

# Contents

|          |   |    |
|----------|---|----|
| <b>1</b> | <b>Introduction</b> .....   | 1  |
| 1.1      | Background.....   | 1  |
| 1.2      | Background Literature.....  | 2  |
| 1.3      | Terminology.....  | 3  |
| <b>2</b> | <b>Aquatic Organisms of Concern</b> .....   | 5  |
| 2.1      | Fishes.....   | 5  |
| 2.2      | Sea Turtles.....  | 6  |
| 2.3      | Eggs and larvae.....  | 6  |
| <b>3</b> | <b>Hearing – A General Overview</b> .....   | 7  |
| 3.1      | Fish Hearing: Sensitivity to Sound.....   | 7  |
| 3.2      | Lateral Line System.....  | 10 |
| 3.3      | Turtle Hearing.....   | 11 |
| 3.4      | Masking.....  | 12 |
| 3.5      | Auditory Scene Analysis.....  | 13 |
| 3.6      | Directional Hearing.....  | 13 |
| <b>4</b> | <b>Classification of Fishes and Sea Turtles with Respect to Sound Exposure Risk</b> ..... | 15 |
| 4.1      | Fishes.....   | 15 |
| 4.2      | Sea Turtles.....  | 16 |
| 4.3      | Larval Fish.....  | 16 |
| 4.4      | Categories.....   | 16 |
| <b>5</b> | <b>Effects of Sound Exposure</b> .....  | 17 |
| 5.1      | Death and Injury.....   | 17 |
| 5.2      | Effects on Hearing.....   | 18 |
| 5.3      | Effects on Behavior.....  | 19 |
| 5.4      | Population-Level Effects on Fitness and Survival.....                                     | 20 |

- 6 The Nature of Man-Made Sound**..... 23
  - 6.1 Metrics ..... 24
    - 6.1.1 Sound Pressure..... 24
    - 6.1.2 Particle Motion..... 24
    - 6.1.3 Peak Levels ..... 25
    - 6.1.4 Sound Intensity ..... 25
    - 6.1.5 Impulse..... 26
    - 6.1.6 Sound Exposure Level ..... 26
    - 6.1.7 Cumulative Energy (Cumulative Sound Exposure Level) ..... 26
    - 6.1.8 Frequency Weighting ..... 27
  - 6.2 Sources..... 28
    - 6.2.1 Explosions..... 28
    - 6.2.2 Seismic Airguns ..... 29
    - 6.2.3 Pile Driving ..... 30
    - 6.2.4 Active Sonar..... 31
    - 6.2.5 Continuous Sound Sources ..... 31
- 7 Sound Exposure Guidelines** ..... 33
  - 7.1 Current Guidelines for Injury..... 33
  - 7.2 Current Guidelines for Behavior..... 35
  - 7.3 Practical Approach to Recommending Sound Exposure Guidelines ..... 36
  - 7.4 Explanation of the Analyses ..... 37
  - 7.5 Guidelines ..... 37
    - 7.5.1 Source: Explosions..... 37
    - 7.5.2 Source: Pile Driving..... 41
    - 7.5.3 Source: Seismic Airguns..... 44
    - 7.5.4 Source: Low- and Mid-Frequency Naval Sonar ..... 47
    - 7.5.5 Source: Shipping and Other Continuous Noises..... 49
- 8 Research Recommendations** ..... 53
  - 8.1 General Comments..... 53
    - 8.1.1 The Importance of Providing an Appropriate Acoustic Environment for Experiments..... 53
    - 8.1.2 The Difficulties in Examining Behavior ..... 54
    - 8.1.3 The Diversity of Fishes and Sea Turtles ..... 55
  - 8.2 Research Requirements of Highest Priority..... 55
    - 8.2.1 Fishes ..... 55
    - 8.2.2 Eggs and Larvae..... 57
    - 8.2.3 Sea Turtles..... 57
- 9 Summary and Conclusions**..... 59
- References**..... 61

ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI

Popper, A.N.; Hawkins, A.D.; Fay, R.R.; Mann, D.; Bartol, S.; Carlson, Th.; Coombs, S.; Ellison, W.T.; Gentry, R.; Halvorsen, M.B.; Lokkeborg, S.; Rogers, P.; Southall, B.L.; Zeddes, D.G.; Tavolga, W.N.

2014, XVI, 76 p. 64 illus., 53 illus. in color., Softcover  
ISBN: 978-3-319-06658-5