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Review

History of the International Organization for Biological Control Global Working Group on Mass Rearing and Quality Assurance

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Abstract

The International Organization for Biological Control Global Working Group on Mass Rearing and Quality Assurance (MRQA) was established in 1980 as the Working Group on Quality Control (WGQC) to assure success of insect mass rearing for pest management that was being developed in the 1950s and 1960s. Due mostly to the efforts of WGQC, quality control became institutionalized in several insect mass rearing facilities during the 1980s. After addressing autocidal control programs, the WGQC concentrated on entomophagous insects, especially testing the quality of commercial biological control products. Universal Implementation of Quality Control for Mass-Reared Arthropods was finally achieved in the 1990s, having encompassed all aspects from insect production to field application and evaluation. This increased scope prompted a name change from WGQC to Arthropod Mass Rearing and Quality Control (AMRQC). Subsequently, the scope of the Working Group was expanded again and it was renamed MRQA to include a range of applications for mass-reared beneficial invertebrates. The geographic range of MRQA recently was extended beyond North and South America and Europe to include India. This expansion continued as insects for food and feed, networking and instruction, and legal and ethical issues were added to the most recent workshop held in Mexico. Thus, the MRQA continues to evolve as additional invertebrate organisms are mass produced for both established and novel applications.

Keywords: arthropod, rearing, quality, workshops

The impetus for assuring the quality of mass-reared insects was the need to provide a consistent supply of insects suitable for developing and implementing new pest management technologies (Knipling 1959). Initially, the greatest need for quality control in insect mass production was to enable the sterile insect technique (SIT) for area-wide management of the screwworm, *Cochliomyia hominivorax* (Coquerel), and tephritid fruit flies, such as the Mediterranean fruit fly, *Ceratitis capitata* (Wied.). The screwworm SIT program had been operational since the 1950s (Klassen and Curtis 2005) but periodically failed due to the production and release of poor-quality flies (Baumhover et al. 1966, Bushland 1975, Bush et al. 1976). Mass-produced sterile male tropical fruit flies also were not always competitive relative to wild males in mating with wild females. Major investments were being made to build and operate mass rearing facilities without a means of assuring that the screwworm flies and medflies would be effective. Causes proffered for the ineffectiveness of mass-produced flies included inadequate mass rearing methods that resulted in fewer and smaller flies, associated reductions in dispersal and mating competitiveness, and undefined 'genetic deterioration'. It became apparent that the laboratory colonies differed from wild populations as the insects adapted to the laboratory environments. Consequently, quality control methods were needed to collect appropriate biotypes, minimize genetic changes during colonization, improve mass production processes, and assure that the insects mass-produced for pest management could perform their intended functions (Dame 1968; Boller and Chambers 1977a,b; Chambers 1977).

Pioneering research and associated technological development that depended on mass-reared insects included not only SIT but also screening compounds to discover new insecticides and repellents, producing hosts for biological control agents, extraction and identification of insect pheromones, and infesting plants to breed pest resistant cultivars (Schneider 2009). In addition to screwworm flies and medflies, several more tephritid fruit fly species; the gypsy moth, *Lymantria dispar* (L.); pink bollworm, *Pectinophora gossypiella* Saunders; boll weevil, *Anthonomus grandis* Boheman; codling moth, *Cydia pomonella* (L.); some mosquitoes; and a few other pests targeted for SIT were mass-produced. Additionally, *Trichogramma* spp. were mass-produced for managing certain lepidopteran pests and a nascent biological control industry was being created. Since

mass production of insects was becoming an industrial process, quality control concepts were adapted from established manufacturing systems (Leppla et al. 1977). This approach and numerous advancements, such as quality control methods and tests, enabled pest management technologies dependent on a continuous supply of high-quality insects to be implemented. The purpose of this paper is to describe how quality control was developed within the context of insect mass production for pest management and document the history of the International Organization for Biological Control (IOBC) Global Working Group on Mass Rearing and Quality Assurance (MRQA), formatively the Working Group on Quality Control (WGQC), and then the Arthropod Mass Rearing and Quality Control Working Group (AMRQC). IOBC is a voluntary organization that promotes environmentally safe methods of pest and disease control. MRQA is one of the seven IOBC Global Working Groups (www.iobc-global.org).

1950–1968 Insect Mass Rearing for Pest Management and Initial Quality Control

One of the earliest efforts to address insect mass rearing and quality control took place in 1963 at Excelsior Springs, Missouri, when Edward Knipling assembled 124 USDA, Agricultural Research Service (ARS) scientists from across the United States, who were conducting pioneering research on insect nutrition and rearing, advising them that 'The ability to colonize insects successfully in the laboratory is one of the most vital requisites to progress in many phases of entomological research' (USDA, ARS 1963) (Table 1). Beginning in 1963, the International Atomic Energy Agency (IAEA) published proceedings of a series of panels that included papers on the quality of mass-reared insects (Lindquist 1963; LaBrecque and Keller 1965; Beck and Chippendale 1968; Gast 1968; Dame 1968; IAEA 1963, 1968a,b, 1969; Economopoulos 1987). Some of the scientists who contributed to these proceedings also published papers in 'Insect Colonization and Mass Production', the first book to emphasize large-scale insect production needed for developing new pest management technologies (Smith 1966). Chapters were written by 57 authors, including some from the USDA, ARS workshop in 1963, and others from the USDA, U.S. universities, foreign institutions, and the private sector. Their chapters were divided into the following sections: Animal Parasites and Haematophagous Arthropods; Domestic and Stored Product Insects; Phytophagous Insects and Mites; Insect Parasites, Predators, and Pathogens; and Insects by the Million (screwworm, tephritid fruit flies, and yellow fever mosquitoes). The need for 'plentiful supplies' of insects of 'standard quality' was emphasized by the editor, Carroll Smith. In 1966, Edward Knipling chaired a meeting sponsored by the American Association for the Advancement of Science in Montreal, Canada, 'Pest Control by Chemical, Biological, Genetic and Physical Means' (Knipling 1966).

