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# Chapter 1

## Host-Associated Bacteriophage Isolation and Preparation for Viral Metagenomics

Juris A. Grasis

### Abstract

Prokaryotic viruses, or bacteriophages, are viruses that infect bacteria and archaea. These viruses have been known to associate with host systems for decades, yet only recently have their influence on the regulation of host-associated bacteria been appreciated. These studies have been conducted in many host systems, from the base of animal life in the Cnidarian phylum to mammals. These prokaryotic viruses are useful for regulating the number of bacteria in a host ecosystem and for regulating the strains of bacteria useful for the microbiome. These viruses are likely selected by the host to maintain bacterial populations. Viral metagenomics allows researchers to profile the communities of viruses associating with animal hosts, and importantly helps to determine the functional role these viruses play. Further, viral metagenomics show the sphere of viral involvement in gene flow and gene shuffling in an ever-changing host environment. The influence of prokaryotic viruses could, therefore, have a clear impact on host health.

**Key words** Metagenomics, Viral metagenomes, Virome, Microbiome, Prokaryotic virus, Bacteriophage, Host-microbe interactions, Holobiont, Symbiosis

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## 1 Introduction

Prokaryotic viruses (commonly known by the anachronistic term bacteriophage, *see Note 1*) infect bacteria and archaea. There are two modes of the prokaryotic viral life cycle, lytic and temperate. The lytic phase involves the infection, replication, and lysis of the bacterium, leading to the death of the cell and escape of viral progeny. The temperate phase involves the integration of the prokaryotic virus into the genome of the bacterium in a proviral form, which when activated at a later time can then become a lytic virus.

The involvement of prokaryotic viruses in host-associated regulation of the microbiome has only recently been appreciated. These viruses likely help to regulate the number of bacteria and the strains of bacteria associating with a host. These associations have an impact on host metabolism [1], immunity [2], as well as animal health and disease [3]. To best evaluate the effects these viruses

have on host ecosystems, it is useful to use viral metagenomics to fully assess which genes in the viral genomes have these effects on the microbiome. This protocol will allow the researcher to isolate, purify, and prepare viral nucleic acid for sequencing.

It is important to purify viruses because the total amount of viral nucleic acid is small compared to that of bacterial and host nucleic acid content [4]. The amount of nucleic acid per virus is estimated to be approximately 1 attogram ( $10^{-18}$  g). Most current sequencing platforms require at least 1 nanogram ( $10^{-9}$  g) of DNA. Therefore, if you have less than  $10^9$  viruses in your sample, you will need to enrich the viruses and amplify the DNA. Physical enrichment of viruses increases the number of viral sequences. Increased number of viral sequences means greater representation in databases, which will increase the likelihood of database matches. Further, enrichment of viruses for sequencing is necessary, as less than 5% of the unenriched metagenome sequences will contain viral sequences. The most effective purification method is a three-step technique utilizing centrifugation, filtration, and nuclease treatment. Using this technique eliminates more than 80% of host/bacterial contamination as compared to without purification, while using additional purification methods (e.g., density gradients) selects for certain populations of viruses. Similarly, use of viral DNA/RNA extraction kits is not recommended, as they create biases in viral populations [5]. Random shotgun sequencing libraries are recommended, as one can amplify a sample using barcoding primers. Even if you have enough DNA, it is recommended to exercise this protocol to barcode your samples for sequencing. It is not recommended to use multiple displacement amplification for amplifying viral DNA, as the Phi29 polymerase preferentially amplifies circular and single-stranded DNA and can, therefore, amplify contaminating host/bacterial DNA as well as small, circular viral DNA, which can alter the viral community profile prior to sequencing.

The use of a CsCl density gradient for purification of bacteriophages is up to the user. CsCl density gradients are effective at removing host and bacterial DNA, leaving more viruses for sequencing. This comes at a cost, as these gradients select for certain viruses while discriminating against others according to viral specific density. Further, reproducibility of CsCl density gradients is an issue [6]. It is therefore recommended to avoid using CsCl density gradients if accurate viral populations and reproducibility are of concern. If host and bacterial contaminations are of concern, this section is provided as an option. Also, an ultracentrifuge is needed for this optional step. Alternatively, one can repeat nuclease treatment prior to viral nucleic acid purification.

Although only two families of RNA bacteriophages have been described to date, this does not mean that the number and the diversity of RNA bacteriophages are less than those of DNA

bacteriophages. More likely, the large percentage of DNA bacteriophages found in databases is due to the purification and selection method used (e.g., CsCl gradient selection) and consequent preferential sequencing of these selected viruses. Further, working with RNA samples is difficult due to the labile nature of RNA and the ubiquitous presence of RNases. Therefore, it is recommended to split the samples into DNA and RNA fractions to sample both DNA and RNA bacteriophages. Make sure that the working space, equipment, and reagents are as RNase free as possible. Keep in mind that the low number of characterized RNA bacteriophages will yield low numbers of hits in databases. However, as researchers sequence more RNA bacteriophages, more of these viruses will be characterized, and the RNA bacteriophage database will increase. Therefore, it is recommended to sequence both DNA and RNA bacteriophages.

This protocol takes the user from the isolation of bacteriophages (and other viruses, *see Note 2*) in host-associated environments, purification of bacteriophages, enumeration of viral-like particles (VLPs) through epifluorescence microscopy [7], characterization of VLPs through transmission electron microscopy [8, 9], extraction of viral DNA (vDNA) [10] and viral RNA (vRNA) [11, 12], and barcoding and amplification of viral nucleic acids for sequencing using Illumina sequencing technologies.

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## 2 Materials

### 2.1 Extraction of Bacteriophages from Host Tissue

1. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).
2. Saline magnesium (SM) buffer, pH 7.5, per 100 mL: To 80 mL molecular grade dH<sub>2</sub>O add 0.58 g NaCl (100 mM), 5 mL 1 M Tris-HCl pH 7.4 (50 mM), 0.25 g MgSO<sub>4</sub> 7H<sub>2</sub>O (10 mM), 0.1 g gelatin (0.1%, optional), adjust to pH 7.4, fill to 100 mL with molecular grade dH<sub>2</sub>O, autoclave to sterilize, store at room temperature.
3. Microcentrifuge pestle (cleaned with 70% ethanol and RNA-Zap).
4. Handheld electric tissue homogenizer (cleaned with 70% ethanol and RNA-Zap).
5. 5 mL Sterile syringes.
6. 0.45 μm Syringe filters, PVDF, 28 mm diameter, sterile.
7. 0.02 μm Syringe filters, 25 mm diameter, sterile (Whatman Anotop-25).
8. Chloroform, use in a chemical hood.

9. DNase I (10 U/ $\mu$ L) and 10 $\times$  DNase buffer (100 mM Tris pH 7.5, 5 mM CaCl<sub>2</sub>, 25 mM MgCl<sub>2</sub>).
10. RNase I (10 U/ $\mu$ L).
11. 4% Paraformaldehyde (PFA), per 10 mL: To 10 mL molecular grade dH<sub>2</sub>O add 0.4 g PFA, heat at 50 °C for 1 h, fill to 10 mL with molecular grade dH<sub>2</sub>O, 0.02  $\mu$ m filter sterilize, good for 1 month at 4 °C.
12. 5% Formaldehyde (FA), per 10 mL: To 8 mL molecular grade dH<sub>2</sub>O add 0.5 g formaldehyde, mix, and fill to 10 mL with molecular grade dH<sub>2</sub>O, 0.02  $\mu$ m filter sterilize, good for 1 month at 4 °C.

