**MARINE REPORTS**
e-ISSN: 2822-5155
Journal homepage: https://scopesscience.com/index.php/marep/

*Received: 04 November 2024; Received in revised form: 11 November 2024*
*Accepted: 27 November 2024; Available online: 28 December 2024*
RESEARCH PAPER

**Citation:** Karga, M. (2024). Management and determination of hazardous occupational health and safety risks in recirculating aquaculture systems (RAS). *Marine Reports*, *3*(2), 167-175. https://doi.org/10.5281/zenodo.14567014

# MANAGEMENT AND DETERMINATION OF HAZARDOUS OCCUPATIONAL HEALTH AND SAFETY RISKS IN RECIRCULATING AQUACULTURE SYSTEMS (RAS)

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## Abstract
Responding to the increasing demand for protein consumption globally, the aquaculture sector continues to grow exponentially every day. Recirculating Aquaculture Systems (RAS) are advanced technology systems that provide sustainable fish farming opportunities by ensuring the efficient use of water resources. In addition, ornamental aquarium fish farming is also intensively carried out in RAS. There is a need for manpower to meet the increasing workload in RAS as well as in offshore aquaculture facilities. However, the working environment in RAS also brings with it various occupational health and safety (OHS) risks. The main hazards affecting occupational safety in these systems can be listed as chemical substance use, biological risks, electrical hazards, physical ergonomic difficulties and psychosocial working conditions. The aim of this study is to determine the OHS risks encountered in the RAS environment in Türkiye, based on 3 different enterprises, and to evaluate solution strategies for these risks and methods for creating a safe working environment. In the study, 3 different RAS were examined (A, B, C) and as a result of our study, it was seen that the risk assessment, emergency planning and employee training criteria were fully met in RAS workplaces where occupational health and safety specialist services were provided. Accordingly, it was determined that risk scores decreased in businesses employing occupational safety specialists. In addition, the total percentage risk score was calculated and it was shown that the total percentage risk score was lower in RAS with occupational safety specialists compared to the others.

**Keywords:** Recirculating aquaculture, occupational health, occupational safety, risk analyzes

## Introduction

Fishing and aquaculture are some of the most important activities that come with the globalizing world and increasing population. Since fish and other aquaculture products are important food sources today, people first turned to fishing and then to controlled aquaculture. In addition, aquarium fish farming, which has become a popular hobby in recent years, has become more controlled and easier to manage in Recirculating Aquaculture Systems (RAS). These systems give the operator greater control over environmental and water quality parameters, thus providing optimum conditions for fish culture (Heinen et al., 1996). The intensification of farming practices (Steinfeld & Wassenaar, 2007) and the steady increase in demand for fish (FAO, 2022) have forced the aquaculture sector to seek practices that are environmentally, socially and economically acceptable. This has resulted in an increase in the application areas of RAS. RAS are currently used in broodstock farming, larvae farming, marketable size farming, health and nutrition research experiments, aquaponics systems and aquarium fish farming. RAS obviously constitute an important part of aquaculture. However, RAS are not simple systems; they are technology-biology interaction systems and require performance monitoring (Soares, 2024). The application of technology to the industry is still in a rapid evolutionary phase for a variety of vertebrate and invertebrate species, both freshwater and marine. RAS technology for livestock farms has many advantages as well as significant challenges (Murray et al., 2014). Occupational Health and Safety (OHS) is basically defined as the science of predicting, identifying, evaluating and controlling hazards that arise in the work environment and may impair the health of employees (Alli, 2008). In many countries of the world and in Türkiye, the issue of OHS has been protected by various legal regulations for many years. In 2012, the Occupational Health and Safety Law No. 6331 came into force, thus, in addition to the Labor Law, the regulations made directly on this issue were collected in a single law. In the case of risk management, a series of strategies are created and implemented to minimize critical risks (Khalilzadeh et al., 2021). The "NACE" code, which stands for "Statistical Classification of Economic Activities" in the European Union, is a six-digit code created by a system that classifies the hazard levels of workplaces according to their activity sectors. For this reason, it is also known as the six-digit activity code. According to this international classification, in Türkiye, according to the Occupational Health and Safety Hazard Classes Communiqué published in the Official Gazette numbered 26.12.2012/28509 and amended in the Official Gazette numbered 27.02.2017/29992, although RAS are not specifically included under the Fisheries and Aquaculture code, the closest business line is the 03.2 code. Its sub-branches are defined as "Low-hazard" and "Hazardous" business lines. NACE codes and hazard classes are shown in Table 1. However, when potential hazards are examined, the risks that can be considered hazardous in closed-circuit aquaculture system applications are high.