1969–1975 Creating Quality Control for Mass-Produced Arthropods

The mass production of insects for specific purposes created a requirement for insect quality to meet established standards; quantity alone was no longer acceptable. Techniques for measuring the competitiveness of sterile male tropical fruit flies were discussed by a panel on 'Sterile-Male Technique for Control of Fruit Flies' assembled by IAEA in Vienna, Austria (Chambers et al. 1970, IAEA 1970). Soon thereafter, formative papers on the behavior and genetics of mass-reared insects were presented at the 1971 IOBC symposium in Rome 'Implications of Permanent Insect Production' by Ernst Boller (1972) on phytophagous insects and Manfred Mackauer (1972) on parasitoids and predators. Both papers considered how to manage genetic changes that occur in colonized insects and provided a foundation for the second USDA, ARS national scientific assembly, 'Workshop on the Genetics of Insect Behavior'. The workshop was convened at Gainesville, Florida, in September 1974 with the premise that 'The use of mass-reared sterile or genetically altered insect pests for the management of populations of their own species and the use of programmed releases of predators and parasites are highly desirable approaches to managing pest populations'. Participants identified many deficiencies in current colonization techniques and recommended improvements to produce high-quality insects (FRASS 1978 #1). The International Arthropod Rearing Group (IARG) was established to advance the 'reliable and low-cost production and use of high-quality insects and other arthropods'. The group eventually produced and distributed 19 issues of the Insect Rearing Newsletter, FRASS (1975–1996) to about 500 members from institutions throughout the world. In 1975, Derrell Chambers described principles and techniques used to study insect behavioral performance and quality at the workshop, 'Controlling Fruit Flies by the Sterile Insect Technique' held in Vienna, Austria (Chambers 1975).

1976–1979 Principles and Practices of Quality Control for Mass-Reared Arthropods

The XV International Congress of Entomology was held in Washington, DC, at the beginning of this period in the development of arthropod mass rearing and quality control. A symposium, 'Characterization and Evaluation of Insect Colonies', was moderated by Norman Leppla and, in a symposium on natural enemies, Manfred Mackauer and Ernst Boller, respectively, delivered papers on genetic aspects and quality considerations in insect mass rearing (Boller 1986). According to Ernst Boller and Derrell Chambers, the 'time had come to compile the many bits and pieces of information about quality control concepts' to assure that fruit flies and other mass-reared insects are 'adequate for their intended purposes'. Under their leadership, brief submissions were solicited from 52 scientists working with tephritid fruit flies and published as 'Quality Control, An Idea Book for Fruit Fly Workers' that contains the following sections: 'Concepts and Approaches', 'Measuring Overall Performance', 'Measuring Individual Performance Traits', 'Monitoring Production', and 'Implementation of Quality Control' (Boller and Chambers 1977a). This timely and unifying work became the foundation for the now well-established subject of quality control in arthropod mass production. Among several important contributions of the book, quality control concepts and practices were adapted from industry for arthropod mass rearing (Juran et al. 1979, Feigenbaum 1983, Deming 1982, Burt 2002). During the next few years, members of the IOBC Working Group on Fruit Flies of Economic Importance and cooperators conducted research and training projects to implement quality control in tephritid fruit fly SIT programs. A RAPID quality control system was developed and tested for the Mediterranean fruit fly (Boller et al. 1981, Chambers et al. 1983) and subsequently evaluated at an international workshop and training course conducted by Ernst Boller and Derrell Chambers at Castellon de la Plana, Spain, in 1979 (Calkins et al. 1979). Significant publications during this period addressed monitoring the quality of laboratory-reared insects (Huettel 1976) and the potential for genetic improvement of predators (Mackauer 1976, Hoy 1979).

Table 1. Periods of development and major advancements in quality control for arthropod mass rearing

1950–1969
Insect Mass Rearing for Pest Management and Initial Quality Control
1959: 'Sterile-male method of population control' (Knipling 1959)
1963: 'USDA, ARS National Conference on Insect Nutrition and Rearing'. Excelsior Springs, Missouri
1963: International Atomic Energy Agency (IAEA) panel proceedings (continuing)
1966: 'Insect Colonization and Mass Production' (Smith 1966)
1969–1975
Creating Quality Control for Mass-Produced Arthropods
1969: IAEA panel, 'Sterile-Male Technique for Control of Fruit Flies'. Vienna, Austria
1970: 'Recent research in Hawaii on the Mediterranean fruit fly' (Chambers et al. 1970)
1971: IOBC symposium, 'Implications of Permanent Insect Production'. Rome, Italy
1972: 'Behavioral aspects of mass-rearing of insects' (Boller 1972)
1972: 'Genetic aspects of insect production' (Mackauer 1972)
1974: USDA, ARS 'Workshop on the Genetics of Insect Behavior'. Gainesville, Florida
1974: International Arthropod Rearing Group (IARG) and FRASS Newsletter
1975: IAEA panel, 'Controlling Fruit Flies by the Sterile Insect Technique'. Vienna, Austria
1975: 'Quality in mass-produced insects: definition and evaluation' (Chambers 1975)
1976–1979
Principles and Practices of Quality Control for Mass-Reared Arthropods
1976: XV International Congress of Entomology. Washington, DC
1977: 'Quality Control, An Idea Book for Fruit Fly Workers' (Boller and Chambers 1977)
1977: Industrial quality control practices for arthropod mass rearing (Leppla et al. 1977)
1079: RAPID quality control system (Boller et al. 1981, Chambers et al. 1983)
1979: IOBC training course on fruit fly quality control. Castellon, Spain
1980–1986
Institutionalizing Quality Control in Insect Mass Rearing Facilities
1980: USDA workshop, 'Advances and Challenges in Insect Rearing'. Atlanta, Georgia (King and Leppla 1984)
1980: IOBC WGQC established (Boller 1986)
1982: WGQC workshop #1. Gainesville, Florida
1983: Quality control manual for Mediterranean fruit fly (Orozco et al. 1983, followed by other manuals)
1984: WGQC workshop #2. Wadenswil, Switzerland
1986: WGQC workshop #3. Guatemala City, Guatemala
1987–1992
Science and Applications of Quality Control for Mass-Reared Arthropods
1988: WGQC workshop #4. Vancouver, Canada
1989: 'Quality assessment and control in entomophagous insects used for biological control' (Bigler 1989)
1989: 'Total quality control in insect mass production' (Leppla and Fisher 1989)
1990: Association of Natural Biocontrol Producers founded. California
1990: USDA, APHIS National Biological Control Institute founded. Hyattsville, Maryland
1991: WGQC #5. Wageningen, Netherlands (European biological control companies)
1992: WGQC #6. Horsholm, Denmark (quality control for commercial biological control)
1992: 'Guidelines for product control of natural enemies' (van Lenteren and Bigler 1992)
1992: 'Advances in Insect Rearing for Research and Pest Management' (Anderson and Leppla 1992)
1993–1998
Universal Implementation of Quality Control for Mass-Reared Arthropods
1993: WGQC #7. Rimini, Italy
1995: International Biocontrol Manufacturers' Association founded. Brighton, England
1995: WGQC #8. Santa Barbara, California
1995: ANBP Product Profiles for suppliers and end-users
1995: IBMA Invertebrate Biocontrol Agents (IBCA) Professional Group established.
1996: 'Code of Conduct for the Import and Release of Exotic Biological Control Agents' (FAO 1996)
1996: 'Technology Transfer in Biological Control: From Research to Practice'. Montpellier, France
1997: 'Product Quality Control for Sterile Mass-Reared and Released Tephritid Fruit Flies' (FAO/IAEA/USDA 2014)
1998: WGQC #9. Cali, Colombia
1999–2010
Protocols for Mass Rearing and Quality Control
2003: AMRQC #10. Montpellier, France
2003: 'Quality Control and Production of Biological Control Agents' (van Lenteren 2003)
2007: AMRQC #11. Montreal, Canada
2009: 'Principles and Procedures for Rearing High Quality Insects' (Schneider et al. 2009)
2010: AMRQC #12. Vienna, Austria