## **2.2 Purification of Bacteriophages (Optional)**

1. Cesium chloride (CsCl) density step gradient—made in buffer used for resuspension of sample.
  - (a) 1.7 g/mL (w/v): To 7.5 mL of resuspension buffer add 9.5 g CsCl, weigh 1 mL to adjust to final concentration of 1.7 g/mL with buffer or CsCl.
  - (b) 1.5 g/mL (w/v): To 8.2 mL of resuspension buffer add 6.7 g CsCl, weigh 1 mL to adjust to final concentration of 1.5 g/mL with buffer or CsCl.
  - (c) 1.35 g/mL (w/v): To 9.9 mL of resuspension buffer add 5.0 g CsCl, weigh 1 mL to adjust to final concentration of 1.35 g/mL with buffer or CsCl.
  - (d) 1.2 g/mL (w/v): To 9.9 mL of resuspension buffer add 2.4 g CsCl, weigh 1 mL to adjust to final concentration of 1.2 g/mL with buffer or CsCl.
2. Ultracentrifuge tubes (Ultraclear 14  $\times$  89 mm, Beckman Coulter).
3. SW41 Ti swinging bucket ultracentrifuge rotor.
4. Ultracentrifuge (Beckman Coulter).
5. 18-gauge needles.
6. 5 mL Syringes.

## **2.3 Viral-Like Particle Counts Using Epifluorescent Microscopy**

1. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).
2. 0.02  $\mu$ m Anodisc.
3. SYBR Gold (10,000 $\times$ ).
4. Mounting solution, 0.1% ascorbic acid, 50% glycerol. Per 10 mL: To 4.9 mL molecular grade dH<sub>2</sub>O add 100  $\mu$ L of 10% ascorbic acid, then slowly add 5 mL glycerol, mix thoroughly, divide into 1 mL aliquots, and store at -20 °C.
5. Vacuum pump.
6. Microscopy slides.

7. Microscopy coverslips.
8. Forceps.
9. Petri dish.
10. Epifluorescent microscope with standard objective orientation (63× objective).

#### **2.4 Transmission Electron Microscopy of Viral-Like Particles**

1. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).
2. 2% Uranyl acetate, pH to 4.5. Per 10 mL: To 9 mL molecular grade dH<sub>2</sub>O add 0.2 g uranyl acetate, adjust pH to 4.5 with NaOH, and fill to 10 mL with molecular grade dH<sub>2</sub>O; this chemical should be handled with care since it is both toxic and slightly radioactive [8, 9], and stored at 4 °C for up to 2 years.
3. Electron microscopy grids, 200–400 square mesh, copper, stabilized with a 2–10 nm thick carbon-layer Formvar film: Grids can become hydrophobic over time and may show poor adsorption of bacteriophages; therefore, it is recommended to treat the grids with UV light or poly-L-lysine to make the grids hydrophilic again.
4. Parafilm.
5. Forceps.
6. Filter paper.
7. Transmission electron microscope.

#### **2.5 Viral DNA Extraction**

1. 0.5 M EDTA, pH 8.0: Per 10 mL: To 8 mL molecular grade dH<sub>2</sub>O add 1.86 g EDTA, adjust pH to 8.0 with NaOH (~200 µL), fill to 10 mL with molecular grade dH<sub>2</sub>O, sterilize through 0.02 µm filter, and store at room temperature.
2. 2 M Tris-HCl, 0.2 M EDTA, pH 8.5: Per 10 mL: To 3 mL molecular grade dH<sub>2</sub>O add 2.4 g Tris, 4 mL 0.5 M EDTA pH 8.0, adjust pH to 8.5 with HCl, fill to 10 mL with molecular grade dH<sub>2</sub>O, sterilize through 0.02 µm filter, and store at room temperature.
3. Formamide (10 mL): Store at 4 °C.
4. Glycogen (20 mg/mL): Store at -20 °C.
5. 100% Ethanol (100 mL): Store at room temperature.
6. 1 M Tris-HCl pH 8.0: Per 10 mL: To 8 mL molecular grade dH<sub>2</sub>O add 1.21 g Tris, adjust to pH 8.0, fill to 10 mL with molecular grade dH<sub>2</sub>O, sterilize through 0.02 µm filter, and store at room temperature.
7. 10 mM Tris, 1 mM EDTA (TE), pH 8.0: Per 100 mL: To 80 mL molecular grade dH<sub>2</sub>O add 1 mL 1 M Tris-HCl pH 8.0, add 2 mL 0.5 M EDTA, adjust pH to 8.0, fill to 100 mL with

molecular grade dH<sub>2</sub>O, sterilize through 0.02 μm filter, and store at room temperature.

8. 10% Sodium dodecyl sulfate (SDS): Per 10 mL: To 10 mL molecular grade dH<sub>2</sub>O add 1 g SDS, store at room temperature.
9. Proteinase K (20 mg/mL): Store at −20 °C.
10. 5 M NaCl: Per 10 mL: To 10 mL molecular grade dH<sub>2</sub>O add 2.92 g NaCl, sterilize through 0.02 μm filter, and store at room temperature.
11. 10% Cetyltrimethyl ammonium bromide (CTAB), 700 mM NaCl: Per 10 mL: To 6 mL molecular grade dH<sub>2</sub>O add 1 g CTAB, add 0.4 g NaCl, heat to 65 °C to dissolve CTAB/NaCl, fill to 10 mL with molecular grade dH<sub>2</sub>O, store at room temperature, and preheat to 65 °C before use.
12. Chloroform (100 mL): Keep in glass container, store at room temperature, and use in a chemical hood.
13. Phenol:chloroform:isoamyl alcohol (25:24:1), pH 8.0 (100 mL): Keep in glass container, store at 4 °C, and use in a chemical hood.
14. Isopropanol (100 mL): Store at room temperature.
15. 70% Ethanol (100 mL).
16. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

## **2.6 Viral RNA Extraction**

1. RNase-ZAP (Thermo Fisher Scientific) or 1% SDS: Per 100 mL: To 100 mL molecular grade dH<sub>2</sub>O add 1 g SDS, store at room temperature.
2. Guanidine isothiocyanate RNA lysis buffer (GITC buffer, TRIzol LS, Thermo Fisher Scientific) (100 mL): Store at 4 °C.
3. 10 mM Dithiothreitol (DTT): Store at −20 °C.
4. Chloroform (100 mL): Keep in a glass container, store at room temperature, and use in a chemical hood.
5. Isopropanol (100 mL): Store at room temperature.
6. Glycogen (20 mg/mL): Store at −20 °C.
7. RNase-free 70% ethanol (100 mL): Use RNase-free molecular grade dH<sub>2</sub>O to make 70% ethanol.
8. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

## **2.7 Quality Control to Determine Bacterial/Host Contamination**

1. 10× *Taq* polymerase buffer: 100 mM Tris-HCl pH 8.4, 500 mM KCl, store at −20 °C.
2. BSA (1 mg/mL): Store at −20 °C.
3. 10 mM MgCl<sub>2</sub>: Store at −20 °C.

4. 10 mM dNTPs: Store at  $-20^{\circ}\text{C}$ .
5. *Taq* polymerase (10 U/ $\mu\text{L}$ ): Store at  $-20^{\circ}\text{C}$ .
6. Molecular grade  $\text{dH}_2\text{O}$  (sterile, nuclease-free, virus-free  $\text{dH}_2\text{O}$ ).
7. Prokaryotic primers: Store at  $-20^{\circ}\text{C}$ :
  - (a) 1 mM Eub27F—20-mer: 5'—AGR GTT TGA TCM TGG CTC AG—3'.
  - (b) 1 mM Eub1492R—19-mer: 5'—GGH TAC CTT GTT ACG ACT T—3'.
8. Eukaryotic primers: Store at  $-20^{\circ}\text{C}$ :
  - (a) 1 mM EukF—21-mer: 5'—AAC CTG GTT GAT CCT GCC AGT—3'.
  - (b) 1 mM EukR—24-mer: 5'—TGA TCC TTC TGC AGG TTC ACC TAC—3'.