The economic impact of occupational accidents and diseases is much greater than is generally known. Spending on OHS reduces both direct and indirect costs while improving performance and productivity. It also increases attendance and improves worker morale. The fisheries and aquaculture sector employs more than 58 million people. Approximately 37% of these are full-time, 23% part-time, and the rest are occasional fishermen or in unspecified status (ILO, 2021). There is no specific law regarding RAS in the sub-regulations of the Occupational Health and Safety Law No. 6331 in Türkiye. In Türkiye, in this OSH law No.6331 and sub-regulations, as in other sectors, in the RAS sub-sector, importance should be given to issues such as OHS, hazards and risks encountered in the workplace, risk assessment, possible accidents and occupational diseases (Resmi Gazete 28339, 2012).

**Table 1.** List of Workplace Hazard Classes for Aquatic Products

| | | |
|---|---|---|
| **03** | **Fishing and aquaculture** | |
| **03.1** | **Fishing** | |
| **03.11** | **Marine fishing** | |
| 03.11.01 | Fishing in sea and coastal waters (including purse seine fishing and fisheries) | Hazardous |
| 03.11.02 | Collection of shellfish (mussels, lobsters, etc.), mollusks, other marine life and products (mother-of-pearl, natural pearls, sponges, corals, seaweed, etc.) | Very Hazardous |
| **03.12** | **Fresh water fishing** | |
| 03.12.01 | Fishing in fresh waters (rivers, lakes) (trout, carp, catfish, etc.) | Hazardous |
| **03.2** | **Aquaculture** | |
| **03.21** | **Marine aquaculture** | |
| 03.21.01 | Fish farming at sea (including sea bream, bream, mullet, etc. farming, fish eggs and fry) | Hazardous |
| 03.21.02 | Other marine aquaculture (mussels, oysters, lobsters, shrimps, arthropods, crustaceans, seaweeds, etc.) (excluding fish) | Hazardous |
| **03.22** | **Freshwater aquaculture** | |
| 03.22.01 | **(Change:RG-31/1/2018-30318)** Freshwater fish farming (including ornamental fish, cultured fish, fish eggs and fry) | Less Hazardous |
| 03.22.02 | Freshwater aquaculture (molluscs, crustaceans, frogs, etc.) (excluding fish) | Hazardous |

Source: Workplace Hazard Classes List
https://www.resmigazete.gov.tr/eskiler/2017/02/20170227M1-1-1.pdf

Despite the qualified workforce and modernization in RAS, OHS practices remain in the background. Since a comprehensive data collection system has not yet been established in Türkiye, the number of workers working in the RAS sector is not fully known. In addition, the number of occupational accidents and occupational diseases cannot be determined. Aquaculture in RAS is one of the most dangerous fields when working conditions are considered. In addition, when risk assessments are made and risks are scored with various methods, the risks scored at the "unacceptable" level are both too many and too diverse. As the variety of techniques and devices used increases, OHS risks also increase and the probability and severity of risks increase. Occupational diseases have also started to emerge along with fatal and non-fatal accidents. The high number of employees increases the importance of OHS practices. Considering the potential hazards and risk factors, one of the most important issues of RAS is the health problems of employees and their working environments. Analyzing risks, using the right equipment, providing training, emergency plans and regular inspections are the basic components of a safe production environment. The main hazards in aquaculture environments are exposure to chemical substances, biological risks, physical hazards from electricity and water, and ergonomic problems (de Oliveira et al., 2017).

This study emphasizes the importance of conducting risk analyses, taking preventive safety measures and providing regular training in order to ensure the safety of employees in RAS systems. In the current study, three different RAS in Türkiye were examined and many predetermined criteria were evaluated according to the "5X5 L Type Matrix" method. In

addition, the differences in RAS work areas with and without OHS experts were revealed with the original percentage calculation method.

## Material and Method

In this study, a total of three RAS operating in Çanakkale 18 Mart University and Kastamonu University in Türkiye were examined and evaluated in terms of OHS. At the workplace, 16 criteria were examined. Risk assessment and emergency plans, personnel training and information, personal protective equipment, work equipment machine use, health and safety symbols, firefighting equipment, first aid equipment, workplace order, floors and waste storage, equipment using license, manual handling works, lightning, electrical hazards, ventilation, chemical and biological hazards.

In the evaluation section, scores were given for each of the 16 criteria on the 5 x 5 L type matrix method for each of them, and the overall evaluation was calculated from 25 points. In order to perform risk analysis, first the hazards were defined. Then the risks were analyzed according to the 5x5 L type matrix method. In order to be analyzed, the probability of the hazard occurring and the severity of the hazard were multiplied numerically (Özkiliç, 2005).