Table 1. *Continued*

2011–2018 **Increased Scope of Mass Rearing and Quality Control**
2013: MRQA #13. Bangalore, India 2014: 'Grower Guide: Quality Assurance of Biological Products' (Buitenhuis 2014) 2017: MRQA #14. Merida, Mexico 2021: MRQA #15. Bologna, Italy (planned)

1980–1986 Institutionalizing Quality Control in Insect Mass Rearing Facilities

The workshop, 'Advances and Challenges in Insect Rearing' was held in 1980 at Atlanta, Georgia, primarily for about 50 USDA, ARS scientists to address the topics: 'Establishment and Maintenance of Insect Colonies Through Genetic Control'; 'Diets and Containerization for Insect Rearing'; 'Engineering for Insect Rearing'; 'Control of Pathogens and Microbial Contaminants in Insect Rearing'; 'Production, Use, and Quality Testing in Insect Rearing'; and 'Management of Insect Rearing Systems' (King and Leppla 1984). A considerable number of quality control principles and practices developed for mass rearing fruit flies were adapted for use with a variety of other taxa, eventually establishing quality control as an accepted practice in the mass production of arthropods for autocidal and biological control (Neuenschwander et al. 1989). Nevertheless, more research and development were needed to design and implement effective quality control programs (Chambers et al. 1983, Chambers and Ashley 1984, Moore et al. 1985). This need prompted Ernst Boller and Derrell Chambers to propose the IOBC Global Working Group on Quality Control of Mass-Reared Arthropods (WGQC) that was established officially on 13 October 1980, based on their proposal submitted to the Global Council of the IOBC (Boller 1986). This historic event was an outcome of several attempts to advance and coordinate quality control in insect rearing to support dependent pest management technology being developed by the IAEA and the USDA, ARS. The IOBC WGQC was created to institutionalize quality control in insect mass production systems with the official mission to conduct 'international biannual workshops on quality control, where scientists, plant managers and administrators involved in mass-rearing operations could meet, exchange information and develop standardized technologies and concepts in quality control' (Boller 2002). The WGQC workshops became the primary forums for determining the status of quality control for mass-produced arthropods and recommending actions to assure their usefulness in pest management. For almost 40 yr, these workshops have facilitated the generation and exchange of knowledge among researchers, producers, and users of sterile insects and natural enemies (Table 2).

The WGQC workshop series began in 1982 at Gainesville, Florida, and the first attracted worldwide participation by >100 scientists who attended sessions not only on the quality of mass-produced tephritid fruit flies but also flies of medical and veterinary importance, such as the screwworm, and mass-reared Lepidoptera. A special postworkshop excursion to southern Mexico familiarized the scientists with the screwworm mass rearing facility at Tuxtla Gutierrez, Mexico, and the Mediterranean fruit fly facility at Metapa, Mexico. At the time, these were the largest insect rearing facilities in the world and neither had a formal quality control program, although the general need had become apparent (Itô and Koyama 1982). The second workshop at Wadenswil, Switzerland, in 1984 provided a forum for exchanging information on quality control research, added some new members to the WGQC, and encouraged by Manfred Mackauer expanded the scope of the working group to include natural enemies. In 1986, the third workshop was conducted at Guatemala City, Guatemala, in proximity to the Mediterranean fruit fly mass rearing facility under development at nearby San Miguel Petapa (Tween 2002). A quality control manual was written for use in producing medflies at 'Petapa' (Orozco et al. 1983) and protocols followed for other facilities (Calkins et al. 1982, Brazzel et al. 1986, Minno and Holler 1987, Calkins 1989, Bruzzone et al. 1993, Calkins et al. 1996, Anonymous 1997, Caceres et al. 2007, Enkerlin 2007, Sagarpa-Senasica 2013, Zavala-López and Enkerlin 2017). Rather than continuing the past structure based on taxonomic group, this third workshop was organized around the following topics: 'Insect Colonization and Strain Development' (Bartlett 1985); 'Colony Maintenance'; 'Quality Control of Production and Products' (laboratory bioassays); 'Irradiation, Shipment and Distribution'; 'Field Assessment'; and 'Management of Quality Control Systems' (Leppla 2002). An interesting debate ensued over locating the quality control function within or outside of production, as an internal assessment or a means of independently monitoring rearing processes and products. Subsequently, in mass rearing facilities, so called 'biofactories', the quality control function has been located outside of production, as it is in other industries. Another concern was the benefit: cost of adding quality control units to the facilities. The history of quality control in mass-reared insects and the WGQC through this period was described by Ernst Boller (1986), quality control in insect mass production was reviewed by Leppla and Ashley (1989), and Milton Huettel (1986) produced a relevant book on the genetics of insect behavior.