## **2.8 Viral RNA First-Strand Synthesis**

1. Reverse Transcriptase (200 U/ $\mu\text{L}$ , SuperScript III, Thermo Fisher Scientific).
2. 5 $\times$  Reverse transcriptase reaction buffer: 250 mM Tris-HCl pH 8.3, 375 mM KCl, 15 mM  $\text{MgCl}_2$ , store at  $-20^{\circ}\text{C}$ .
3. 10 mM dNTPs: Store at  $-20^{\circ}\text{C}$ .
4. 10  $\mu\text{M}$  Random hexamer primer (N6): Store at  $-20^{\circ}\text{C}$ : 5'—NNN NNN—3'.
5. 50 nM Anchored oligo dT primer (dT18a): Store at  $-20^{\circ}\text{C}$ : 5'—TTT TTT TTT TTT TTT TTT VN—3'.
6. 10 mM Dithiothreitol (DTT): Store at  $-20^{\circ}\text{C}$ .
7. RNase inhibitor (40 U/ $\mu\text{L}$ ): Store at  $-20^{\circ}\text{C}$ .
8. 10 mM  $\text{MgCl}_2$ : Store at  $-20^{\circ}\text{C}$ .
9. 1 M Dimethyl sulfoxide (DMSO): Store at  $-20^{\circ}\text{C}$ .

## **2.9 Viral Second- Strand Synthesis**

1. Molecular grade  $\text{dH}_2\text{O}$  (sterile, nuclease-free, virus-free  $\text{dH}_2\text{O}$ ).
2. T4 DNA polymerase (5 U/ $\mu\text{L}$ ).
3. 10 $\times$  T4 DNA polymerase buffer: 250 mM Tris-acetate pH 7.5, 1 M potassium acetate, 100 mM magnesium acetate, and 5 mM DTT, store at  $-20^{\circ}\text{C}$ .
4. 10 mM dUTPs: Store at  $-20^{\circ}\text{C}$ .
5. RNase H (250 U/ $\mu\text{L}$ ): Store at  $-20^{\circ}\text{C}$ .
6. 10 mM DTT: Store at  $-20^{\circ}\text{C}$ .

## **2.10 DNA Cleanup**

1. SPRI Beads (Agencourt AMPure XP Beads, Beckman Coulter): Store at  $4^{\circ}\text{C}$ . Bring to room temperature before use.
2. Magnetic tube rack.



3. 70% Ethanol (70% EtOH).
4. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

### **2.11 DNA Shearing**

1. Covaris shearing microtubes (microTUBE-50).
2. Covaris focused ultrasonicator (M220).

### **2.12 DNA End Repair**

1. T4 DNA polymerase (5 U/μL).
2. 10× T4 DNA ligase reaction buffer: 500 mM Tris-HCl pH 7.5, 100 mM MgCl<sub>2</sub>, 10 mM ATP, and 100 mM DTT, store at -20 °C.
3. T4 polynucleotide kinase (10 U/μL): Store at -20 °C.
4. 10 mM dNTPs: Store at -20 °C.
5. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

### **2.13 Adenylate**

#### **3' Ends**

1. DNA polymerase (5 U/μL), Klenow Fragment (3'-5' exo-).
2. 10× Klenow reaction buffer: 500 mM NaCl, 100 mM Tris-HCl pH 7.9, 100 mM MgCl<sub>2</sub>, 10 mM DTT, store at -20 °C.
3. 10 mM dATP: Store at -20 °C.
4. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

### **2.14 Adapter**

#### **Ligation**

1. Annealed adapters (see Section 2.18).
2. T4 DNA ligase (20 U/μL).
3. T4 DNA ligase reaction buffer: 500 mM Tris-HCl pH 7.5, 100 mM MgCl<sub>2</sub>, 10 mM ATP, and 100 mM DTT, store at -20 °C.

### **2.15 Uridine**

#### **Removal for Viral RNA Samples (Skip for Viral DNA Samples)**

1. Uracil-DNA glycosylase (1 U/μL, UDG).
2. 10× UDG reaction buffer: 200 mM Tris-HCl, 10 mM DTT, 10 mM EDTA, pH 8.0, store at -20 °C.

### **2.16 Size Selection**

#### **of Adapter-Ligated Fragments**

1. SPRI Beads: Store at 4 °C, bring to room temperature before use.
2. Magnetic tube rack.
3. 70% Ethanol (70% EtOH).
4. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).

### **2.17 Large-Scale**

#### **PCR of Size-Selected Adapter-Ligated Fragments**

1. Molecular grade dH<sub>2</sub>O (sterile, nuclease-free, virus-free dH<sub>2</sub>O).
2. High-Fidelity DNA Polymerase (2 U/μL, NEB Q5).
3. 5× High-Fidelity DNA polymerase reaction buffer: Store at -20 °C.
4. 10 mM dNTPs: Store at -20 °C.

5. 1 mM PCR Primer 1 (Illumina TruSeq P5): Store at  $-20^{\circ}\text{C}$ :  
5'- AAT GAT ACG GCG ACC ACC GAG ATC TAC ACT  
CTT TCC CTA CAC GA—3'.
6. 1 mM PCR Primer 2 (Illumina TruSeq P7): Store at  $-20^{\circ}\text{C}$ :  
5'- CAA GCA GAA GAC GGC ATA CGA GAT—3'.

### **2.18 Preparation of Adapters and Indices**

1. Purchase Universal Adapter and Indexed Adapters: Universal adapter must have a 3' phosphorothioate bond and indexed adapters must have 5' end phosphorylated: universal adapter (Illumina TruSeq): 5'- AAT GAT ACG GCG ACC ACC GAG ATC TAC ACT CTT TCC CTA CAC GAC GCT CTT CCG ATC\*T—3' {\* = Phosphorothioate bond} and indexed adapters (Illumina TruSeq): 5'- P—GAT CGG AAG AGC ACA CGT CTG AAC TCC AGT CAC—NNN NNN—ATC TCG TAT GCC GTC TTC TGC TTG—3' {5' end needs to be phosphorylated, Ns are barcode}. Note that the latest Illumina TruSeq adapters are pre-annealed, so these steps may not be necessary. Check the Illumina TruSeq manual to make sure. The following steps are listed in the event the adapters are not pre-annealed.
  - (a) Resuspend each adapter in molecular grade  $\text{dH}_2\text{O}$  at  $570\ \mu\text{M}$  (volume for  $100\ \mu\text{M}/5.7$ , store at  $-80^{\circ}\text{C}$ ).
  - (b) For annealing, make a working dilution of  $10\ \mu\text{M}$  by diluting  $5\ \mu\text{L}$  of  $570\ \mu\text{M}$  stock with  $280\ \mu\text{L}$  TE (store at  $-20^{\circ}\text{C}$ ).
  - (c) Mix equal volumes of the universal adapter ( $10\ \mu\text{M}$ ) with each of the indexed adapters ( $10\ \mu\text{M}$ ).
  - (d) Either boil the mixes for 2 min and then cool slowly to room temperature—OR—use thermocycler program set to 1 cycle (Adapt\_Anneal Program):
    - $95^{\circ}\text{C}$  for 10 min
    - $72^{\circ}\text{C}$  for 5 min
    - $60^{\circ}\text{C}$  for 5 min
    - $50^{\circ}\text{C}$  for 5 min
    - $40^{\circ}\text{C}$  for 5 min
    - $30^{\circ}\text{C}$  for 5 min
    - $20^{\circ}\text{C}$  for 5 min
    - $10^{\circ}\text{C}$  for 5 min
    - $4^{\circ}\text{C}$  Hold
  - (e) Store the annealed adapters at  $-20^{\circ}\text{C}$ .

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### 3 Methods

Carry out all procedures at 4 °C or on ice unless otherwise specified.