Risk Score = Likelihood X Severity

**Table 2.** 5x5 L Type Risk Decision Matrix

| | **Likelihood** | | | | | |
|---|---|---|---|---|---|---|
| **Severity** | | **1 Remote** | **2 Unlikely** | **3 Possible** | **4 Likely** | **5 Certain** |
| | **1 Trivial** | **1** | **2** | **3** | **4** | **5** |
| | **2 Minor** | **2** | **4** | **6** | **8** | **10** |
| | **3 Lost Time** | **3** | **6** | **9** | **12** | **15** |
| | **4 Major** | **4** | **8** | **12** | **16** | **20** |
| | **5 Fatal** | **5** | **10** | **15** | **20** | **25** |

A score of 1-5 points can be acceptable, a score of 6-12 points should be take precautions shortly, and a score of 15-25 points is considered unacceptable.

In addition, the total percentage risk level is calculated by the original formula according to 5x5 L type matrix.

Total Evaluation;

(Total Risk Score x 4) / total hazard number

The criteria used in the research were selected by inspiration of the causes and frequency of work accidents in the aquaculture sector (Myers & Durborow, 2012).

## Results and Discussions

The aquaculture and its sub-sectors are included in the "Less Hazardous" and "Hazardous" category by code 03.2 when it is observed in the NACE communiqué in the legislation. Due to the potential dangers and risks that it has, it is necessary to provide OHS, which is one of the most important problems in the aquaculture sector. In addition, since closed circuit systems are not included in the legislation, systematic and scientific studies should be done by the government. In our study, 3 RAS were examined in terms of OHS 16 criteria and the results were evaluated. The 5x5 L type matrix method was used in the general evaluation of OHS.

**Table 3.** Risk Analysis and Percentage Differences

| | | RAS | | |
|---|---|---|---|---|
| | **Evaluation Criteria** | **A** | **B** | **C** |
| | Occupational Safety Expert | Y | N | N |
| 1 | Risk Assessment | 5 | 25 | 25 |
| 2 | Emergency Plan | 5 | 25 | 5 |
| 3 | Training of Workers | 3 | 3 | 3 |
| 4 | Personal Protective Equipment | 5 | 5 | 20 |
| 5 | Equipment Using License | 5 | 5 | 5 |
| 6 | Manuel Handling Works | 9 | 9 | 9 |
| 7 | Electrical Hazard | 5 | 25 | 5 |
| 8 | Lighting | 2 | 2 | 2 |
| 9 | Health and Safety Symbols | 10 | 10 | 10 |
| 10 | Fire Extinguishers | 5 | 5 | 5 |
| 11 | First Aid Kit | 5 | 5 | 5 |
| 12 | Floor | 3 | 15 | 3 |
| 13 | Waste Management | 20 | 16 | 16 |
| 14 | Order | 15 | 3 | 9 |
| 15 | Ventilation | 5 | 20 | 15 |
| 16 | Chemical Hazards | 5 | 10 | 10 |
| | Total Evaluation (%) | 26.75 | 45.75 | 36.75 |

It is observed that risk assessment, emergency planning and employee training criteria are fully met in RAS workplaces where OHS expertise services are provided. However, due to the lack of specific OHS legislation for RAS businesses in occupational health and safety laws and regulations and the incomplete implementation of health and safety measures, all risks cannot be reduced to the "Acceptable" level. However, there was a percentage difference in Total Evaluation. While the percentage risk level in enterprise A, which has an occupational safety specialist, was limited to 26.75%, the percentage risk level in enterprises B and C, which do not have an occupational safety specialist, was recorded as 45.75% and 36.75%, respectively. Additionally, differences and improvements are clearly observed in the 5X5 L type matrix.

In the study, care was taken to ensure that the personnel were definitely trained. However, since the training has been completed in all RASs, it has not been possible to analyze how much the training affects the risk analysis. However, it is thought that the training increases the level of awareness and provides more precautions against accidents and injuries (Sabuncu, 2005).

In Türkiye, which is among the fastest growing countries in the world in terms of aquaculture activities, training should be provided to raise awareness of employees in aquaculture companies regarding occupational health and safety. It is thought that companies in the aquaculture sector should conduct on-site risk assessments for their employees and establish a risk management system (Kurtar, 2011). In parallel with this, in our study, risk analysis was performed in RASs where OHS experts were assigned and percentage differences were clearly revealed.

Detailed risk studies in the industry are quite limited and generally focus on case studies involving noise, ergonomic and chemical hazards (Ngajilo and Jeebhay, 2019). In our study, chemical hazards are noted as factors that require precautions when risk analysis is performed. In particular, chemical hazards were highlighted in RASs where risk analysis was not performed. In addition, "Manual Handling Works" is one of the risks that require precautions in all three RAS.