1987–1992 Science and Applications of Quality Control for Mass-Reared Arthropods

The WGQC workshops were structured more formally and proceedings were published beginning with the fourth workshop held in 1988 at Vancouver, Canada, in conjunction with the XVIII International Congress of Entomology (Bigler 1988). The proceedings contains seven papers published as volume 108 of the Journal of Applied Entomology in 1989. This was the first workshop to combine scientists who helped to develop quality control for pestiferous insects (Dame 1989) with others who were applying the concepts and methods to entomophagous insects. Franz Bigler's foundational paper, 'Quality assessment and control in entomophagous insects used for biological control', documented the development and current state of quality control for both inoculative and inundative release of natural enemies (Bigler 1989). Another fundamental paper adapted total quality control from industrial processes and defined the components of insect mass rearing systems (Leppla and Fisher 1989). This information was disseminated by two organizations influential in the development of quality control for mass-reared arthropods in North America: the Association of Natural Biocontrol Producers (ANBP) and the USDA, Animal and Plant Health Inspection Service, National Biological Control Institute (NBCI), both founded in

Table 2. Workshops of the International Organization for Biological Control Global Working Group on MRQA, formerly WGQC and AMRQC

No.	Year	Location	Workshop Chairs[1]	Proceedings[2]
1	1982	Gainesville, Florida	E. F. Boller and D. L. Chambers	No[3]
2	1984	Wadenswil Switzerland	E. F. Boller and D. L. Chambers	No[3]
3	1986	Guatemala City, Guatemala	C. 0. Calkins	No[3]
4	1988	Vancouver, Canada	C. 0. Calkins and F. Bigler	Yes
5	1991	Wageningen, The Netherlands	F. Bigler and J. C. van Lenteren	Yes
6	1992	Horsholm, Denmark	F. Bigler and J. C. van Lenteren	Yes
7	1993	Rimini, Italy	G. Nicoli, M. Benuzzi, N. C. Leppla	Yes
8	1995	Santa Barbara, California	R. F. Luck and N. C. Leppla	Yes
9	1998	Cali, Colombia	N. C. Leppla and T. R. Ashley	Yes
10	2003	Montpellier, France	S. Grenier, P. De Clercq, N. C. Leppla	Yes
11	2007	Montreal, Canada	S. Grenier and C. S. Glenister	No[4]
12	2010	Vienna, Austria	P. De Clercq, T. A. Coudron, A. G. Parker	No[5]
13	2013	Bangalore, India	P. De Clercq, T. A. Coudron, T. M. Manjunath, C. R. Ballal	Yes
14	2017	Merida, Mexico	P. De Clercq, T. A. Coudron, J. S. Bernal, L. M. LeBeck	No[6]
15	2021	Bologna, Italy	M. L. Dindo and R. Buitenhuis	—

[1]Workgroup chairs sometimes were different than workshop chairs and proceedings editors (Fig. 1).

[2]Proceedings of workshops available at the MRQA website. (http://www.mrqa.unibo.it/)

[3]The first three workshops in 1982, 1984, and 1986 are described in Boller and Leppla (2006).

[4]Proceedings of the 11th workshop at Montreal, Canada (2007) was published as the Bulletin Global IOBC, No. 3, 2007, and is available on request from Patrick De Clercq. (patrick.declercq@ugent.be)

[5]The 12th workshop is described in IOBC Newsletter 88, Dec. 2010, p 15–16. (http://www.iobc-global.org/publications.html)

[6]The abstracts are available at the MRQA website (http://www.mrqa.unibo.it/) and papers based on some of the presentations at the 14th workshop at Merida, Mexico, including this one, were published as a special collection in the Journal of Insect Science (vol.: pages).

1990. ANBP was formed to provide representation for the commercial biocontrol industry and has become the recognized voice and advocate for the industry in North America (http://www.anbp.org/). The organization has a standing quality control committee chaired for years by Angela Hale. The mission of NBCI was to promote, facilitate, and provide leadership for biological control (Oraze and Delfosse 1995). NBCI encouraged and funded research on the quality of commercial natural enemies.

The fifth workshop in 1991 at Wageningen, the Netherlands, focused almost entirely on entomophagous insects and brought in representatives from 12 European biological control companies (Bigler 1991). Detailed quality control specifications were described for beneficial arthropods used in commercial greenhouse crops: *Encarsia formosa* Gahan, *Diglyphus isaea* (Walker), *Dacnusa sibirica* Telenga, *Aphidius* spp., *Aphidoletes aphidimyza* (Rondani), *Phytoseiulus persimilis* Athias-Henriot, and *Chrysoperla carnea* (Stephens) (van Lenteren and Steinberg 1991). Quality control criteria also were included for *Trichogramma evanescens* Westwood and *Trichogramma minutum* Riley reared on the Mediterranean flour moth, *Ephestia kuehniella* Zeller, or the Angoumois grain moth, *Sitotroga cerealella* (Oliver) (Bigler et al. 1991). An additional paper described genetic and statistical methods for evaluating insect quality (Wajnberg 1991).