#### 3.1 Extraction of Bacteriophages from Host Tissue

1. Resuspend sample in equal volume of molecular grade dH<sub>2</sub>O or SM buffer (*see Note 3*) as volume of tissue in appropriate sized tube, e.g., microcentrifuge tube, Falcon tube.
2. Homogenize sample with handheld homogenizer at 4500 × *g* for 60 s or use microcentrifuge mortar and pestle until tissue becomes a slurry.
3. Centrifuge at slow speed (~2500 × *g*) for 20 min at 4 °C to pellet debris (eukaryotic and prokaryotic cells).
4. Optional viral precipitation step (if there is a lot of volume (> 5 mL), *see Note 4*). Add 10% (w/v) polyethylene glycol (PEG) 8000 and 1 M (final concentration) NaCl to sample and dissolve. Incubate overnight at 4 °C. Centrifuge to pellet at 4500 × *g* for 20 min at 4 °C. Resuspend pellet in 1 mL of same buffer used as before. Centrifuge at 4500 × *g* for 5 min at 4 °C.
5. Transfer supernatant to a new microcentrifuge tube.
6. Pre-wet 0.45 μm filter with 100 μL molecular grade dH<sub>2</sub>O or SM buffer.
7. Filter supernatant through 0.45 μm filter to further remove unwanted debris and cells. Expect some volume loss due to filter retention.
8. Optional chloroform treatment step (*see Note 5*):
  - (a) Add 0.2 volumes chloroform and mix by inversion or vortex to lyse any cells that have made it through filtration.
  - (b) Incubate at 4 °C for 30 min, vortexing every 5 min.
  - (c) Centrifuge at 4500 × *g* for 10 min at 4 °C to pellet chloroform.
9. Add DNase buffer to filtered sample to 1× concentration.
10. Add DNase (final concentration 1 U/mL) (*see Note 6*).
11. Optional RNase treatment (final concentration 1 U/mL) (*see Note 7*).
12. Incubate for 2 h at 37 °C or overnight at room temperature.
13. Heat-inactivate DNase for 20 min at 65 °C (*see Note 8*).
14. Sample for epifluorescent microscopy: in a separate microcentrifuge tube transfer 15 μL sample and add 5 μL 4% PFA for a final concentration of 1% PFA.
15. Save 20 μL sample for electron microscopy. Hold at 4 °C until processed for electron microscopy. Add 5 μL 5% formaldehyde

for a final concentration of 1% formaldehyde to fix sample if not processed for a day or longer.

16. Use remaining ~1.0 mL for nucleic acid extraction and continue immediately to convenient stopping points. Split sample in half for viral DNA (vDNA) extraction (Section 3.5) and viral RNA (vRNA) extraction (Section 3.6).

### **3.2 Purification of Bacteriophages (Optional) [13]**

1. For an overlay density step gradient, lay 1 mL of each step in the centrifuge tube starting with the highest density step (1.7 g/mL) and ending with the lowest density step (1.2 mg/mL). Be careful not to mix any of the steps while preparing the gradient.
2. Mark each layer with an indelible pen to note each layer.
3. Overlay the sample on top of the gradient, and fill to the top using the same buffer used for resuspension of the sample. Be careful not to disrupt the gradient.
4. Carefully balance each tube against each other to ensure that the mass is equivalent (<0.001 g difference between tubes); use resuspension buffer to balance the tubes.
5. Ultracentrifuge at  $\sim 82,000 \times g$  using SW41 Ti rotor for 2 h at 4 °C; use a slow acceleration and no brake for the deceleration.
6. Carefully remove each tube from the rotor, making sure not to disrupt the gradient.
7. Using an 18-gauge needle, pierce the tube at the 1.5 g/mL layer mark and extract 1.5 mL of the 1.5 g/mL to 1.35 g/mL layer and interface (*see Note 9*).
8. Split the sample for vDNA and vRNA extractions (Sections 3.5 and 3.6).

### **3.3 Viral-Like Particle Counts Using Epifluorescent Microscopy (See Note 10) [7]**

1. Dilute 10  $\mu$ L fixed viral sample into 5 mL molecular grade dH<sub>2</sub>O (1:500 dilution).
2. Filter sample onto 0.02  $\mu$ m Anodisc filter under vacuum pressure of 10 mm Hg (10 psi or  $\sim 60$  kPa). Filter is unidirectional, so be sure to have the shiny ring side up towards the sample.
3. Remove the filter tower and the filter while still under vacuum pressure.
4. Pipette 100  $\mu$ L freshly made 1–5 $\times$  SYBR Gold (to 995  $\mu$ L molecular grade dH<sub>2</sub>O add 5  $\mu$ L 10,000 $\times$  SYBR Gold (50 $\times$ , which can be stored at  $-20$  °C for 1 month), then do another 1:10 dilution with molecular grade dH<sub>2</sub>O to make 5 $\times$  SYBR Gold) solution onto a Petri dish, and place the filter sample side up on the droplet to stain for 10 min at room temperature in the dark.

5. Using forceps, lift filter and place on another 100  $\mu\text{L}$  droplet of molecular grade  $\text{dH}_2\text{O}$  on the Petri dish to wash the filter for 10 min at room temperature in the dark.
6. Pipette 10  $\mu\text{L}$  of mounting solution onto a clean microscope slide to hold the filter in place.
7. Place stained and washed filter sample side up on microscope slide.
8. Add 10  $\mu\text{L}$  of mounting solution on top of the filter and cover the filter with a coverslip. Be sure not to leave any air bubbles between the filter and the coverslip.
9. Count bacterial cells and viral-like particles (VLPs) under 485 nm light excitation using standard-orientation epifluorescence microscopy.
10. Count and document at least ten fields per slide. Average the number of VLPs and multiply by dilution factor and field/objective factor to obtain VLPs/mL.
11. Slides can be stored at  $-20\text{ }^\circ\text{C}$  in a light-protected container.

**3.4 Transmission  
Electron Microscopy  
of Viral-Like Particles  
[8, 9]**

1. Place 100  $\mu\text{L}$  2% uranyl acetate into a droplet on parafilm.
2. Place another 100  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$  into another droplet adjacent to the uranyl acetate droplet.
3. Place the Formvar-copper grid onto a clean area of the parafilm.
4. Pipette 10  $\mu\text{L}$  of sample onto the copper side of the grid.
5. Allow the sample to adhere to the grid for 5 min.
6. Blot grid with filter paper.
7. Place grid sample side down on uranyl acetate droplet.
8. Allow sample grid to stain for 30 s.
9. Remove grid from uranyl acetate droplet and blot dry.
10. Place grid sample side down on  $\text{dH}_2\text{O}$  droplet.
11. Allow sample grid to wash for 30 s.
12. Remove grid from  $\text{dH}_2\text{O}$  droplet and blot dry.
13. Allow grid to air-dry for 5 min.
14. Visualize by transmission electron microscopy ( $>40,000\times$ ).

**3.5 Viral DNA  
Extraction**

1. Add 0.1 volume 2 M Tris-HCl pH 8.5/0.2 M EDTA to sample (e.g., add 50  $\mu\text{L}$  to 500  $\mu\text{L}$  sample).
2. Add 0.01 volume of 0.5 M EDTA to sample (e.g., add 5  $\mu\text{L}$  to 500  $\mu\text{L}$  sample).
3. Add 1 volume formamide (e.g., add 555  $\mu\text{L}$  to 555  $\mu\text{L}$  sample).
4. Add 1  $\mu\text{L}$  glycogen (20 mg/mL) to each sample tube.

5. Incubate at room temperature for 30 min.
6. Split sample into two microcentrifuge tubes.
7. Add 2 volumes of room temperature 100% EtOH to each tube.
8. Centrifuge at  $13,800 \times g$  for 20 min to pellet.
9. Wash pellet 2 $\times$  with 250  $\mu$ L 70% EtOH.
10. Resuspend with 567  $\mu$ L TE (10 mM Tris, 1 mM EDTA, pH 8.0).
11. *Optional stopping point: Store samples at  $-20$  °C for up to 1 month.*
12. Add 30  $\mu$ L 10% SDS.
13. Add 3  $\mu$ L proteinase K (20 mg/mL).
14. Mix and incubate for 1 h at 37 °C.
15. Add 100  $\mu$ L 5 M NaCl.
16. Add 80  $\mu$ L CTAB/NaCl solution.
17. Mix and incubate at 65 °C for 10 min.
18. Add equal volume ( $\sim$ 780  $\mu$ L) of chloroform. Be sure to use chloroform in a chemical hood.
19. Mix and centrifuge at  $13,800 \times g$  for 10 min at room temperature.
20. Transfer top aqueous layer to a new microcentrifuge tube.
21. Add equal volume of 25:24:1 phenol:chloroform:isoamyl alcohol to supernatant. Be sure to use phenol:chloroform in a chemical hood.
22. Mix, and centrifuge at  $13,800 \times g$  for 10 min at room temperature.
23. Transfer top aqueous layer to a new microcentrifuge tube.
24. Add equal volume of chloroform to supernatant. Be sure to use chloroform in a chemical hood.
25. Mix, and centrifuge at  $13,800 \times g$  for 10 min at room temperature.
26. Transfer top aqueous layer to a new microcentrifuge tube.
27. Add 0.7 volumes isopropanol to supernatant.
28. Add 1  $\mu$ L glycogen (20 mg/mL) to each sample tube.
29. Gently mix, and incubate at 4 °C overnight to precipitate DNA.
30. Centrifuge at  $13,800 \times g$  for 20 min at 4 °C.
31. Wash with cold 70% EtOH.
32. Allow air-drying for 15 min.
33. Resuspend with 50  $\mu$ L molecular grade dH<sub>2</sub>O.