In the research by Minaz (2024), the highest risk scenario for academics working in the aquaculture sector was shown as the lack of an insulation mat in the electrical panel throughout the facility. Electrical hazards are also among the risk factors that should be considered in RAS. In our study, in a RAS without risk analysis, the electrical hazards have the highest risk scores. Another study reported that two out of six deaths in the aquaculture sector in Australia between 2003 and 2013 were due to electric shock (Lower, 2015).

Another study reported that falls were the most frequently reported source of serious injuries in aquaculture net cages and boats (Mitchell & Lystad, 2019). Wet floors constitute an important risk factor in the aquaculture sector, and in our study, the floor issue was shown as a serious hazard in the "B" RAS without a risk analysis.

In a study conducted on Lagoons in Türkiye, attention was drawn to the lack of knowledge of the workers and inadequate maintenance (Köken et al., 2019). When the equipment-related sections in the risk analysis are examined in our study, there is a significant difference only in the "Ventilation" section. It is thought that this is due to the correct inspection in the business with an Occupational Safety expert.

One of the most effective ways to prevent work accidents and occupational diseases is to use personal protective equipment (PPE). While it is the employer's responsibility to provide PPE to employees, correct use to provide protection is related to the individual's safety culture (Aydoğan, 2020). In our study, it was determined that PPE was not used in the "C" RAS in the risk analysis and this posed a serious risk.

In the occupational health and safety study conducted in trout farming facilities, culture tanks and feed warehouses with higher risk score averages and risk numbers compared to other groups were identified as potentially hazardous processes (Minaz et al., 2021). The use of culture tanks in RAS is very common and most of the general hazards are associated with it. On the other hand, in our study, the risks in the "Order" section were found to be higher in businesses where occupational health and safety measures were taken, while they were lower in businesses where

occupational health and safety measures were not taken. This shows that it is not possible to completely control the risks in RAS in Türkiye without making a comprehensive OHS legislation on RAS or adding a specific sub-regulation to Law No. 6331. There is not enough information about the causes of occupational injuries and deaths in the aquaculture sector in Türkiye (Soykan, 2023), which indicates the need for comprehensive studies. The results of very limited aquaculture OHS research to date and a detailed description of the various phases of the industry suggest there are multiple, potentially serious occupational hazards associated with the industry (Moreau & Neis, 2009).

In order to reduce work accidents and occupational diseases and to provide employees with a safer and healthier work environment, employers and employees must first be clearly informed about occupational health and safety issues and employers must fulfill their obligations in this regard. A dynamic and flexible system focused on ensuring human health and safety, preventing loss of life and property, and reducing risks in this regard must be established in businesses. In addition, businesses must be inspected at certain intervals by responsible state institutions (Tatar et al., 2019). When we look at the entirety of our study, we think that risk analysis alone is not fully sufficient and that state institutions need to conduct comprehensive work. There is no comprehensive study for RAS. The results of our study revealed the differences between RAS enterprises that employ OHS experts and those that do not.

## Conclusion

It is clear that developing and implementing a planned OHS system, especially by countries that have signed agreements with the International Labour Organization (ILO), can prevent work accidents and reduce the loss of life and property by contributing to both the workplace and the national economy. The well-being, trust and commitment of workers, especially in hazardous jobs such as aquaculture, are considered the cornerstone of production, business success and environmental safety. OSH laws, which are updated regularly and at certain intervals, should be specific to each sector and especially to jobs with specific working conditions such as RAS. However, it is clear that worker health and safety, the environment and production safety can be best protected with specific laws. In order to increase efficiency in economic terms, it is inevitable that there are specific sub-regulations and inspections, especially in sectors such as RAS. This was clearly observed as a result of our study. Our study will shed light on future studies that will detail the risks.

## Acknowledgements

Thanks to Çanakkale 18 Mart University, Faculty of Fisheries and Kastamonu University, Faculty of Fisheries for the Recirculating Aquaculture Systems observed during the investigation phase of the study. This study was presented in abstract from as an oral presentation to the International Congress on Engineering and Life Science "ICELIS 2018", Kastamonu, Türkiye, 26-29 April 2018.

## Ethical approval

No ethical approval needed for this study since no living organisms were used.

## Informed consent

Not available

## Data availability statement

The author declares that data can be provided by corresponding author upon reasonable request.

**Conflicts of interest**
There is no conflict of interests for publishing this study.

**Funding organizations**
No funding available for this study.

**Contribution of authors**
Mustafa KARGA: conceptualization, data curation, formal analysis, writing the original draft, investigation, methodology, resources, validation, visualization, and finalizing

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