The sixth workshop at Horsholm, Denmark, in 1992 was devoted entirely to addressing concerns about regulation of augmentation biological control in Europe and was limited to 26 participants from about 20 companies, including 6 scientists (Bigler 1992). At the time, there were ~50 companies producing beneficial arthropods worldwide, the markets were increasing rapidly, and it was agreed that product control guidelines should be established by the WGQC. Joop van Lenteren and Franz Bigler (1992) added *Orius* spp., *Amblyseius cucumeris* (Oudemans), *Aphelinus abdominalis* (Dalman), and *Trichogramma brassicae* Bezdenko (= *T. maydis*) to the list of species with quality control guidelines. A symposium at the XVIII International Congress of Entomology provided chapters for 'Advances in Insect Rearing for Research and Pest Management' (Anderson and Leppla 1992), including one on evaluating genetic changes in insect colonies maintained for pest management (Mangan 1992).

1993–1998 Universal Implementation of Quality Control for Mass-Reared Arthropods

Quality control for mass-reared arthropods was advancing from research and application in a few rearing facilities to universal implementation by the seventh workshop at Rimini, Italy, in 1993 (Nicoli et al. 1993). The workshop was divided into the following successive sessions: 'Quality Control in Arthropod Rearing Systems', 'Fruit Fly Biological Control', 'Quality Control for Commercial Natural Enemies', 'Natural Enemies I (*Trichogramma*, *Chrysoperla*, *Podisus*, and *Amblyseius* species)', and 'Natural enemies II (predaceous mites)'. Each session compiled a list of needs and actions to accomplish immediately and generated strategic goals. It was determined that the following goals would have to be accomplished for universal implementation of quality control: 1) determine the needs, resources, and actions required to provide quality control for colonization, production, delivery, and field evaluation; 2) extend quality control from production through delivery and field evaluation to provide uniform, quantitative assessment, and optimization through feedback; 3) perform periodic reviews to maintain quality control systems and improve them by incorporating new technologies; and 4) develop comprehensive quality control programs, including reasonable investment of resources, training of employees, and active participation of management. The excursion was to BIOLAB (now Bioplanet, www.bioplanet.eu) and APOFRUIT to learn about their use of biological control in integrated pest management systems. Quality control guidelines for natural enemies were placed in the proceedings (van Lenteren et al. 1993) and a postworkshop session, 'European Economic Community Concerted Action Group' was organized and led by Joop van Lenteren.

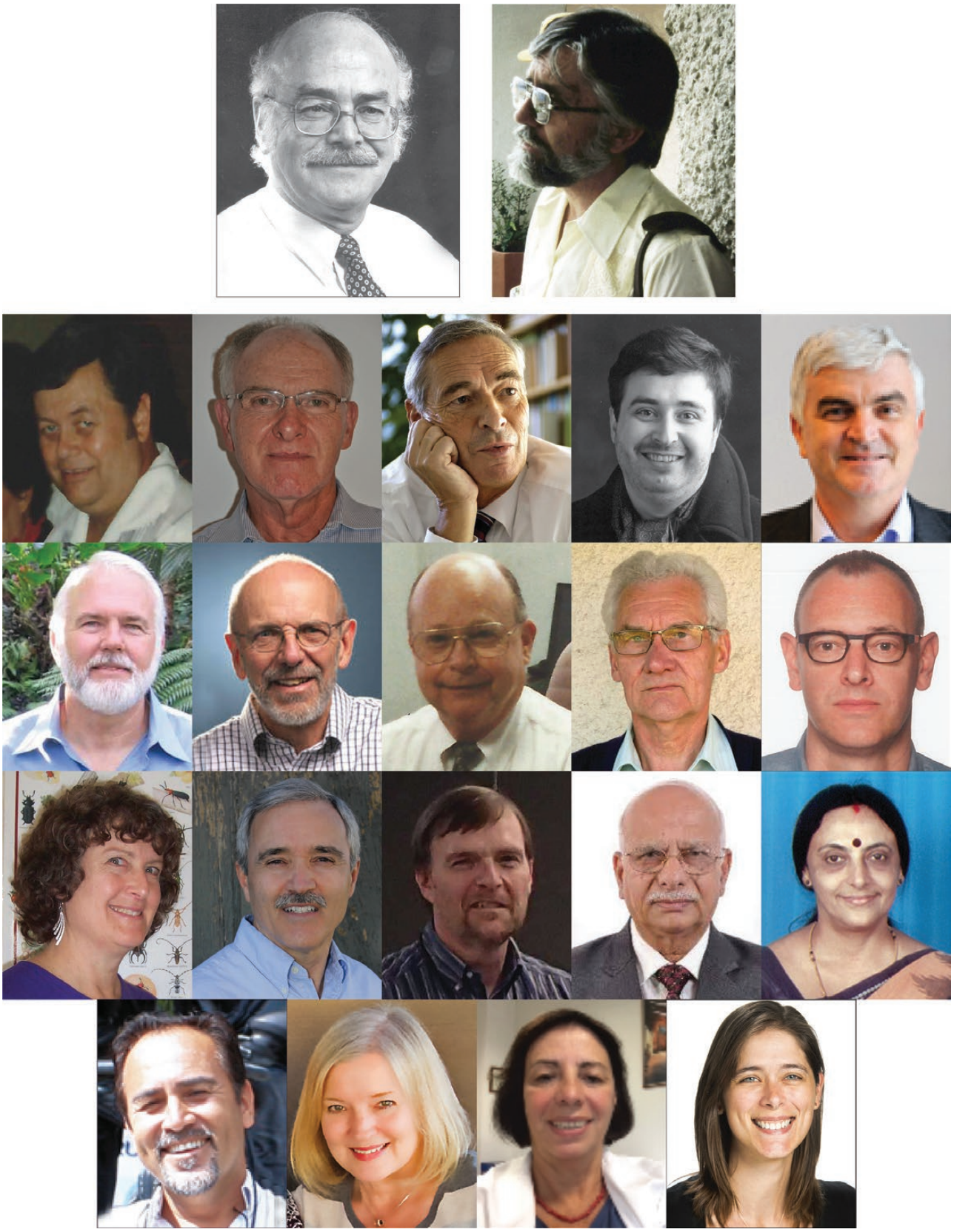

Fig. 1. Workshop chairs of the International Organization for Biological Control Global Working Group on MRQA, formerly WGQC and AMRQC, 1982–2021. In chronological order from Table 2 (left to right from top): Ernst F. Boller (working group co-founder), Derrell L. Chambers (working group co-founder), Carroll 0. Calkins, Franz Bigler, Joop C. van Lenteren, Giorgio Nicoli, Massimo Benuzzi, Norman C. Leppla, Robert F. Luck, Thomas R. Ashley, Simon Grenier, Patrick De Clercq, Carol S. Glenister, Thomas A. Coudron, Andrew G. Parker, T. M. Manjunath, Chandish R. Ballal, Julio S. Bernal, Lynn M. LeBeck, Maria Luisa Dindo, and Rose Buitenhuis.