34. Incubate for 5 min at 55 °C to promote resuspension.
35. Check DNA concentration using Qubit (Thermo Fisher Scientific) or spectrophotometer.
36. Check DNA quality using Agilent BioAnalyzer.
37. Check for host/bacterial contamination by 18S/16S PCR (Section 3.7).
38. Samples can be stored at 4 °C for 1–2 days, or at –20 °C for extended periods.

### **3.6 Viral RNA Extraction**

1. Clean area with RNase-ZAP (or use 1% SDS solution) to ensure that working area is RNase free.
2. Split sample into another microcentrifuge tube (~250 µL per tube).
3. Add 3 volumes GITC buffer (e.g., add 750 µL GITC buffer to 250 µL sample).
4. Add 1 µL DTT (10 mM) to each sample tube.
5. *Optional stopping point: Store samples at –80 °C for up to 1 month.*
6. Add 0.2 volume chloroform (e.g., add 200 µL chloroform to 1 mL sample with GITC buffer), vortex, and incubate for 20 min at 4 °C.
7. Centrifuge at 13,800 × *g* for 20 min at 4 °C.
8. Transfer top aqueous layer into an RNase-free tube.
9. Add equal volume of isopropanol (e.g., add 500 µL isopropanol to 500 µL sample).
10. Add 1 µL glycogen (20 mg/mL).
11. Mix and incubate overnight at 4 °C to precipitate RNA.
12. Centrifuge at 13,800 × *g* for 20 min at 4 °C.
13. Wash with 250 µL cold RNase-free 70% EtOH.
14. Centrifuge at 13,800 × *g* for 5 min at 4 °C.
15. Repeat cold 70% EtOH wash.
16. Allow air-drying for 15 min.
17. Resuspend with 50 µL molecular grade dH<sub>2</sub>O.
18. Incubate for 5 min at 55 °C to promote resuspension of RNA.
19. Check RNA concentration using Qubit or spectrophotometer.
20. Check quality of RNA using Agilent BioAnalyzer RNA Nano.
21. Check for host/bacterial contamination using 18S/16S PCR (Section 3.7).
22. Samples can be stored at –20 °C for 1–2 days, or at –80 °C for extended periods.

### 3.7 Quality Control to Determine Bacterial/Host Contamination

1. Standard PCR setup, per sample:
  - (a) 2.5  $\mu\text{L}$  PCR buffer (10 $\times$ ).
  - (b) 1.0  $\mu\text{L}$  BSA (1 mg/mL).
  - (c) 1.0  $\mu\text{L}$   $\text{MgCl}_2$  (10 mM).
  - (d) 1.0  $\mu\text{L}$  dNTPs (10 mM).
  - (e) 1.0  $\mu\text{L}$  Taq polymerase (10 U/ $\mu\text{L}$ ).
  - (f) 1.0  $\mu\text{L}$  Primer 1 (1 mM).
  - (g) 1.0  $\mu\text{L}$  Primer 2 (1 mM).
  - (h) 20 ng sample DNA.
  - (i) Use positive vDNA control and negative control (no template) in separate sample reactions (*see Note 11*).
  - (j) Fill to 25  $\mu\text{L}$  with molecular grade  $\text{dH}_2\text{O}$ .
2. Touchdown PCR:
  - (a) 94  $^\circ\text{C}$  for 5 min.
  - (b) 94  $^\circ\text{C}$  for 30 s.
  - (c) 65  $^\circ\text{C}$  for 1 m: -1  $^\circ\text{C}/\text{cycle}$ .
  - (d) 72  $^\circ\text{C}$  for 2 min.
  - (e) Repeat steps (b) to (d) 14 cycles.
  - (f) 94  $^\circ\text{C}$  for 30 s.
  - (g) 50  $^\circ\text{C}$  for 1 min.
  - (h) 72  $^\circ\text{C}$  for 2 min.
  - (i) Repeat steps (f-h) 14 cycles.
  - (j) 72  $^\circ\text{C}$  for 10 min.
  - (k) Hold at 4  $^\circ\text{C}$  until analysis.
  - (l) Analyze for 18S/16S contamination by gel electrophoresis.

### 3.8 Viral RNA (vRNA) First-Strand Synthesis

1. Add 10  $\mu\text{L}$  purified vRNA template.
2. Use a negative control of no vRNA template: Add 10  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$  rather than template (*see Note 11*).
3. Use a positive control of known vRNA, if possible.
4. Add 4  $\mu\text{L}$  5 $\times$  reverse transcriptase (RT) buffer.
5. Heat at 65  $^\circ\text{C}$  for 5 min to prime RNA.
6. Cool at 4  $^\circ\text{C}$  for 5 min.
7. Quick centrifugation spin to collect precipitation.
8. Primer mix setup, per sample:
  - (a) 1.0  $\mu\text{L}$  dNTPs (10 mM).
  - (b) 1.0  $\mu\text{L}$  N6 Primer (10  $\mu\text{M}$ ).
  - (c) 1.0  $\mu\text{L}$  dT18a primer (50 nM) (*see Note 12*).



9. Add 3  $\mu\text{L}$  primer mix to each 14  $\mu\text{L}$  sample.
10. Heat at 72  $^{\circ}\text{C}$  for 5 min to anneal primers to template.
11. Cool at 4  $^{\circ}\text{C}$  for 5 min.
12. Quick centrifugation spin to collect precipitation.
13. First Strand Master Mix Setup, per sample:
  - (a) 0.5  $\mu\text{L}$  DTT (10 mM).
  - (b) 0.5  $\mu\text{L}$  RNase inhibitor (40 U/ $\mu\text{L}$ ).
  - (c) 0.5  $\mu\text{L}$   $\text{MgCl}_2$  (10 mM).
  - (d) 0.5  $\mu\text{L}$  DMSO.
  - (e) 1.0  $\mu\text{L}$  Reverse transcriptase (200 U/ $\mu\text{L}$ ).
14. Add 3  $\mu\text{L}$  first-strand master mix to each 17  $\mu\text{L}$  sample.
15. Run 1st\_Strand program on thermocycler for first-strand synthesis:
  - (a) 25  $^{\circ}\text{C}$  for 10 min (to initiate reverse transcription).
  - (b) 42  $^{\circ}\text{C}$  for 60 min.
  - (c) 50  $^{\circ}\text{C}$  for 1 min.
  - (d) 42  $^{\circ}\text{C}$  for 1 min.
  - (e) Repeat steps (c–d) 9 cycles.
  - (f) 65  $^{\circ}\text{C}$  for 20 min (to inactivate).
  - (g) 4  $^{\circ}\text{C}$  for 5 min.
  - (h) 4  $^{\circ}\text{C}$  Hold.
16. Quick centrifugation spin to collect precipitation.
17. *Optional stopping point: Store samples overnight at 4  $^{\circ}\text{C}$ .*

### **3.9 Viral Second-Strand Synthesis**

1. Use 20  $\mu\text{L}$  first-strand vRNA converted to cDNA.
2. Use a negative control of no cDNA template (*see Note 11*).
3. Use a positive control of cDNA template.
4. Second-strand synthesis reaction per reaction:
  - (a) 4.0  $\mu\text{L}$  Molecular grade  $\text{dH}_2\text{O}$ .
  - (b) 3.0  $\mu\text{L}$  10 $\times$  T4 DNA polymerase buffer.
  - (c) 1.0  $\mu\text{L}$  dUTPs (10 mM stock).
  - (d) 0.5  $\mu\text{L}$  RNase H (250 U/ $\mu\text{L}$ ).
  - (e) 0.5  $\mu\text{L}$  DTT (10 mM stock).
  - (f) 1.0  $\mu\text{L}$  T4 DNA polymerase (150 U/ $\mu\text{L}$ ).
5. Add 10  $\mu\text{L}$  second-strand master mix to 20  $\mu\text{L}$  sample.
6. Run 2nd\_Strand program on thermocycler:
  - (a) 4  $^{\circ}\text{C}$  for 2 min.
  - (b) 16  $^{\circ}\text{C}$  for 90 min.

