavior of the simple trawl net. Further, additional studies are needed to shed light on the effects of extended tow durations on the mean catch size, size composition and abundance estimations of other species in deeper-water bottom trawl fisheries.

The Kagoshima Bay fishery presents a complex resource calling for specific fishery management strategies. However, there has been a considerable lack of data on stock-size and socio-economic conditions of the fishery. Therefore, the present study presents good estimates on biomass for the demersal fish and shellfish in the bay and the use of calibrated tow durations provided for higher precision in the estimations of the fish and shellfish biomass in the bay.

However, variations due to terrain, catchability predation and other factors should be taken into consideration in future studies in order to increase the precision of the current estimations. The observed annual variations in fish and shellfish biomass calls for reconciliation of experimental trawl surveys with commercial catch analysis in order to explain the observed trends. Noting that the dynamics of top predators in marine ecosystems greatly influences stock dynamics and catches of target species, a holistic approach for assessment of the demersal fish and shellfish in Kagoshima Bay fishery by use of trophic analysis was recommended in order to provide a clearer understanding of the Kagoshima Bay ecosystem. This notwithstanding, the present analysis provided a good base for future stock assessment of Kagoshima Bay, southern Japan.

The fish assemblage was dominated by *Coelorinchus jordani* (24.1%) during 2006-2011 and by six additional species that together accounted for over 56.6% of the total numbers: *Amblychaeturichthys sciistius* (9.4%), *Malakichthys griseus* (8.2%), *Hoplostethus crassispinus* (5.6%), *Champsodon snyderi* (4.4%), *Synagrops philippinensis* (1.8%) and, *Chelidoperca hirundinacea* and *Apogon kiensis* accounting for 1.6% each. Crustacean species assemblages were mainly dominated by fewer species with *Plesionika semilaevis* (66.4%) together with seven other species accounting for 95.5% of the total numbers: *Metapenaeopsis sibogae* (8.0%), *Plesionika izumiae* (6.9%), *Trachysalambria curvirostris* (6.1%), *Crangon affinis* (3.3%), *Solenocera melantho* (3.0%), *Trachysalambria curvirostris* (4.5%), *Charybdis (Gonioneptunus) bimaculata* (1.9%) and. On the other hand, molluscan species were dominated by *Raetellops pulchellus* (33.6%) followed by *Acla divaricata divaricarta* (28.3%) and *Abralia (Heterabralia) andamanica* (14.4) which together with together with four other species accounted for 95.5% of the total numbers: *Euprymna morsei* (8.9%), *Sepia (Platysepia) madokai* (5.4%) and *Sepiolina* *nipponensis* (4.9%). Other notable molluscan species included *Portlandia lischkei* (1.7%), *Sepia* (*Platysepia) esculenta* (0.6%), *Inquisitor flavicula* (0.5%) and *Loligo edulis* (0.4%).

Cluster analysis of the demersal fish and shellfish assemblages in Kagoshima Bay using Ward's (1963) squared Euclidean distance method revealed similarity in Shannon-Wiener *H'* diversity and Pielou's *J'* evenness for the species in the four zones of the bay. Three clusters revealed similarity in fish species diversity and evenness between bay head and channel area (Sts. 1, 2, 3), the bay mouth and coastal strata of the central basin (Sts. 6, 7 and 8) and the central basin inshore strata (Sts. 4 and 5). Similarly, in the analysis of crustacean species diversity and evenness, three clusters were evident: Sts. 4 and 5, Sts. 6 and 8, and Sts. 1, 2, 3 and 7. Molluscan species also showed three cluster within the bay, with the bay head St. 8 isolated from the rest of the strata, where Sts. 1, 2, 4 and 7, and St. 3, 5 and 6 were clustered together. Therefore, species diversity and evenness in Kagoshima Bay shows a high degree of separation between strata and area of the bay: the bay mouth, central basin and, the bay head and channel areas.

In this study, the directional food webs were quantified for the Kagoshima Bay fishery, southern Japan using stable isotope techniques and trophic analysis. Therefore, the use of stable isotope techniques provides a powerful tool for elucidating the trophic relationships in marine fisheries for design of an ecosystem approach to management. Furthermore, there are other possible quantitative approaches for analyzing food web differences based on the stable isotope techniques including overall shapes of the food webs changes over time and space by calculation of polygon dispersion metrics (Layman et al., 2007) also complement the current analysis providing the tools necessary for answering important ecological questions regarding food web change. In conclusion, this study provides an addition to the ecologist's toolbox for understanding the Kagoshima Bay fishery and ecosystem and is crucial in aiding the design of sustainable ecosystem management approaches to fisheries resource utilization. Moreover the versatility of the study approach, from experimental research survey standardization, stock assessment, use of stable isotope techniques in food web analysis and trophic modelling provides a set of powerful tools to the clearer understanding of the Kagoshima Bay fishery. Lastly, the development of quantitative methods stock assessment, stable isotope ecology and trophic analysis will lead to more rigorous research questions with more powerful interpretation of the current and future research results. The analysis presented in this dissertation therefore will provide a foundation for future assessment of the Kagoshima Bay fishery and ecosystem, quantification and hypothetical tests regarding spatial-temporal variations in observed food webs based on time-series analysis of available data and information. Future studies should embark on the use as well as further development of stable isotope related ecology and novel statistical approaches for the assessment of the Kagoshima Bay fishery as well as other fisheries worldwide since they form the livelihoods of many coastal fisher communities and are important in the attainment of the country's food and protein sufficiency.

This is the first study to elucidate the trophic relationships in fish and shellfish species using stable isotope techniques and trophic analysis. The results of the present study confirm that stable isotopes are a powerful tool for the study of trophic linkages in coastal and marine systems for inference on the possible food items and tracing of carbon flows (δ^{13}C‰) and trophic positions (δ^{15}N‰) of fish and shellfish in marine ecosystems. Numerous studies have examined and documented the utility of stable carbon isotopic analysis in studies of diet and trophic dynamics (Smith, 1972; DeNiro and Epstein, 1978; Tieszen et. al., 1983; Jackson and Harkness, 1987). The highest feeding species were *A. kagoshimae, U leptiurus* and *M. Manazo* with δ^{15}N‰ signatures averaging between 15.0‰ and 1.60‰. Based on the 3.4‰ average δ^{15}N enrichment for each trophic step (Minagawa and Wada, 1984; Hobson and Welch, 1992), this suggests that these "top predators" in the analysed food web were feeding on average 3 to 4 trophic levels above the primary producers. This trophic data generally confirms the available dietary information on the analysed species and provides an important basis for future trophic modelling of Kagoshima Bay in endeavours to define ecosystem management of approaches for the bay and fishery.

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