The eighth workshop in 1995 at Santa Barbara, California, was described in detail by Robert Luck in IOBC Newsletter 62. An indication of the widespread institutional involvement with WGQC was combined sponsorship of the workshop by IOBC; the University of California Department of Entomology and Center for Exotic Pest Research; USDA, APHIS, NBCI; and ANBP. The first session focused on general quality control procedures used in industry, such as Total Quality Management (Deming 1982) and the International Organization for Standardization (ISO-9000 1987). Increased regulation of the importation and release of commercial natural enemies was becoming a concern in North America as it had been in Europe, so the entire second session was devoted to that topic, including presentation of the 1996 Food and Agriculture Organization of the United Nations (FAO) 'Code of Conduct for the Import and Release of Exotic Biological Control Agents' (FAO 2017). Regulation of commercial biological control was of particular interest to participants from the newly formed and primarily European International Biocontrol Manufacturers Association (IBMA), Invertebrate Biocontrol Agents (IBCA) Professional Group. The IBMA was founded in 1995 in Brighton, England, and has since moved its headquarters to Brussels, Belgium (http://www.ibma-global.org/). Sessions also were organized on field effectiveness, population genetics, and nematode biological control agents. The first version of the 'ANBP Product Profiles for Suppliers and End-Users' was made available for evaluating the quality attributes of natural enemy products. Included were 20 species with the following 14 North American species added to the European list compiled by Joop van Lenteren (2002): *Aphidoletes aphidimyza* (Rondani), *Muscidifurax zoraptor* Girault & Sanders, *Cryptolaemus montrouzieri* Mulsant, *Trichogramma platneri* Nagarkatti, *T. pretiosum* Riley, *Goniozus legneri* Gordh, *Pentalitomastix plethorica* Caltagirone, *Aphytis melinus* DeBach, *Thripobius semiluteus* Bouček, *Galendromus* (=*Typhlodromus*=*Metaseiulus*) *occidentalis* (Nesbitt), *Mesoseiulus longipes* (Evans), *Neoseiulus californicus* (McGregor), *N. cucumeris* (Oudemans), and *Steinernema carpocapsae* (Weiser) (Leppla et al. 2002). The workshop addressed 'Quality Control of Predators and Parasitoids', 'Field Performance of Natural Enemies', 'Nematode Quality Control', and the 'Status of Quality Control in North America and Europe'. Excursions included a visit to Buena BioSystems that was implementing ISO-9000 and the historic 'Fillmore Protective District Insectary', one of the first organizations to mass-produce natural enemies for augmentation biological control. During this period, 'Product Quality Control for Sterile Mass-Reared and Released Tephritid Fruit Flies' was published initially in 1997 and has been updated periodically to provide international product quality control standards for mass-reared tephritids (FAO/IAEA/USDA 2014). Routine tests were described for mass-reared pupae and flies before and after irradiation, and for pupae and flies at emergence and release facilities. Also included were more involved periodic quality control and ancillary tests. Additionally, general principles of quality control in insect rearing were published in the Soviet Union during this period (Zlotin and Chepurnaya 1995).

The ninth WGQC workshop was a joint meeting with the 'IOBC Working Group on *Trichogramma* and Other Egg Parasitoids' held in 1998 at the International Center for Tropical Agriculture (CIAT) in Cali, Colombia (Leppla 2002). CIAT is one of 15 CGIAR centers (formerly the Consultative Group for International Agricultural Research) that is part of the largest global network of agricultural centers uniting organizations engaged in research for a food-secured future (https://www.cgiar.org/). Almost 50 participants registered representing 14 countries: Brazil (2), Colombia (24), Costa Rica (1), Cuba (2), Egypt (1), France (1), Germany (1), India (1), Italy (2), Malaysia (2), Mexico (2), South Africa (1), Switzerland (1), and United States (6). The unusually diverse workshop agenda included sessions on 'Quality Control in Sterile Insect Technique Programs', 'Quality Control in Nematode Production and Utilization', 'Biological Control in Protected Cultures', 'New Markets for Efficacious Natural Enemies', 'Quality Control of In Vitro-Reared Natural Enemies', 'ANBP Quality Standards Based on the American Society for Testing and Materials (ASTM) Program', 'IBMA Quality Standards, Status and Needs', and 'Quality Control for *Trichogramma* spp.' that overlapped with the egg parasitoid working group. The goals of the workshop were to 1) institutionalize quality control in arthropod mass rearing, 2) address regulation of commercial natural enemies, and 3) determine how to assure the effectiveness of artificially reared natural enemies. It was a forum for determining the status of these important issues and recommending future action. The primary issues of interest to ANBP were the product profiles, status of biological control regulations, and practical methods for measuring product quality. Priorities of IBMA were to consider independent quality control certification of commercial biological control products, harmonization of beneficial insect product labeling, and the inappropriateness of labeling natural enemies based on the system for labeling chemical pesticides. Self-regulation capacities for the international biological control industry were advanced, along with quality control principles and practices for mass rearing beneficial arthropods. The final 2 d of sessions were devoted to *Trichogramma* spp. and other egg parasitoids, along with a tour of research sites at CIAT, an excursion to a *Trichogramma* spp. mass production facility, 'Biofabrica', demonstrations at *Trichogramma* spp. release sites, and a tour of the 'Valle'. Session topics for the egg parasitoid working group included biosystematics and genetics, host relation and biology, physiology and behavior, ecology and population dynamics, rearing (in vivo and in vitro), mass production, compatibility (environmental, biological, chemical), and effectiveness and assessment. Members of WGQC always had an appreciation for supportive research on artificial diets and rearing techniques for phytophagous species but later placed more emphasis on entomophages. Participants at the ninth workshop decided to link quality control more directly with underlying rearing techniques and expand the scope of the WGQC to incorporate a new group focused on artificial rearing of entomophagous insects that was being developed by Simon Grenier and Pat Greany. The amalgamation, named the 'Arthropod Mass Rearing and Quality Control Working Group (AMRQC)' was established under the leadership of Simon Grenier, Patrick De Clercq and Norman Leppla, and future workshops had at least one co-chair each from Europe and North America. Initially, the new AMRQC had about 250 members.