- (c) 65 °C for 20 min (to inactivate DNA polymerase).
  - (d) 4 °C for 5 min.
  - (e) 4 °C Hold.
7. Quick centrifugation spin to collect precipitation.

### **3.10 DNA Cleanup**

1. Allow SPRI beads to equilibrate to room temperature. Vortex to mix well.
2. Add equal volumes of sample and vortexed SPRI beads into microcentrifuge tube (e.g., add 30  $\mu$ L SPRI beads to 30  $\mu$ L sample).
3. Vortex briefly and incubate at room temperature for 5 min.
4. Place microcentrifuge tube on magnet holder and allow for beads to bind to magnet at the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
5. Keep tube on magnet and remove all supernatant.
6. While leaving the tube on the magnet, wash twice with 250  $\mu$ L freshly made 70% EtOH, and remove all liquid between washes.
7. Remove tube from magnet and allow beads to air-dry for 5 min, or until EtOH has fully evaporated.
8. Resuspend beads in 52.5  $\mu$ L molecular grade H<sub>2</sub>O, vortex, and place tube back on magnet. Allow beads to bind to magnet for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
9. Transfer 50  $\mu$ L of eluted sample from beads and place in a new microcentrifuge tube.

### **3.11 DNA Shearing**

1. Transfer 52.5  $\mu$ L DNA (vDNA and molecular grade dH<sub>2</sub>O to 52.5  $\mu$ L volume) to Covaris shearing tube.
2. Briefly spin to move sample to the bottom of the tube.
3. Turn on Covaris machine, open SonoLab program, and fill water bath to appropriate level with DI water.
4. Run DNA\_Shear\_45Sec program to shear DNA:
  - (a) Covaris shearing settings:
    - 45 s
    - 50 W peak power
    - Duty factor 20%
    - 200 cycles/burst
    - Room temperature
5. Quick centrifugation spin to collect precipitation.

6. Transfer sheared DNA to PCR tube to continue with end repair.
7. Close SonoLab program, turn off Covaris machine, and clean and dry water bath.

### **3.12 End Repair**

1. End-repair reaction setup, per sample reaction:
  - (a) 6.0  $\mu\text{L}$  10 $\times$  T4 DNA ligase buffer (contains ATP)
  - (b) 2.0  $\mu\text{L}$  Molecular grade  $\text{dH}_2\text{O}$
  - (c) 1.0  $\mu\text{L}$  10 mM dNTPs
  - (d) 0.5  $\mu\text{L}$  5 U/ $\mu\text{L}$  T4 DNA polymerase
  - (e) 0.5  $\mu\text{L}$  10 U/ $\mu\text{L}$  T4 polynucleotide kinase (PNK)
2. Add 10  $\mu\text{L}$  of end-repair master mix to 50  $\mu\text{L}$  sheared DNA.
3. Run End\_Repair program on thermocycler:
  - (a) 4  $^\circ\text{C}$  for 2 min
  - (b) 20  $^\circ\text{C}$  for 30 min
  - (c) 25  $^\circ\text{C}$  for 30 min
  - (d) 4  $^\circ\text{C}$  for 5 min
  - (e) 4  $^\circ\text{C}$  Hold
4. Add 60  $\mu\text{L}$  SPRI beads. Vortex before use.
5. Repeat DNA cleanup steps (Section 3.10).
6. Elute with 50  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$ .

### **3.13 Adenylate 3' Ends**

1. Adenylation reaction setup, per sample reaction:
  - (a) 2.0  $\mu\text{L}$  Molecular grade  $\text{dH}_2\text{O}$
  - (b) 6.0  $\mu\text{L}$  10 $\times$  Klenow buffer
  - (c) 1.0  $\mu\text{L}$  10 mM dATP
  - (d) 1.0  $\mu\text{L}$  5 U/ $\mu\text{L}$  Klenow fragment DNA polymerase (3'-5' exo-)
2. Add 10  $\mu\text{L}$  of adenylation master mix to 50  $\mu\text{L}$  end-repaired DNA.
3. Run DA\_Tail program on thermocycler:
  - (a) 4  $^\circ\text{C}$  for 2 min
  - (b) 37  $^\circ\text{C}$  for 30 min
  - (c) 4  $^\circ\text{C}$  Hold
4. Add 60  $\mu\text{L}$  SPRI beads. Vortex before use.
5. Repeat DNA cleanup steps (Section 3.10).
6. Elute with 50  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$ .

### **3.14 Adapter Ligation**

1. Primary adapter ligation setup, per sample reaction:
  - (a) 6.0  $\mu\text{L}$  10 $\times$  T4 DNA ligase buffer (contains 10 mM ATP)

- (b) 1.0  $\mu\text{L}$  10  $\mu\text{M}$  Annealed indexed adapter (*see Note 13*)
  - (c) 0.5  $\mu\text{L}$  20 U/ $\mu\text{L}$  T4 DNA ligase
2. Add 6.5  $\mu\text{L}$  of primary adapter ligation master mix to 50  $\mu\text{L}$  3' adenylated DNA + 1  $\mu\text{L}$  each annealed indexed adapter.
  3. Run End\_Repair program on thermocycler:
    - (a) 4  $^{\circ}\text{C}$  for 2 min
    - (b) 20  $^{\circ}\text{C}$  for 30 min
    - (c) 25  $^{\circ}\text{C}$  for 30 min
    - (d) 4  $^{\circ}\text{C}$  Hold
  4. Secondary adapter ligation setup, per sample reaction:
    - (a) 11.0  $\mu\text{L}$  Molecular grade dH<sub>2</sub>O
    - (b) 1.0  $\mu\text{L}$  T4 DNA ligase buffer (contains 10 mM ATP)
    - (c) 0.5  $\mu\text{L}$  20 U/ $\mu\text{L}$  T4 DNA ligase
  5. Add 12.5  $\mu\text{L}$  of secondary adapter ligation master mix to 57.5  $\mu\text{L}$  of primary adapter ligation.
  6. Run Adap\_Lig program on thermocycler:
    - (a) 4  $^{\circ}\text{C}$  for 2 min
    - (b) 16  $^{\circ}\text{C}$  for 2 h
    - (c) 4  $^{\circ}\text{C}$  Hold
  7. Add 70  $\mu\text{L}$  SPRI beads. Vortex before use.
  8. Repeat DNA cleanup steps (Section 3.10).
  9. Elute with 50  $\mu\text{L}$  molecular grade dH<sub>2</sub>O.

**3.15 Uridine  
Removal for Viral RNA  
Samples (Omit  
for Viral DNA Samples)**

1. Add 5  $\mu\text{L}$  UDG reaction buffer.
2. Add 0.5  $\mu\text{L}$  UDG.
3. Incubate at 37  $^{\circ}\text{C}$  for 30 min.
4. Add 55  $\mu\text{L}$  SPRI beads. Vortex before use.
5. Repeat DNA cleanup steps (Section 3.10).
6. Elute with 50  $\mu\text{L}$  molecular grade dH<sub>2</sub>O.

**3.16 Size Selection  
of Adapter-Ligated  
Fragments**

**3.16.1 For a 550 bp  
Insert (for 300 bp  
Paired-End Sequencing)**

1. For each sample, pipette 40  $\mu\text{L}$  SPRI beads into a new microcentrifuge tube. Vortex before use.
2. Dilute beads with 40  $\mu\text{L}$  molecular grade dH<sub>2</sub>O.
3. Transfer 50  $\mu\text{L}$  adapter-ligated sample into diluted SPRI bead centrifuge tube.
4. Vortex to mix.
5. Incubate at room temperature for 5 min.
6. Place microcentrifuge tube on magnet holder and allow for beads to bind to magnet at the side of the tube for 5 min or

longer, until bead pellet has formed on the magnet side of tube and solution has cleared.

7. Transfer supernatant to a new microcentrifuge tube. Discard tube with beads.
8. Add 30  $\mu\text{L}$  undiluted and vortexed SPRI beads to supernatant tube.
9. Vortex to mix.
10. Incubate at room temperature for 5 min.
11. Place microcentrifuge tube on magnet holder and allow for beads to bind to magnet at the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
12. Keep tube on magnet and remove all supernatant.
13. While leaving the tube on the magnet, wash twice with 250  $\mu\text{L}$  freshly made 70% EtOH, and remove all liquid between washes.
14. Remove tube from magnet and allow beads to air-dry for 5 min, or until EtOH has fully evaporated.
15. Resuspend beads in 52.5  $\mu\text{L}$  molecular grade  $\text{H}_2\text{O}$ , vortex, and place tube back on magnet. Allow beads to bind to the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
16. Transfer 50  $\mu\text{L}$  of eluted sample from beads and place in a new microcentrifuge tube.

*3.16.2 For a 250 bp  
Insert (for 150 bp  
Paired-End Sequencing)*

1. For each sample, pipette 55  $\mu\text{L}$  SPRI beads into a new microcentrifuge tube. Vortex before use.
2. Dilute beads with 25  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$ .
3. Transfer 50  $\mu\text{L}$  adapter-ligated sample into diluted SPRI bead centrifuge tube.
4. Vortex to mix.
5. Incubate at room temperature for 5 min.
6. Place microcentrifuge tube on magnet holder and allow for beads to bind to magnet at the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
7. Transfer supernatant to a new microcentrifuge tube. Discard tube with beads.
8. Add 30  $\mu\text{L}$  undiluted and vortexed SPRI beads to supernatant tube.
9. Vortex to mix.

10. Incubate at room temperature for 5 min.
11. Place microcentrifuge tube on magnet holder and allow for beads to bind to magnet at the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
12. Keep tube on magnet and remove all supernatant.
13. While leaving the tube on the magnet, wash twice with 250  $\mu\text{L}$  freshly made 70% EtOH, and remove all liquid between washes.
14. Remove tube from magnet and allow beads to air-dry for 5 min, or until EtOH has fully evaporated.
15. Resuspend beads in 52.5  $\mu\text{L}$  molecular grade  $\text{H}_2\text{O}$ , vortex, and place tube back on magnet. Allow beads to bind to the side of the tube for 5 min or longer, until bead pellet has formed on the magnet side of tube and solution has cleared.
16. Transfer 50  $\mu\text{L}$  of eluted sample from beads and place in a new microcentrifuge tube.

### **3.17 Large-Scale PCR**

1. PCR setup, per sample reaction:
  - (a) 6.5  $\mu\text{L}$  Molecular grade  $\text{dH}_2\text{O}$
  - (b) 5.0  $\mu\text{L}$  5 $\times$  High-fidelity polymerase buffer
  - (c) 1.0  $\mu\text{L}$  10 mM dNTPs
  - (d) 1.0  $\mu\text{L}$  1  $\mu\text{M}$  PCR Primer 1 (Illumina TruSeq P5)
  - (e) 1.0  $\mu\text{L}$  1  $\mu\text{M}$  PCR Primer 2 (Illumina TruSeq P7)
  - (f) 0.5  $\mu\text{L}$  2 U/ $\mu\text{L}$  High-fidelity DNA polymerase
2. Add 15  $\mu\text{L}$  of master mix to 10  $\mu\text{L}$  adapter-ligated and size-selected DNA.
3. Run LargeScale program on thermocycler:
  - (a) 95  $^\circ\text{C}$  for 5 min
  - (b) 95  $^\circ\text{C}$  for 30 s
  - (c) 60  $^\circ\text{C}$  for 60 s
  - (d) 72  $^\circ\text{C}$  for 90 s
  - (e) Repeat steps (b–d) using optimal # cycles (*see Note 14*)
  - (f) 72  $^\circ\text{C}$  for 10 min
  - (g) 4  $^\circ\text{C}$  Hold
4. Reconditioning PCR setup, per sample reaction (increases yield and decreases heteroduplex formation):
  - (a) 11.5  $\mu\text{L}$  Molecular grade  $\text{dH}_2\text{O}$
  - (b) 10.0  $\mu\text{L}$  5 $\times$  High-fidelity polymerase buffer

- (c) 1.0  $\mu\text{L}$  10 mM dNTPs
  - (d) 1.0  $\mu\text{L}$  1  $\mu\text{M}$  PCR Primer 1 (Illumina TruSeq P5)
  - (e) 1.0  $\mu\text{L}$  1  $\mu\text{M}$  PCR Primer 2 (Illumina TruSeq P7)
  - (f) 0.5  $\mu\text{L}$  2 U/ $\mu\text{L}$  Q5 High-fidelity DNA polymerase
5. Add 25  $\mu\text{L}$  of master mix to 25  $\mu\text{L}$  amplified DNA.
  6. Run Recondition program on thermocycler:
    - (a) 95  $^{\circ}\text{C}$  for 2 min
    - (b) 95  $^{\circ}\text{C}$  for 30 s
    - (c) 60  $^{\circ}\text{C}$  for 60 s
    - (d) 72  $^{\circ}\text{C}$  for 90 s
    - (e) Repeat steps (b–d) 3 cycles
    - (f) 72  $^{\circ}\text{C}$  for 10 min
    - (g) 4  $^{\circ}\text{C}$  Hold
  7. Perform DNA cleanup steps (Section 3.10).
  8. Elute in 55  $\mu\text{L}$  molecular grade  $\text{dH}_2\text{O}$ .
  9. Quantify by Qubit.
  10. Quality control by BioAnalyzer.
  11. Samples can be stored at 4  $^{\circ}\text{C}$  for 1–2 days, or at  $-20$   $^{\circ}\text{C}$  for extended periods.

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## 4 Notes

1. The term “bacteriophage” was originally used to describe entities that “ate” bacteria [14]. Hence, the Greek root meaning of “phage” is to eat, or bacteriophage, the “eater of bacteria.” Prokaryotic viruses do not “eat” bacteria; they either lyse cells or integrate into genomes upon infection. Therefore, it is more accurate to term these viruses as what they infect, prokaryotic viruses.
2. Although the title of this chapter is for the isolation of bacteriophages from host-associated systems, you will also isolate eukaryotic viruses. This protocol is good for viral metagenome studies; simply substitute the word “virus” for “bacteriophage,” and one will be able to obtain a full viral metagenome. If the goal is to select for prokaryotic viruses, it is recommended to use the optional CsCl step density gradient purification (Section 3.2).
3. Other buffers to consider using other than SM buffer are 1% potassium citrate (to 100 mL, add 1 g potassium citrate, 0.14 g  $\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$ , and 0.024 g  $\text{KH}_2\text{PO}_4$ , pH to 7) and 10 mM sodium pyrophosphate (to 100 mL, add 0.27 g  $\text{Na}_2\text{P}_2\text{O}_7$ )

[15]. These buffers are supposed to help detach viruses from tissue. We have not had much success with these buffers, and have had the most success with SM buffer. These alternatives are included in case the user would like to try these buffers.