1999–2010 Protocols for Mass Rearing and Quality Control

In the preface to the proceedings of the tenth workshop of the now AMRQC at Montpellier, France, in 2003 (Grenier et al. 2003), IOBC President, Les Ehler reemphasized the importance of field performance of mass-reared arthropods. Field performance also had been a primary consideration stated by a previous IOBC President, Jeff Waage, at the IOBC conference held at Montpellier in September 1996, 'Technology Transfer in Biological Control: From Research to Practice'. A keynote address delivered at the 2003 AMRQC workshop by Allen Cohen, 'The Past and Present of Insect Diets and Rearing as Precursors to a Bright Future', highlighted the importance of supportive research on developing artificial diets and rearing techniques. AMRQC had recently shifted its focus from phytophagous species

with relatively simple rearing requirements to entomophages that depend on more complex diets, often involving another trophic level. The quality of artificial diets and associated rearing methods determine the survival and effectiveness of mass-reared arthropods (Taylor 1992, Cayol 2000). Consequently, the workshop had the following five sessions: 'Artificial and Factitious Foods', 'Tools for Quality Control', 'Innovative Methods for Quality Control', 'Production Techniques', and 'Post-Production Quality Assurance'. Papers in these sessions served as a basis for discussion and exchange, with the aim of improving collaboration among scientists, practitioners, and regulators. The workshop also shifted away from an emphasis on regulation of augmentation biological control back toward arthropod-rearing research and technology, and linking quality control more closely to the underlying rearing techniques (Robinson et al. 1999, Grenier and De Clercq 2003, Rendon et al. 2005) and commercial applications (Penn et al. 1998; Bolckmans 1999, 2003; Glenister et al. 2003). The renewed mission of AMRQC, therefore, was 'to facilitate and advance cost-effective rearing of high-quality arthropods in support of biological control and integrated pest management' (Leppla 2003). The history and traditions of the working group were described from its beginning until about 2006 by Boller (2002), Leppla (2002), Leppla and De Clercq (2002) with periodic updates, and Boller and Leppla (2006). Additionally, the overall history of the first 50 yr of IOBC was documented (Boller et al. 2006) and 'Quality Control of Natural Enemies Used in Biological Pest Control' was published (van Lenteren 2003a). The second book contains sections on 'Quality Control for Natural Enemies', 'Variability in Foraging Behavior of Natural Enemies', 'Coping with Variation in Foraging Behavior', 'Mass-Produced Natural Enemies', 'Quality Control Testing of Natural Enemies', and 'Quality Control Tests' that described detailed tests for 26 natural enemy species, plus a chapter emphasizing the need for quality control of mass-produced biological control agents (van Lenteren 2003b).

'Maintaining Worldwide Connections for Quality Assurance in Arthropod and Nematode Rearing' was the theme of the eleventh AMRQC workshop held in 2007 at Montreal, Canada (van Lenteren et al. 2007). It was a joint workshop of ANBP; the ASTM Subcommittee E35.30 on Natural Multi-Cellular Biological Control Organisms; the IBMA, Invertebrate Biocontrols Group; and AMRQC hosted by the Biocontrol Network of Canada. The workshop included a record ten sessions and for the first time one devoted to education and training: 'Welcoming Partnerships in Biological Control'; 'Quality Assurance Concept: Product to Customer'; 'State of the Biological Control Industry'; 'Rearing and Quality Assurance Methods for Arthropods and Nematodes'; 'Rearing Entomophagous Arthropods Emphasizing Artificial Diets'; 'Production of Sterile Insects and their Quality Assurance'; 'Future Concepts for Mass Production of Phytoseiid Mites'; 'Education and Training in Arthropod Rearing and Quality Control'; 'Fitness, Cold Storage, and Effectiveness'; 'Microorganisms, Genomics, and Insect Quality'; and a 'Round Table on Industry Needs for Research'. The workshop highlighted improvements in rearing entomophagous and phytophagous insects and mites, and entomopathogenic nematodes, and further advanced principles and practices of quality assurance for mass-reared arthropods. There were 44 presentations, with 24 on some aspect of natural enemy rearing and quality control, 8 on general arthropod production, and the remainder on using arthropods to manage plant, animal, and human pests. The proceedings is available on request (see Table 2). At about the same time, principles and practices were described in new books for SIT (Calkins and Parker 2005, Dyck et al. 2005) and for rearing high-quality insects (Schneider 2009, Leppla 2009).