4. It is important to use small volumes in this protocol to help concentrate the sample and to work with less tubes throughout the procedure. Therefore, if one has large volumes of tissue slurry, it would be useful to precipitate the viruses into a smaller volume using pegylation [16]. Alternatively, Amicon filters (50 kD) can be used to concentrate viruses. Note that this will affect viral number counts, so if these counts are important, do not precipitate viruses until after sub-sampling for epifluorescence microscopy.
5. Chloroform is used at this step to lyse lipid membranes, particularly that of eukaryotic and prokaryotic cells. However, chloroform can also affect (and lyse) enveloped viruses. It is not recommended to use chloroform at this step because it can affect enveloped viruses while increasing the amount of host and bacterial DNA in the sample. Rather, an additional 0.45  $\mu\text{m}$  filtration step can be used to remove eukaryotic and prokaryotic cells while preserving the enveloped viruses. This step is included as optional for those wishing to use this step.
6. Free DNA is common in host-associated samples. Further, released DNA through filtration of cells (unlikely) or chloroform lysis of cells (most likely) can obscure viral DNA isolation later in the protocol. It cannot be stressed enough how important it is to DNase your samples, as it affects viral number counts (*see Note 10*), and can affect what is sequenced. If host or bacterial contamination is observed, a second DNase step should be added during the isolation of viruses in future experiments.
7. It is optional to treat the sample with RNase. RNase is useful to remove prevalent rRNAs from a host-associated sample (>80% of the sample). This is particularly necessary when isolating RNA viruses. However, it is difficult to remove RNases from a sample once added. They are not heat-inactivated. It is necessary to use DTT or 2-mercaptoethanol to inactivate the RNases prior to RNA isolation.
8. Heat inactivation works for DNase, but not for RNase. It is necessary to use DTT or 2-mercaptoethanol to inactivate the RNases prior to RNA isolation.
9. After removal of sample with needle, the hole left behind will cause the rest of the gradient to come out of the tube, so have another waste container available to collect it.
10. The enumeration of viruses is rife with pitfalls. Often, viral-like particle (VLP) counts are overestimated in host-associated



systems due to not eliminating host-generated factors (such as vesicles and free DNA) [17]. Therefore, it is important that VLP counts are conducted after filtration, and importantly after DNase treatment to eliminate host factors. When enumerated properly, the VLP numbers are usually equivalent to bacterial numbers in host-associated systems. Please refer to the work by Ortmann and Suttle for reference [7].

11. It is of vital importance to use both positive and negative controls throughout the random amplification library preparation and during the PCRs. A positive control is needed to ensure that your protocol is working throughout. More importantly, a negative control is needed to ensure that contaminating DNA is not infiltrating your protocol and potentially sequenced as a false positive. These controls are often erroneously omitted from the protocol, but if not included false outcomes can creep into your sequencing results.
12. The VN-anchored oligo dT primer allows the primer to only anneal to the 5' end of the poly(A) tail of mRNA, allowing for more efficient cDNA synthesis.
13. Excess adapters can interfere with sequencing [18]. The adapters have to be diluted relative to the starting material. Using 10  $\mu$ M adapter stock, for samples >100 ng, do not dilute. For samples 10–100 ng, make a 1:10 dilution of 10  $\mu$ M adapter stock to 1  $\mu$ M. For samples 1–10 ng, make a 1:20 dilution, or 500 nM. For samples <1 ng, make a 1:30 dilution, or 250 nM. Add 1  $\mu$ L of these diluted adapters to each reaction.
14. Use the minimum number of cycles to barcode and amplify the amount of DNA needed to sequence [19]. One should ensure that each fragment of DNA has an adapter on it for sequencing. To achieve this, use the minimum number of cycles of 8, so if starting with more than 1 ng of DNA, use 8 cycles. If one has 1 ng of DNA or less, use 12 cycles. If one has 1 pg of DNA or less, use 21 cycles. Keep in mind that amplifying with too many cycles can lead to amplification bias and sequencing artifacts, so use the minimum number of cycles to obtain the amount of DNA needed to sequence.

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## References

1. Grasis JA, Lachnit T, Anton-Erxleben F, Lim YM, Schmieder R, Fraune S et al (2014) Species-specific viromes in the ancestral holobiont hydra. *PLoS One* 9:e109952. <https://doi.org/10.1371/journal.pone.0109952>
2. Duerkop BA, Clements CV, Rollins D, Rodrigues JL, Hooper LV (2012) A composite bacteriophage alters colonization by an intestinal commensal bacterium. *Proc Natl Acad Sci U S A* 109:17621–17626. <https://doi.org/10.1073/pnas.1206136109>
3. Cadwell K (2015) The virome in host health and disease. *Immunity* 42:805–813. <https://doi.org/10.1016/j.immuni.2015.05.003>
4. Daly GM et al (2011) A viral discovery methodology for clinical biopsy samples utilizing massively parallel next generation sequencing. *PLoS One* 6:e28879. <https://doi.org/10.1371/journal.pone.0028879>
5. Hall RJ et al (2014) Evaluation of rapid and simple techniques for the enrichment of viruses prior to metagenomic virus discovery. *J Virol Meth* 195:194–204. <https://doi.org/10.1016/j.jviromet.2013.08.035>
6. Kleiner M et al (2015) Evaluation of methods to purify virus-like particles for metagenomic sequencing of intestinal viromes. *BMC Genomics* 16:7. <https://doi.org/10.1186/s12864-014-1207-4>
7. Ortman AC, Suttle CA (2009) Determination of virus abundance by epifluorescence microscopy. In: Clokie MR, Kropinski AM (eds) *Bacteriophages: methods and protocols*, volume 1: isolation, characterization, and interactions, vol 501. Humana Press, New York, pp 87–95. [https://doi.org/10.1007/978-1-60327-164-6\\_10](https://doi.org/10.1007/978-1-60327-164-6_10)
8. Ackermann H-W, Heldal M (2010) Basic electron microscopy of aquatic viruses. In: Wilhelm SW, Weinbauer MG, Suttle CA (eds) *Manual of aquatic viral ecology*, vol 18. American Society of Limnology and Oceanography, Waco, TX, pp 182–192. <https://doi.org/10.4319/mave.2010.978-0-09845591-0-7.182>
9. Ackermann H-W (2009) Basic phage electron microscopy. In: Clokie MR, Kropinski AM (eds) *Bacteriophages: methods and protocols*, volume 1: isolation, characterization, and interactions, vol 501. Humana Press, New York, pp 113–126. [https://doi.org/10.1007/978-1-60327-164-6\\_12](https://doi.org/10.1007/978-1-60327-164-6_12)
10. Lim YW et al (2014) Purifying the impure: sequencing metagenomes and metagenomes from complex animal-associated samples. *J Vis Exp* 94:e52117. <https://doi.org/10.3791/52117>
11. Culley AI, Suttle CA, Steward GF (2010) Characterization of the diversity of marine RNA viruses. *Manual of Aquatic Viral Ecol.* 19:193–201. <https://doi.org/10.4319/mave.2010.978-0-9845591-0-7.193>
12. Weynberg KD et al (2014) Generating viral metagenomes from the coral holobiont. *Front Microbiol* 5:1–11. <https://doi.org/10.3389/fmicb.2014.00206>
13. Lawrence JE, Steward GF (2010) Purification of viruses by centrifugation. *Manual of Aquatic Viral Ecol* 17:166–181. <https://doi.org/10.4319/mave.2010.978-0-9845591-0-7.166>
14. Summers WC (1999) *Felix d'Herelle and the origins of molecular biology*. Yale University Press, USA, p 248
15. Williamson KE et al (2003) Sampling natural viral communities from soil for culture-independent analyses. *Appl Environ Micro* 69:6628–6633. <https://doi.org/10.1128/AEM.69.11.6628-6633.2003>
16. Hjelmso MH et al (2017) Evaluation of methods for the concentration and extraction of viruses from sewage in the context of metagenomic sequencing. *PLoS One* 12:e0170199. <https://doi.org/10.1371/journal.pone.0170199>
17. Forterre P, Soler N, Krupovic M, Marguet E, Ackermann H-W (2013) Fake virus particles generated by fluorescence microscopy. *Trends Microbiol* 21:1–5. <https://doi.org/10.1016/j.tim.2012.10.005>
18. Solonenko SA et al (2013) Sequencing platform and library preparation choices impact viral metagenomes. *BMC Genomics* 14:320. <https://doi.org/10.1186/1471-2164-14-320>
19. Duhaime MB, Deng L, Poulos BT, Sullivan MB (2012) Towards quantitative metagenomics of wild viruses and other ultra-low concentration DNA samples: a rigorous assessment and optimization of the linker amplification method. *Environ Microbiol* 14:2526–2537. <https://doi.org/10.1111/j.1462-2920.2012.02791.x>