fThe 2010 joint workshop in Vienna, Austria, was supported by the same collaborative organizations as in Montreal and held in cooperation with the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. However, the theme changed to 'Blueprint for the Future of Arthropod Rearing and Quality Assurance' and participants were asked to predict the growth in mass production of arthropods and nematodes and to address associated concepts and demands for improved quality control. Sessions included the following: 'The Role of Microbiota in Insect Mass Rearing and Quality Control'; 'Entomopathogenic Nematodes: Producing a High Quality, Effective Product for Expanding the Agricultural Market'; 'SIT Applications and Other Uses of Irradiation Technology'; 'Application of New Technology to Mass Insect Rearing and Quality Control'; 'New, Novel, Innovative and Emerging Applications of Insect Rearing'; 'New and Future Applications for Mass Rearing Insects and Quality Control'; and 'Predatory Mites'. Included were about 40 oral presentations and 24 posters that fit into the session topics. There were structured discussions and an excursion to the IAEA Insect Pest Control Laboratory and associated insect rearing facilities at Seibersdorf, Austria. Attendance exceeded 100 registered participants from 29 countries and there was increased interest in insect pathology, mass producing additional species of tephritid fruit flies, mosquito SIT, and insects for food and feed produced from waste materials, as well as mass rearing crickets and butterflies. By that time, the screwworm SIT program was expanding in Panama, marketing of phytoseiid mites and the economics of production were increasingly popular subjects, biological control companies were being established in more countries, and new artificial diets were under development for natural enemies. Due to this increased scope of AMRQC, a proposal was made and accepted by the members to change the name of the Working Group to the 'IOBC Global Working Group on Mass Rearing and Quality Assurance (MRQA)'.

2011–2018 Increased Scope of Mass Rearing and Quality Control

The theme for the thirteenth workshop in 2013 was 'Emerging Opportunities for the Mass Production and Quality Assurance of Invertebrates' (De Clercq et al. 2013). This first workshop to be held in Asia was co-organized by MRQA, the Indian Council of Agricultural Research (ICAR), the Society for Biocontrol Advancement of India (SBA), the National Bureau of Agriculturally Important Insects (NBAII), and the Invertebrate Biocontrol Agents Group (IBAG) of IBMA. The NBAII hosted the workshop in Bangalore, India. There were 40 scientific and technical presentations, 34 delivered orally, and 16 posters, divided into four topics: 'Development and Validation of Protocols for Invertebrate Mass Rearing and Quality Assurance'; 'Mass Rearing of Invertebrates for Management of Arthropod Pests, Veterinary and Medical Field Applications, and Production of Microbial Biocontrol Agents'; 'Biocontrol in High Value and Export Crops and Emerging Markets'; and 'Legal and Ethical Issues Associated with Mass Rearing Invertebrates'. Particular attention was given to the technical and socioeconomic challenges faced by emerging economies in Asia and elsewhere related to the mass production, regulation, and release of invertebrate biological control agents.

Several publications of significant importance were produced during this period, including the 'Grower Guide: Quality Assurance of Biological Products' (Buitenhuis 2014). This guide enables growers who purchase biological control products to evaluate their quality when received. Tests are presented for evaluating 28 species of parasitoids and predators. Moreover, publications appeared on quality

versus quantity of mass-reared insects (Rull et al. 2012), the history of quality control for the Queensland fruit fly (Fanson et al. 2014), and quality assurance for mass-reared natural enemies (Leppla 2014), the latter in 'Mass Production of Beneficial Organisms, Invertebrates and Entomopathogens' (Morales-Ramos et al. 2014). This comprehensive book contains 20 chapters divided into three sections: 'Parasitoids and Predators', 'Pathogens', and 'Invertebrates for Other Applications'. It describes the newest large-scale rearing methods for beneficial invertebrates and entomopathogens used for biological control, food and feed, pollination, and other purposes.

In 2016, representatives of the MRQA met with the president of the Sociedad Mexicana de Control Biologico, Julio Bernal, in Orlando, Florida, at the XXV International Congress of Entomology to plan the fourteenth workshop of the MRQA to be conducted jointly with the XL Congreso Nacional de Control Biológico, ANBP, and IBAG. This joint conference was held at Merida, Yucatán, Mexico, in 2017 and attendance exceeded 100 participants from 18 countries. The conference was preceded by a 'Workshop on Breeding and Quality Control of Entomophagous Insects and Entomopathogenic Fungi' conducted by Juan Morales-Ramos, Guadalupe Rojas, Peter Ebling, Richard Ward, Angela Hale, Andrew Parker, and Norman Leppla, organizer and moderator. This rearing workshop was based on the 'International Insect Rearing Workshop' led by Frank Davis annually at Mississippi State University (Schneider et al. 2017) and the new 'Mass Rearing of Insects Workshop' organized and conducted by Des Conlong at Stellenbosch University, South Africa. The second half of the workshop in Mexico on entomophagous insects and entomopathogenic fungi organized by Hugo Arredondo and Martín Palomares was delivered in Spanish. Participants in the joint conference and rearing workshop were invited to visit the local '*Tamarixia radiata* Mass Breeding Laboratory'. The theme of the MRQA workshop was appropriately, 'Mass Rearing High Quality Invertebrates for Multiple Purposes', because the meeting consisted of the following seven symposia: 'Mass Rearing Invertebrates for Management of Arthropod Crop Pests', 'Mass Rearing for Veterinary and Medical Applications', 'Mass Rearing Insects for Feed and Food', 'Development and Validation of Protocols for Invertebrate Mass Rearing and Quality Assurance', 'Breeding of Beneficial Arthropods', 'Networking and Instruction on Arthropod Rearing', and 'Legal and Ethical Issues Associated with Mass Rearing Invertebrates'. Discussions ensued at the business meeting on the usefulness and future of the Insect Rearing Google Group maintained by Leon Westerd (goo.gl/r8MXcz, 'insect rearing'). Also, MRQA came under the new leadership of Maria Luisa Dindo and Rose Buitenhuis, and the website was moved from Ghent University under Patrick De Clercq to the University of Bologna to be managed by Maria Luisa Dindo. The abstracts from the fourteenth workshop were archived by Andrew Parker and placed on the MRQA website (http://www.mrqa.unibo.it/). Presenters at the workshop were invited to publish their papers, including this one, in a special collection of the Journal of Insect Science. Moreover, an initiative was launched by Angela Hale (ANBP), Tom Groot (IBMA), and Rose Buitenhuis (MRQA) to update the IOBC quality control guidelines. The next MRQA workshop has been scheduled for 2021 at Bologna, Italy.

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